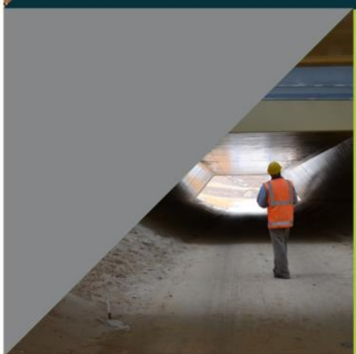
WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

Identifying Best Pavement Practice for Major Projects



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Identifying Best Pavement Practice for Major Projects
2016-003

for Main Roads Western Australia

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IDENTIFYING BEST PAVEMENT PRACTICE FOR MAJOR PROJECTS

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COMMENTS				

SUMMARY

Construction of new heavy-duty pavements represents a significant component of current and future Main Roads WA capital expenditure. Given the significant capital expenditure being invested in heavy-duty pavements, Main Roads WA initiated a review of pavement engineering practices for major freeway projects. Established as part of the Western Australian Road Research and Innovation Program (WARRIP), the review actively sought the input of both the construction industry and pavement design consultants into the scope of the review.

Two workshops were held at the start of the project to provide opportunity for the Western Australian pavements industry to explore opportunities for improvement regarding pavement type and materials selection options used by Main Roads Western Australia and to focus on subsequent activities.

Workshop attendees expressed a need for contract frameworks that allow and encourage innovation. It is recommended that Main Roads WA undertake an investigation into contract models with more risk sharing and flexibility for changes. Refinement in acceptance criteria, and the penalties/bonuses that are applied, could encourage contractors to deliver better outcomes rather than just focusing on minimum requirements. Additionally, it is recommended that further investigation is carried out on the development of performance-based specifications; this will give contractors/designers more flexibility to achieve cost-effective pavement solutions.

The review of heavy-duty pavement types used on major projects across Australia identified deep strength asphalt pavements and composite pavements as the two types used in other states that could be further investigated for adoption in WA.

Based on a review of the different pavement materials discussed at the workshops, and other emerging technologies being adopted nationally, the following recommendations are suggested for Main Roads WA to consider:

- Investigate ways to increase the utilisation of construction and demolition (C&D) recycled materials, including the development of an assessment framework for approval of suppliers and further investigation of the risk of rehydration of these materials.
- Continue to monitor and participate in the Austroads project TT1825 *Improving the Design and Performance of Foamed Bitumen Stabilised Pavements* and move to implement the test methods and design procedures that arise from the project.
- Investigate the long-term performance of bitumen-stabilised pavements.
- Investigate the A5EP binder used in NSW and SA and determine its suitability for WA conditions.
- Continue to monitor and participate in the development of performance-based specifications.

During the project, it became apparent that industry needs to better understand the technical and historical background of the decisions made by Main Roads WA and prescriptive pavement requirements. It is recommended that Main Roads WA develop a rolling timetable of events to actively engage with industry outside specific contract processes.

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1 INTRODUCTION

Main Roads Western Australia is responsible for the management of over 18 000 km of national and state highways and main roads in Western Australia (Main Roads WA 2017). In the 2016–17 financial year a record $2.28 billion was invested across all service areas of Main Roads. The latest valuation of total Main Roads WA assets, including land value, was $46.3 billion (Main Roads WA 2017).

A significant component of current and future Main Roads WA capital expenditure is dedicated to the construction of new heavy-duty highways and main roads. For example, the NorthLink WA project, currently underway, has an approximate budget of $1.12 billion (Main Roads WA 2017).

Given the significant capital expenditure being invested in heavy-duty pavements, Main Roads WA initiated a review of pavement engineering practices for major freeway projects, particularly in the urban environment where high-cost, heavy-duty pavement configurations are required. Established as part of the Western Australian Road Research and Innovation Program (WARRIP), input was sought from both the construction industry and pavement design consultants into the scope of the review.

This report presents the outcomes of the review. The main project activities reported are:

- Two workshops for the Western Australian pavements industry, one for contractors and another for pavement designers. At these workshops views were sought on current Main Roads WA practices and a range of issues were raised. The workshops were held at the start of the project to inform the scope and focus of subsequent activities.
- A review was undertaken of the major project pavement practices of the other major Australian state road agencies (SRAs), including:
  - pavement types used for major projects, including what each state permits (or not), and why
  - identification of emerging technologies and likely future innovations being considered by each of the states
  - major project practices and contract documents, including Scope of Works and Technical Criteria (SWTC) documents, defects liability periods, pavement condition performance measures and principle supplied pavement designs
  - design standards and project specifications that lie outside the SWTC documents.
- A review of pavement materials technologies and other items of interest identified in the workshops, including the use of recycled materials, stabilised materials, reclaimed asphalt pavement (RAP), high-performance asphalts, permeable pavements, etc. Emerging technologies and other innovations were also identified.
- A summary of the key issues, recommendations and future actions.

Running parallel to this project a separate WARRIP project, *Cost-effective pavement thickness design* (WARRIP project 2016-003), focussed on a detailed review of pavement design thickness issues identified by Main Roads WA and industry. That project examined issues such as the selection of pavement design periods and project reliability levels, minimum thickness of pavements containing polymer modified binders (PMBs) and structural asphalt, minimum subbase requirements for full depth asphalt pavements and other detailed design rules.

2 DESIGN OF MAJOR ROAD PROJECTS

Two major contract forms are used to deliver major projects within the SRAs. A brief review of these contract forms is provided as a background to the details of the industry workshops and the review of other road agency practices that are discussed in subsequent sections of this report.

Most major road pavement construction projects in Australia are built under contract using a design and construct (D&C) approach. This contract model generally gives responsibility for the design and construction of the project to the contractor, while the principal provides the project scope, sets acceptable design standards and manages the contract.

A D&C project will typically involve the following steps:

1. Preparation and release of contract tender documents by the road agency. These outline the project scope and include the SWTC document which defines the design rules for all project elements.
2. Preparation and submission of proposals by competing tenderers.
3. Assessment of the alternative tenders by the agency, typically using a comparative scoring approach that considers cost, resourcing, program, capability, industry participation, technical issues and other measures.
4. Award of the contract to the winning tenderer, who becomes the contractor.
5. Completion of design by the contractor. An independent review of the design for conformance with the SWTC and other requirements is also undertaken. This is often completed by a private sector consultancy proof engineer and the road agency's technical groups.
6. Construction, in accordance with the completed design and project specification, under a quality assurance system. An independent verifier typically oversees construction and is responsible for signing off on conformance of constructed elements with the design and specification.
7. Opening of the completed asset, and the commencement of any defects correction period and ongoing performance monitoring activities.
8. Final handover of the asset to the agency at the end of the defects liability period, subject to acceptance criteria having been met.

Some major projects follow an Alliance contract form, where the road agency works collaboratively with the contractor(s) and designer(s) and shares the project risks and outcomes. This type of contract allows more flexibility in the design and construction, encouraging the use of innovative solutions. The SWTC, in Alliance projects, is often revised after the project is awarded, to allow for changes proposed by the Alliance that are believed to bring a better outcome than the original SWTC would allow.

An Alliance project will typically involve the following steps:

1. Preparation and release of contract tender documents by the road agency. These outline the project scope and include a preliminary SWTC, which defines the design rules for all project elements.
2. Preparation and submission of proposals by competing tenderers.
3. Assessment of the alternative tenders by the agency, typically using a comparative scoring system similar to that used for D&C contracts.

4. Award of the contract to the winning tenderer team. This team will join with the road agency to form the Alliance.
5. The design is undertaken in collaboration with the SRA, with agreed changes to the SWTC being incorporated as required. An independent review by a private sector consultancy proof engineer is undertaken, in addition to a review by the SRA's technical groups.
6. Construction, in accordance with the completed design and project specification, under a quality assurance system.
7. Opening of the completed asset, and the commencement of the defects correction period and performance monitoring.
8. Final handover to the SRA at the end of the defects liability period, subject to meeting acceptance criteria.

Another type of contracting approach used for major projects is the Construct Only, where the contractor tenders based on an existing design; this does not involve the contractor taking any risk for the design, only for the construction.

3 INDUSTRY WORKSHOPS

3.1 Introduction

Construction is delivered by the head contractor, who typically subcontracts construction of the different project elements to other sub-contractors. The pavement design is usually prepared by an engineering design team, again subcontracted to the head contractor.

Recognising that both the head contractor and engineering design team are key stakeholders in major project design and delivery, Main Roads WA and ARRB organised two industry workshops – one for each of the two groups – to examine the current processes used by Main Roads WA to select pavement types suitable for major projects. The key focus was to identify potential improvements and more cost-effective pavement options.

As part of the workshop, the participants were given the opportunity to comment on any other issues regarding contracting forms and requirements, SWTCs, design guides, pavement materials and any other topics that they thought relevant.

3.2 Workshop Details

The two workshops were conducted on 20 April 2016. The workshop with contractors was conducted from 9 to 11 am and the workshop with the pavement design industry from 1 to 4 pm. Additional time was allocated to the pavement design workshop as it was expected that participants would spend longer discussing aspects of the pavement thickness design processes. Main Roads WA requires that pavement thickness design be undertaken using the design processes contained in the *Austroads guide to pavement technology: part 2 – pavement structural design* (Austroads 2012) supplemented by the Main Roads WA document *Engineering road note 9, procedure for the design of road pavements* (Main Roads WA 2013a). This second document is referred to as ERN9 within Main Roads WA and industry, and this report similarly refers to the document as ERN9 where appropriate.

Prior to the workshops, participants were informed via email of the objectives of the workshop and were asked to consider the following questions as preparatory thought-starters for the workshops:

- When preparing SWTCs for major projects Main Roads WA currently selects the pavement type(s) suitable for specific projects from a list of potential types:
  - flexible unbound granular pavement with surfacing treatment
  - flexible modified granular pavement with surfacing treatment
  - full depth asphalt pavement with surfacing treatment
  - composite and deep strength asphalt pavement
  - continuously reinforced concrete pavement
  - plain concrete or steel fibre reinforced concrete pavement.
- Regarding these pavement types:
  - Should more options be considered?
  - Should some options be excluded for all major projects?
- Have some of the potential pavement type options been unreasonably excluded as options in the SWTCs?

- How does current contractual handling of risk issues affect pavement type selection by Main Roads WA, by contractors and by designers?
- Are minimum pavement layer thicknesses (including tolerances) reasonable? Do such thickness requirements have construction consequences (that increase cost) unforeseen by some designers?

Both workshops followed the same agenda:

- Welcome by Doug Morgan, Executive Director, Planning & Technical Services, Main Roads WA
- Introduction and scene setting by Les Marchant, Manager, Materials Engineering, Planning & Technical Services/Materials Engineering Branch, Main Roads WA
- Project overview by Dr Michael Moffatt, National Technical Leader, Pavements, ARRB
- Discussion facilitated by Michael Moffatt.

There were 19 participants at the Contractors Workshop, and 19 participants in the Pavement Designers Workshop. The participants are listed in Appendix A.

3.3 Issues Identified in the Workshops

During both workshops, discussion notes were recorded on a screen visible to participants. These notes were compiled with additional notes taken by Main Roads WA and ARRB staff during the workshops and circulated to participants after the workshops. The compiled notes are included in Appendix B. Opinions raised during the workshops, and documented in the notes, do not necessarily reflect the views of all workshop participants.

It was desirable that the workshops not become excessively bogged down in technical detail at the expense of spending time raising additional issues and ideas. Accordingly, it was decided that Main Roads WA personnel attending the workshop would focus their contributions on teasing out and understanding the issues being raised by industry participants and not on providing counter points or arguments. Whilst the approach proved to be a successful means of documenting industry concerns, it resulted in the workshop notes, and the following summary of issues, being somewhat one-sided.

The following sections summarise the issues raised by participants of the workshops, categorised by discussion topic.

3.3.1 Form of Contract

The participants discussed which contract models are best to promote innovation. It was generally agreed by the contractors and design consultants that D&C contracts inhibit innovation. Pavement designers were particularly concerned, saying that all the risk is transferred from the owner to the contractor and then to the designer. Additionally, SWTC documents in D&C projects are often very prescriptive and restrictive, only allowing the contractor to construct pavements that have been extensively proven by the road agency.

Contractors cited Alliance and Early Contractor Involvement (ECI) projects as offering a greater opportunity for the implementation of innovative approaches. One designer, however, criticised the current Alliance model in WA (more specifically the contract used in the Gateway WA project) as not being reflective of international best practice. No details to support this opinion were provided.

Another type of model cited was the staged construction model, used in WA in the 1980s. However, it was acknowledged that this approach is potentially difficult for the designer and is limited by the lack of a standard method for assessing whole-of-life-cycle costs (WOLCC).

3.3.2 Contract Requirements

Contractors commented on the defects correction period discouraging innovation, as the contractor will generally focus on the defects period rather than proposing innovations that could minimise the overall risks to Main Roads WA.

Another concern raised was that Main Roads WA typically specifies minimum pavement compositions as well as performance, so that even if the contractor follows the prescriptive SWTC design, all the performance risks are still borne by the contractor. Besides discouraging innovative solutions, this approach is viewed by the contractors as inconsistent. In many contractors' view, if Main Roads WA requires a certain performance and the contractor is taking all the risk, then the contractor should be able to determine the pavement composition to achieve the required performance. Alternatively, contractors think that, if Main Roads WA is prescriptive about what pavement type and thickness is required, then Main Roads WA should take the risk for the design, not the contractor.

It was suggested that different design options should be associated with different acceptable liability periods.

Designers also commented on the use of incentives and penalties as alternatives to reconstruction when non-conformances are encountered. It was mentioned that in New Zealand contractors are capable of delivering reduced roughness if adequately incentivised.

3.3.3 Improved Engagement between Parties – Knowledge Transfer

Both contractors and designers commented on the need for Main Roads WA to share more information with industry to assist in decision making. While contractors are required to achieve strict performance outcomes they do not consider that they have sufficient historical information on the previous performance of Main Roads WA pavements to be able to make their own interpretations and conclusions. In the current scenario, contractors and designers rely on Main Roads WA-prescribed pavement types and minimum requirements to achieve the specified performance requirements.

To overcome this, the participants suggested more interaction between Main Roads WA and the road construction and design industry, not only in Alliance projects, but also as a general rule.

As noted earlier, in order to ensure that the majority of workshop time was spent raising issues and opportunities for improvements, discussion and argument about issues raised between Main Roads WA staff and other participants was deliberately minimised. However, in later conversations with Main Roads WA staff it became clear that they believe that there are necessary and soundly-based reasons for some of the practices which some workshop participants considered to be overly restrictive. It was considered to be in the best interests of both Main Roads WA and industry that open discussions of some of these issues be proactively undertaken.

It is suggested that Main Roads WA more actively outreach to industry outside specific contracts, and undertake more collective information exchange activities. These could be workshops, Main Roads WA TechXchange presentations, webinars, the publication of findings from the Western Australia Pavements Group (WAPG) and inclusion of the construction industry in the WAPG.

3.3.4 Knowledge/Experience

Workshop participants identified a lack of available performance information for designers to be confident that they can achieve the performance criteria, especially in regard to new technologies.

Some participants at the contractors workshop thought that the risks associated with the introduction of innovative pavement technologies should be balanced by different performance thresholds in the defects liability period.

The definition of a 'trial' as opposed to a 'demonstration' was questioned. It was pointed out that widespread investment in a new technology, whilst it was being 'trialled', was unlikely.

Additionally, it was suggested by some pavement designers that when a 'trial' of a technology is being undertaken that Main Roads WA clearly state the desired outcomes of the trial. Some designers also cited a lack of long-term commitment to trials.

3.3.5 Whole-of-Life-Cycle Cost (WOLCC) Analysis

Some of the workshop participants emphasised the need for consideration of WOLCC when considering pavement options, as well as in the selection of pavement performance criteria. It was suggested that Main Roads WA should consider bids based on a WOLCC analysis. It was also suggested that the whole-of-life-cycle analysis should not only consider construction costs, but also environmental aspects, rehabilitation options and user costs.

It is the understanding of the authors that, in the selection of pavement type options and minimum thicknesses for D&C contracts, Main Roads WA does consider some WOLCC issues. It is suggested that this is a topic that should be discussed at a special workshop, webinar or TechXchange event as discussed in Section 3.3.3.

3.3.6 Construction

The following specific construction issues were raised during the workshops:

- the minimum refusal density during winter months
- the requirement for waterproofing approaches for full depth asphalt (FDA) pavements (placing and removing temporary seals being too expensive)
- the current requirements in regard to asphalt stripping ('lot of cost for a perceived risk')
- the requirement of a 7-day unconfined compressive strength (UCS) less than 1.0 MPa for modified materials.

3.3.7 Materials

Several pavement materials were identified as either not being used to their full potential or not yet being properly investigated. These included:

- recycled materials from construction and demolition (C&D) waste
- in situ foamed bitumen stabilisation
- bitumen-stabilised limestone (BSL)
- lime-stabilised subbase and subgrade
- reclaimed asphalt pavement (RAP) in stabilised pavements
- geosynthetics

- high-performance materials in addition to the enrobés à module élevé Class 2 (EME2) asphalt material currently being implemented throughout Australia
- permeable concrete and asphalt pavements
- saline water for construction.

As part of the project an examination of the current state-of-the-art regarding these materials within Australia was undertaken. This is documented in Section 6.

3.3.8 Design

Several design issues and suggestions were raised as follows:

- Suggestions:
  - in situ stabilised subgrade with thin bituminous surfacing
  - deep strength asphalt with a thickness of approximately 100 mm may be viable
  - cement-stabilised subbases on FDA pavements
  - heavy-duty unbound granular pavement with stabilised subbase
  - staged approach to pavement construction (especially for rural WA, where pavement roughness is routinely assessed)
  - inclusion of options for widening structures when overlays are not accepted
  - reducing the required design life on widening projects, possibly matching the expected life of the adjacent structure
  - new pavement types in the SWTC (excluding pavement types only when deemed to be not feasible and not excluding types based on Main Roads WA pre-selection)
- Issues:
  - there is no method to consider the structural contribution of geosynthetic-reinforced seals in the design
  - the design life is not always achieved as there are often rapid changes in geometry requirements
  - conflicting information between different technical sections of the SWTC
  - conflicting information between the ERN9 and the SWTC
  - ERN9 is difficult to follow
  - ERN9 limits the utilisation of subsurface drainage features, forcing expensive pavement alternatives
  - FDA pavement design is likely over conservative.

Besides the suggestions and issues cited above, several more specific comments were made regarding ERN9. These are summarised in Appendix B. Consideration of these issues was referred to in WARRIP project *Cost effective pavement thickness design* (Project No. 1604).

3.4 Conclusions

Workshop participants and Main Roads WA staff recognised that the information exchange undertaken during the workshops was excellent and that there were benefits to be realised in more open forum discussion. As a result of the workshops it became apparent that industry needs to better understand the technical or historical background of Main Roads WA decisions and prescriptive pavement requirements, in order to be able to collaborate with Main Roads WA in developing new solutions.

It is recommended that Main Roads WA develop a rolling timetable of events to actively engage with industry outside specific contract processes. These events could comprise a combination of workshops, Main Roads WA TechXchange presentations and webinars.

It also became evident that the industry is seeking different forms of contract where the risk is shared between contractors, designers and Main Roads WA, enabling innovative solutions.

Using the issues raised during the workshops as input, Main Roads WA determined that the major focus of the project should be examining the following issues:

- What pavements are permitted and used?
- How they are designed?
- What defects liability processes are appropriate?

Section 4 of this report discusses the processes used by Main Roads WA in selecting contract forms and pavement types for major projects. Additionally, a summary of the practices of other road agencies is provided.

Section 5 compares the heavy-duty pavement types typically specified by Main Roads WA in SWTC documents to those used by other Australia road agencies. Additionally, Section 6 provides a summary of the state-of-the-art use of different material types suggested by workshop participants (Section 3.3.7) for consideration by Main Roads WA.

4 NATIONAL MAJOR PROJECT PRACTICES AND CONTRACT DOCUMENTATION

4.1 Introduction

The current major project practices of VicRoads, Roads and Maritime Services (RMS), New South Wales (RMS), Queensland Department of Transport and Main Roads (TMR) and the Department of Planning, Transport & Infrastructure, South Australia (DPTI) were reviewed and compared against Main Roads WA practice.

The following key documents utilised within the contract were reviewed:

- SWTC requirements, including allowable pavement types, detailed design requirements, pavement performance requirements, defects correction period and use of a principal supplied design
- relevant parts of the *Austroads Guide to Pavement Technology* series and road agency supplements to these documents
- road agency construction specifications.

Each road agency representative on the Austroads Pavements Task Force and the Pavements Structures Working Group was contacted and asked to provide relevant documents. They also answered questions and provided clarification regarding their agency's practice and documents.

4.2 Scope of Works and Technical Criteria

4.2.1 Introduction

SWTC requirements cover the design of all project elements, including road geometry, drainage, traffic control layout, lighting, roadside furniture, earthworks and pavements. As a minimum, these documents typically state the required pavement design standards, design period, project reliability level and permitted pavement types for each road element. They often also include other key pavement design parameters such as design traffic, design subgrade conditions, allowable material types, minimum pavement thicknesses and other detailing.

All SRAs use a SWTC-type document, although it is described differently in each state. Details are as follows:

- RMS uses a project-specific document titled *RMS Specification PS341: Pavement investigation and design*. They supplied the generic template document for this review.
- TMR utilise a *Scope of Works and Technical Criteria* document for each major project. TMR provided the SWTC document from the recent Bruce Highway Upgrade project, which they stated was representative of typical major D&C projects.
- VicRoads utilise a *Tender Design Brief* document for each project. VicRoads provided a generic template for consideration.
- DPTI uses a *Contract scope & technical requirements* (CSTR) document, with Part D26 of this document containing the pavement design requirements. DPTI supplied the generic template for this document.
- A recent Main Roads WA SWTC was also provided, from the Northlink WA Stage 1 – Tonkin Highway Grade Separation and Reconstruction Project.

For simplicity, the Western Australian term, SWTC, has been used when describing all the SRA design scope documents.

4.2.2 Major Project Pavement Types

The SWTC states what pavement types are allowed for the various road elements within the project. Each state has different preferences, in response to local issues such as material sources; experience with design, construction and long-term pavement performance; traffic loading; climate; soil types; professional expertise; materials and construction industry capability and preferences; costs; and asset management strategies.

Section 5 of this report provides a review of the pavement types used on major projects in Australia.

4.2.3 Pavement Type Selection

The pavement types allowed for major projects is based on the consideration of many factors. There is not a simple, uniform approach in how allowable pavement types are selected, nor is there consistent selection and use of the same pavement types across Australia.

Ideally, multiple pavement types would be allowed by SWTC to generate competition and provide the lowest whole-of-life cost pavement that achieves the design and performance standards.

However, in practice, SRAs may only allow one or two pavement types for their main roads. This is obviously not ideal in terms of maximising competition, although there is still competition between competing material suppliers and construction companies within a particular industry sector.

The SRAs indicated that the allowed pavement types are generally chosen on a project-by-project basis, as a joint decision between internal pavement specialists, senior projects staff and asset owner representatives.

Typically, a range of pavements will be considered at the project planning stage. WOLCC and capital cost may be used to inform the selection of allowable pavement types, but this does not necessarily mean selecting the lowest WOLCC or capital cost option. Project-specific budget constraints and/or acceptable performance risk can lead to other pavement types being allowed.

Similarly, project-specific technical constraints will influence the allowed pavement types. An important issue is whether the project is occurring on a new ‘greenfield’ or existing ‘brownfield’ site. Brownfield sites can impose numerous constraints, including traffic management and land access dictating the construction staging. This favours those pavement types more readily and economically constructed in shorter runs.

The subgrade soils can also substantially influence the pavement type. For example, rigid pavements are less favoured where there are soft soils or highly-expansive soils, as they are considered to be less able to accommodate subgrade movement.

The SRAs indicated they did consider WOLCC to varying degrees. Sometimes this was done through a formal analysis of net present value of the capital costs, ongoing maintenance and rehabilitation costs over the analysis period, including a discount rate sensitivity analysis (for example on recent projects in South Australia). In other instances, this WOLCC assessment was based on experience rather than a formal analysis. For example, both South Australia and Queensland have moved away from deep strength asphalt configurations due to concerns about cracking gained from historical project performance.

Lack of experience with a particular pavement type can also be a barrier to the adoption of new pavement types. For example, whilst RMS leads Australia with concrete pavement technology, most other SRAs have limited experience, expertise and industry capacity with this pavement type. Utilising it for the first time has substantial commercial, technical, performance, social and political risks. Technical risks can include adapting or adopting another agency's specifications, but this can be a complicated task given the general lack of harmonisation of specifications across Australia.

Utilisation of a new pavement technology may require the importation of expertise, equipment, materials, etc. from interstate, but this generates increased establishment costs, as well as negatively impacting local industry and jobs (and associated social and political risks). Although these issues can be managed, they may offset the primary gains associated with adopting the new approach.

DPTI noted that the South Australian market is smaller than that in the eastern states, and generally only one or two major projects are occurring at the same time. This limits opportunity for the development of a diverse range of alternative materials and configurations. Larger states, such as Queensland and New South Wales, usually have a greater number of major projects in progress and a larger industry. As a result, they tend to allow more alternative pavement types, confident that they have the expertise and capacity to deliver them to an acceptable standard.

For projects where more than one pavement type is permitted, the allowable pavement types are included in the SWTC. It is then up to the tenderers to propose their preferred option, based on their assessment of capital costs, constructability, programming, performance risk, etc.

Main Roads WA mainly uses FDA pavements or granular pavements with thin surfacings on major urban projects, with some localised use of rigid pavements for particular technical needs. FDA pavements are typically used when the 40–year design traffic surpasses 3×10^7 Equivalent Standard Axles (ESA). Opportunities to explore other heavy-duty pavement types are discussed in Section 5 of this report.

4.2.4 Principal-Supplied Pavement Design

Practice of other SRAs

Most SRAs prepare their own pavement design for major projects. As a minimum, it is used for initial internal project scoping and costing. It can also be included in the project tender documents, with tenderers required to cost this the design. This design allows the SRAs to compare tender submissions based on a similar scope of works in terms of price, construction program, expected pavement performance and other issues.

Tenderers can also propose alternative, so-called 'non-conforming', pavement designs in their submission – with an accompanying outline of cost, program, environmental or other benefits versus the reference design – for the agency's consideration.

VicRoads prepares most of its major project pavement designs in-house; this is termed the 'Principal's nominated pavement design'. The contractor can propose alternative designs, if for example they believe a higher subgrade design California Bearing Ratio (CBR) is appropriate based on additional data gathered post-tender. VicRoads would then accept or reject these changes based on evidence provided. This approach can sometimes introduce issues when there is poor pavement performance, if the contractor believes they have built the works in accordance with the VicRoads design and specification, i.e. they can claim that the deficiency is with the design or specification, not their workmanship. But VicRoads experience is that typically performance issues arising within the defects liability period can be clearly linked to workmanship issues, given the conservative nature of the designs and specifications.

DPTI's typical process is to prepare a reference pavement design in-house and include this in the tender documents. It is stated as being 'for information only', with the tenderers expected to prepare their own design that conforms with the SWTC. The winning contractor takes full ownership of the final design. The intention is that DPTI should not own any design related liability or risk. The contractor typically provides a 70% and a 100% design (so termed because they are considered to be the 70% complete and final designs respectively) for the independent proof engineer and DPTI to review for conformance with the SWTC. The final design is certified by the proof engineer as meeting the SWTC and issued for construction. The proof engineer is an engineering consultancy from outside of the contractor's team.

In Queensland, TMR may prepare and provide a reference pavement design. Similar to DPTI, it is provided for information only and has no contractual standing. The contractor must always undertake the final design and carry the design risk. The reference design is often lacking in full detail, due to its preparation during early stages of the project, when full geometric, traffic, subgrade and other design inputs may not have been available or finalised. TMR's role in the process is usually as a design reviewer/verifier, with design packages provided at 15%, 50%, 85% and *permission to use* (i.e. 100%) stages.

RMS was unable to provide detailed information on its current approach within this project timeline.

TMR noted that it had moved away from construct-only contracts with principal-supplied designs due to past experience with construction issues being blamed on design deficiencies, resulting in contractual problems. DPTI had similar experience, with its last construct-only project occurring more than 10 years ago. VicRoads is therefore unique in using a principal-supplied design approach for major projects.

Comparison with Main Roads WA practice

Main Roads WA typically prepares a preliminary design traffic analysis and a preliminary pavement thickness design. The outcomes are presented in the SWTC in the form of tables containing minimum design traffic and selected pavement layer thickness requirements for each section within the project. Although the SWTC does not explicitly present minimum pavement composition requirements or minimum thickness requirements for each pavement layer, the information contained in the SWTC, when read in conjunction with ERN9 (Main Roads WA 2013a), defines the minimum requirements for the pavement configuration at each section. The contractor is responsible for collating appropriate traffic information, defining an appropriate design traffic and proposing a pavement design that complies with all the requirements in the SWTC, which includes compliance with the Austroads design processes (Austroads 2012) and the Main Roads WA supplement, ERN9. According to ERN9, the requirements in Austroads (2012), Main Roads WA guidelines and specifications may need to be exceeded at the discretion of the designer.

For major projects, the contractor usually tenders based on a preliminary tender design prepared by the designer, rather than the minimum requirements in the SWTC. Traffic analysis is usually not carried out at tender stage, unless the SWTC does not include minimum design traffic requirements, such as in Alliance contracts. Often, the tender design will match the minimum thickness requirements in the SWTC, but sometimes a thicker pavement is required. The contractor can propose non-conforming alternatives that provide thicknesses below the SWTC requirements, but these are rarely accepted by Main Roads WA. The contractor provides a 15%, 85% and 100% design for the independent verifier and Main Roads WA to review. The reviews not only address conformance with the SWTC and standards, but also any other issues that may affect the performance of the pavement. Once the verifiers are satisfied that all the comments have been addressed, or at least considered, the final 100% design is issued for construction.

4.2.5 Pavement Design Requirements

Overview

The pavement design must conform with the requirements of the SWTC. The SWTC typically requires:

- Use of the Austroads *Guide to Pavement Technology* series, particularly Part 2 (Austroads 2012) for new pavement design) and Part 5 (Austroads 2011a) for the assessment and rehabilitation of existing pavements – these guides are maintained and developed by Austroads, particularly the technical working groups which have SRA, ARRB and industry representatives on them.
- Use of SRA supplements to these design guides, as well as other local guides (e.g. some SRAs have a separate guide to bikeway pavement design) – these supplements are maintained by each SRA and are unique to each state. The Main Roads WA design supplement is ERN9 (Main Roads WA 2013a).
- Use of RMS documentation for concrete pavement design and detailing (all SRAs refer to RMS documentation for concrete pavement design and construction).
- Use of linear-elastic software (typically the CIRCLY software) for mechanistic design calculations, which is referred to in the Austroads design guides (Austroads 2011, 2012) – CIRCLY is owned and maintained by MinCAD Systems Pty Ltd.
- Additional minimum content needed in the pavement design report and construction drawings.

The pavement design parameters that are typically nominated include:

- pavement design period and desired project reliability level
- design traffic loading – some SRAs provide traffic count data, others the design traffic loading in ESA, along with the SAR5/ESA, SAR7/ESA and SAR12/ESA (refer Austroads 2012 for definitions), or a design traffic distribution
- design parameters for pavement materials and select fill, including weighted mean annual pavement temperature (WMAPT) and design speed for asphalt moduli selection
- natural subgrade design CBR values
- wearing course mixes for different road locations, the need for spray seal interlayers, primes on granular subbases, bridge decks, etc., and other detailing requirements
- prescribed pavement configurations, usually for secondary pavements like footpaths, shared user paths and maintenance bays, and, possibly, bridge decks
- consideration of geotechnical conditions and earthworks treatments, possibly with maximum allowable design CBR for select fill and subgrade layers stated
- consideration of the need for, and design of, subsurface drainage (usually in accordance with Part 8 of the Austroads *Guide to Pavement Technology* (Austroads 2009).

Some of this content may already be stated in the SRA's pavement design guide supplement, in which case it is typically not duplicated in the SWTC.

These design inputs are controlled by SRAs to ensure that an acceptable technical standard is achieved by the design, and consequently acceptable long-term pavement performance.

There can be an incentive for contractors to adopt higher risk design parameters to give cheaper pavement configurations for the commercial benefit of the contractor. These higher risk designs can have an associated reduced technical standard/higher performance risk. This may not concern the contractor given the performance issues may only develop in the long term, well after the end of any defects correction period.

The elements stated in SWTCs have generally been built up based upon experience with previous major D&C projects to ensure the minimum standard design still achieves the expected long-term performance.

The downside is that the design parameters may be restricted to the point where there is little scope for the pavement designer and contractor to optimise or innovate, preventing potential improvements in cost, program and other benefits, without compromising performance. Most SRAs allow the contractor to propose alternative non-conforming designs when the contractor believes there is a significant benefit. Such alternative designs are typically assessed by the SRA on a case by case basis.

Comparison with Main Roads WA practice

The sample Main Roads WA SWTC document provided to the authors is similar to those used by other SRAs in specifying, for each road element, the required design standards, allowable pavement types, wearing course mixes, the design traffic loadings, some material moduli and compaction requirements, and pavement performance condition requirements.

There were three notable differences between Main Roads WA practice and practice by other SRAs.

Firstly, the Main Roads WA SWTC states the minimum pavement and basecourse thickness for granular pavements, or the minimum asphalt and subbase thickness for full depth asphalt pavements. With the exception of VicRoads, which provides full pavement designs, all other SRAs do not state minimum required thicknesses. They instead accept the pavement thickness arising from the application of the Austroads design system and their supplement's requirements. Any concerns about deficient pavement thickness are addressed through setting appropriate design traffic loadings, material moduli and other properties determining pavement thickness, when the Austroads design system is applied. Some SRAs also state the maximum allowable subgrade design CBR, as the other main determinant of pavement thickness.

It is recommended that this approach be considered by Main Roads WA, i.e. that it removes the minimum pavement thickness and instead rely on the Austroads design system outputs. There appears little risk if this restriction is removed, provided the key pavement design inputs are appropriately controlled.

Secondly, the Main Roads WA SWTC includes detailed pavement construction requirements. For example, as-constructed density requirements for granular and asphalt layers, asphalt mix specification requirements and asphalt production tolerance limits. This detailed level of information is generally contained in the construction specification with other SRAs. Some of the information in the SWTC appears to also be contained in the construction specification. The SWTC may require the contractor to develop additional project-specific specifications for elements of the project, with these taking precedence over the standard documents. Such specifications are submitted for 85% and 100% review by an independent verifier and Main Roads WA, prior to being issued for construction.

Lastly, Main Roads WA specifies minimum design traffic requirements but expects contractors/designers to carry out their own traffic analysis rather than adopting the minimum requirements in the SWTC. The contractor is required to take full responsibility for the design, including the selection of the design traffic. In practice, however, most designers for D&C projects adopt the minimum design traffic requirements given in the SWTC without conducting a detailed traffic analysis. A detailed traffic analysis is typically not carried out during the tender stage and therefore any increase in pavement costs due to increased design traffic volumes after the contract is awarded would incur extra costs to the contractor. Additionally, it is known by contractors/designers that Main Roads WA carries out a traffic analysis prior to releasing the minimum design traffic numbers in the SWTC. It was stated in the workshops (Section 3) that contractors/designers believe that the traffic data that Main Roads WA uses is generally more comprehensive or similar to the data that the contractors/designers would be able to obtain, and therefore Main Roads WA has more knowledge to be able to assume realistic traffic growth values than contractors/designers. The requirement that contractors/designers develop their own design traffic levels would appear motivated by a Main Roads WA desire for risks to future pavement performance resulting from selection of design traffic being carried by the contractors/designers and not Main Roads WA.

Beyond these issues, the Main Roads WA SWTC document has a very similar approach to the other SRAs, supporting Main Roads WA current practice.

4.2.6 Pavement Performance Requirements and Defects Correction Period

Pavement performance requirements are quantified in contracts as pavement condition parameters to be measured and reported throughout the contract defects correction period (DCP). These condition parameters must achieve the stated minimum or maximum values. Failure to meet these typically results in penalties, which can comprise payment penalties or being required to undertake physical treatments.

All SRAs, including Main Roads WA, have this requirement. Some SRAs, such as Main Roads WA and TMR, include these in their SWTC document, whereas others, such as DPTI and RMS, have them in their construction specifications.

There is some variation in what parameters are measured and the frequency of testing between SRAs. Table 4.1 summarises the measured parameters by agency. It is noted that these are typical values, with project specific variations occurring when deemed necessary.

Table 4.1: Pavement performance monitoring

Agency	Main Roads WA (WA)	RMS (NSW)	TMR (QLD)	VicRoads (VIC)	DPTI (SA)
Typical defects correction period	▪ Construct only projects: typically 1 year, but sometimes 2 or 3 years ▪ D&C projects: typically 7 years but sometimes reduced to 5 years for D&C alliance projects ▪ Minor works contracts: 12 months	3 years	2 years	2 years (1)	3 – 5 years (2)
Condition parameters & measurement frequency					
Roughness	PC(5), 1st & 3rd anniversary, end of defects correction period (DCP(6))	PC, end of DCP	Annually	Before end DCP	PC, biannual, end of DCP
Deflection & curvature (FWD device)	PC, 1st & 3rd anniversary, end of DCP	No	Annually	No	No(3)
Skid resistance	PC, 1st & 3rd anniversary, end of DCP (SCRIM device)	PC, end of DCP (SCRIM device)	Annually (SCRIM device)	Visual(4)	PC, biannual, end of DCP (Griptester device)
Cracking	Cracking index: PC, 1st & 3rd anniversary, end of DCP	Not stated	Annually	Visual(4)	Visual
Rutting	PC, 1st & 3rd anniversary, end of DCP	PC, end DCP	Annually	N/A	PC, biannual, end of DCP
Texture	Texture depth, texture index PC, 1st & 3rd anniversary, end of DCP	PC, end DCP	Annually	Visual(4)	PC, biannual, end of DCP
Patching	Patching index (patching extent) PC, 1st & 3rd anniversary, end of DCP	N/A	N/A	N/A	N/A
Concrete pavement texture depth	PC, 1st & 3rd anniversary, end of DCP	PC, end DCP	N/A	N/A	N/A

1 Was previously 3 years but recently reduced to 2 years.
2 Has varied from 3 to 5 years on recent projects.
3 DPTI used to require Deflectograph testing at PC and end of DCP but stopped as the results never identified any structural issues so early in the life of these heavy-duty pavement configurations.
4 VicRoads contract administrator checks for fleshing/bleeding and cracking visually, any issues are then investigated further.
5 The term *PC* represents 'at practical completion' – prior to opening to traffic.
6 The term *end of DCP* represents 'end of defects correction period' – final testing is testing is conducted prior to handover of project to SRA.

Vehicle-mounted automated data collection systems are used for the measurement of most parameters. These systems can efficiently measure, automatically analyse and report the parameters, usually as results per lane, averaged over 100 m intervals. These methods are well proven, with associated Austroads test methods adopted by most SRAs (possibly with some local amendments).

There is significant variation in what pavement condition values are acceptable and how penalties are implemented between SRAs. For example, some SRAs have a blanket acceptable value of roughness for all pavements, whereas others have a sliding scale of values linked to speed limit and road class, seeking better performance on higher speed, higher class roads.

RMS appears unique in implementing performance bonuses for achieving low roughness counts, besides penalties for high roughness counts, in its concrete pavement specification R83. A detailed comparison of each SRA's parameters is beyond the scope of this report. However, such an exercise may be worthwhile undertaking in the future, particularly if Main Roads WA or industry believes there are particular pavement performance issues needing resolution, such as recent non-conformances in rutting and FWD measures.

Overall, Main Roads WA's approach is similar to the other states, supporting its current approach. There may be some opportunities for further refinement in acceptance criteria and penalties/bonuses, following a detailed review of each national practice. The key difference between Main Roads WA and other agencies is the requirement for constructed pavements to remained below deflection thresholds during the defects correction period. It is worth noting the typical defection corrections period of 7 years used by Main Roads WA is longer than other agencies. In conversation with the authors, staff from some other state agencies noted that they would prefer to have longer defect periods than currently used.

4.3 Austroads Guides and SRA Supplements

As already discussed, all states utilise the Austroads *Guide to Pavement Technology* series for pavement design on their major projects. These guides remain under continuous development by Austroads and their supporting technical working groups and draw on relevant national and international research and developments.

Each state also has its own design supplement to these guides, as per Main Roads WA's Engineering Road Note 9 (ERN9) (Main Roads WA 2013a). These documents generally endorse the Austroads design system and provide additional information and requirements for the designer. This is necessary to align generalised Austroads content with local practice. For example, most supplements provide design moduli for their state's unique asphalt mixes and granular pavement materials.

There are numerous design rules, local practices and procedures within these guides, including allowable heavy-duty pavement types. The concurrent WARRIP project 2016-003, *Cost effective pavement thickness design*, has conducted a detailed review of each state's design supplements, focussing on the highest priority issues identified in the workshops and Main Roads WA. The final report from that project should also be read for further review of specific detailed design practices.

4.4 Construction Specifications

4.4.1 Introduction

Every SRA has its own unique construction specification for roadworks. They all have a similar overall structure and content to Main Roads WA's specification, with sections for earthworks, pavement materials, pavement construction and other road items like drainage, line marking, ITS, etc.

There are hundreds of specification parts across the SRAs and a detailed review of the specifications of each SRA is beyond the scope of this project. It is likely that there are opportunities for changes and improvements in some parts of the Main Roads WA specification. The first step in the specification review would be to identify and prioritise specific parts for detailed review. Specification aspects identified in the workshop that could lead to further investigation include:

- the minimum refusal asphalt density during winter months
- the requirements for waterproofing approaches for FDA

- the requirements relating to reducing the risk of asphalt stripping
- the UCS requirements for modified materials.

Some higher-level specification related issues and emerging trends were identified in the industry workshops and in discussion with other SRA staff. These are discussed in the following sections.

4.4.2 Performance-Based Specifications

Most SRA construction specifications are prescriptive in their nature. For example, the specification for an unbound granular pavement material typically states the allowable parameters for particle size distribution, Atterberg limits, aggregate properties (e.g. Los Angeles abrasion value, flakiness index, etc.) and other requirements such as mineralogical exclusions.

If a material conforms with this specification, then it is expected to achieve the minimum engineering properties adopted in the design. For example, a conforming unbound granular pavement is expected to achieve, or exceed, the design modulus used in the pavement design calculations, as well as have acceptable other properties like permeability, aggregate strength and so on. Sometimes there may be direct measurement of these properties required, but these are usually slower, higher cost tests and so done at a lower frequency than the basic parameter tests.

These prescriptive specifications have been developed and used successfully over many decades by SRAs. They have been validated and optimised through experience and observations of long-term field performance of pavements built using these specifications. However, they do have some deficiencies.

The first issue is that they can restrict innovation since they are prescriptive. For example, material suppliers may develop a proprietary product that they believe has equivalent, or better, performance than the materials conforming with the conventional specification, but are unable to use it since it is non-conforming. Some states have addressed this in selected areas through use of a performance-based specification. For example, South Australia allows the use of granular materials that do not conform to its conventional specification based upon the results of resilient modulus testing, combined with reduced prescriptive requirements. This was a key step in allowing greater South Australian uptake of recycled granular materials produced from demolition waste.

Another issue is that the technical basis of some specification requirements can be unclear. There is often limited documentation or commentary on the technical basis of specification clauses. A clause may have been added based upon poor performance on a particular project with a particular material decades ago. The continuing retirement of the ‘baby boomer’ generation, who originally developed these specifications, has also left knowledge gaps. It can therefore be challenging to know how strictly necessary some clauses are, and whether requirement can be relaxed or need further development.

In addition, there has been a long-term trend towards larger, heavier trucks with higher tyre pressures, combined with constantly increasing traffic volumes on Australian roads. This can mean that design approaches and specifications that worked previously are now at the limit of their capacity.

As an alternative to prescriptive specifications, SRAs, ARRB, Austroads and industry have been progressively moving towards performance-based specifications. For example, the *Austroads guide to pavement technology: part 4B – asphalt* (Austroads 2014a) describes performance-based tests for asphalt modulus, deformation resistance and fatigue performance that can be used, in lieu of raw material parameters, to define the acceptable performance of an asphalt mixture.

Within a performance-based framework such as that envisaged by Austroads (2014), industry can innovate and compete to achieve required performance standards more efficiently, within broad boundaries of required performance.

Whilst such an approach appears to be relatively simple, in practice it can be challenging to implement. Potential issues include:

- Advanced performance tests are often more complicated, time consuming and costly than routine standard testing.
- States can use different test methods to each other to measure a similar performance characteristic. Significant work is being undertaken to ensure harmonisation and development of national Austroads test methods.
- There can be resistance to adopting new test methods, when it requires a substantial investment in retraining, new equipment and gaining experience. There are commercial issues as well as the technical consequences of adopting a new approach.
- The relationship between laboratory test results and field performance is not exact. Laboratory testing occurs on precisely-prepared, small-scale samples, over short time intervals in a controlled environment. However, in the full-scale field situation the materials are exposed to a variable climate and loading over periods of several decades and have more inherent variability from construction processes. This issue also exists with prescriptive specifications; however, there is currently more confidence in them producing acceptable field outcomes based on long-term experience with their use. It takes time to gain confidence in new specifications and to be sure they are not creating new problems in the field, whether they are performance-based or prescriptive or a blend of both.
- Performance based specifications can result in a shift towards proprietary products where the technology is commercial in confidence and unknown to SRAs, consultants and contractors. This can reduce knowledge sharing and innovation and best practice at an industry level.

Another type of performance-based specification is specifying the performance required at a road performance level. This involves specification of road performance requirements such as ride quality (roughness), skid resistance, rutting, cracking and texture. This is essentially saying that road users need a smooth road, with adequate skid resistance and texture, that is also free from unacceptable levels of rutting, cracking and other defects. Under this approach the engineering of how to achieve this will not be as strictly prescribed as it currently is.

Whoever is responsible for building and maintain the roads will still need a rational basis for the design and construction, so will, at least initially, draw upon the existing Austroads and SRA systems. In a sense, the entire existing pavement design and construction system currently in use is a prescriptive design and specification that is intended to deliver these road performance outcomes.

Main Roads WA's past experience with performance-based specification concepts is understood to be that the relaxation of prescriptive requirements can result in industry adopting lower cost alternatives that meet performance-based specifications requirements but with reduced pavement outcomes, necessitating the reintroduction of prescriptive requirements to ensure acceptable performance.

At this time, the adoption of significant performance-based specifications for materials is limited. However, work in this area is continuing that Main Roads WA should continue to monitor and be involved with. The ongoing work with asphalt performance-based specifications is particularly interesting because it potentially allows the use of higher-performance asphalt that will address some existing performance issues or allow reduced pavement thickness related to improved strength and fatigue performance.

4.5 Recommendations

Workshop attendees expressed a need for contract frameworks that allow and encourage innovation. It is recommended that a more detailed investigation on contract models be undertaken with more risk sharing and flexibility for change. Suggested contract frameworks that could be investigated further include: Early Contractor Involvement (ECI) contracts, a three-party procurement model (design-construct-owner), a staged construction model and an improved Alliance model.

It is recommended that further refinement in acceptance criteria and penalties/bonuses be considered, to encourage contractors to deliver better outcomes rather than just focusing on minimum requirements.

Additionally, it is recommended that further investigation is carried out on the development of performance-based specifications, giving the contractors/designers more flexibility to achieve cost-effective pavement solutions.

Other relevant recommendations regarding pavement design requirements are included in the report for the WARRIP project *Cost effective pavement thickness design* (WARRIP Project 2016-003).

5 MAJOR PROJECT PAVEMENT TYPES

5.1 Introduction

A review of the pavement types used on major projects by Australian SRAs was undertaken, for comparison against Main Roads WA practice and to identify opportunities for improved practices. The review involved the following steps:

- Review of each SRA's pavement design guide supplement to the Austroads *Pavement design guide* series, as these typically define allowable heavy-duty pavement types and design rules for major projects.
- Responses to queries by senior pavements staff within each SRA on various issues relevant to this project's goals. Typically, they were the SRA representative on the Austroads Pavements Technology Program working groups, either the Pavements Task Force, or the Pavements Structures Working Group.
- Review of a typical major project SWTC document provided by each SRA. They were either recent project specific documents, or a generic template used as the basis for project specific versions.
- The Austroads *Guide to pavement technology: part 2: pavement structural design* (Austroads 2012), which provides a design system for commonly used configurations in Australia.

5.2 Heavy-Duty Pavement Types

Table 5.1 summarises the heavy-duty pavement configurations that are typically used in Australia on major projects. Table C 1 and Table C 7 in Appendix C provide further detail on each of these types, grouped into flexible and rigid pavement categories. Information is provided on the frequency of use, typical configurations (where readily available) and other additional details.

Full Depth Asphalt (FDA) is used in all five states surveyed and is the most commonly used heavy-duty pavement type. This configuration typically comprises 250 mm or more of asphalt on an unbound granular subbase class material (or select material zone in NSW). Queensland, which has a high rainfall environment, requires the use of a cement-modified granular subbase layer to reduce sensitivity and delays associated with moisture ingress. FDA is currently favoured by all SRAs due to perceptions of its reduced performance risk.

The use of other heavy-duty pavement types varies substantially between states.

New South Wales regularly uses asphalt basecourse on lean mix concrete subbase pavements. These so-called 'composite pavements' consist of a minimum of 175 mm of asphalt on a single-layer lean mix concrete (LMC) subbase (150 mm to 230 mm thick). The LMC is produced in a concrete batching plant, with concrete paving expertise required to place the material successfully (although they are considered easier to build than a concrete pavement). Queensland identified two significant projects that have utilised this configuration, which are performing well at this time, but overall its use in Queensland is limited.

Western Australia, South Australia and Victoria have never had any significant use of this type, and do not have construction specifications or supporting industry prequalification systems and capacity in place like NSW.

Deep strength asphalt (DSA) pavements are currently the most commonly used pavement type in Victoria on urban major projects. The configuration typically comprises 175 mm or more of asphalt, on a cement-treated subbase (CTSB). New South Wales also use this pavement type. Its use has been limited in Western Australia. Queensland only selectively uses this pavement type, but noted it was the most common pavement type used 10 years ago; its use has reduced due to cracking concerns. Similarly, South Australia built several freeways with DSA pavements over 10 years ago but has shifted away from these as traffic loadings have increased, with performance concerns about its two-layer CTSB configuration.

Comparison of DSA pavements between each state needs to be undertaken carefully. Some states have specific design rules or specification requirements for the CTSB layer which substantially influences the pavement configuration. For example, VicRoads only allow a 500 MPa design modulus for the CSTB (a constant modulus and not sub-layered in the design model), unless various specification clauses relating to curing and trafficking are observed, which then allows use of a higher design modulus. South Australia's historically-preferred configuration was 175 mm of asphalt over 270 to 330 mm of CTSB, with the CTSB placed in two layers on the same day; other specification requirements relate to curing and trafficking. Such variation in approaches makes simple direct comparison between states difficult.

The main benefit of the CTSB in DSA pavements is that it is substantially stiffer than the unbound granular subbase in a FDA pavement, allowing reduced asphalt thickness, as well as potentially better compaction of the asphalt. The CTSB is also much less moisture sensitive than unbound granular material. The main risks are the development of shrinkage cracks in the CTSB, which migrate to the pavement surface in time, as well as the introduction of fatigue cracking of the CTSB as a failure mechanism.

New South Wales leads Australia with the use of rigid concrete pavements. It has a well-established design system, construction specification, standard detailing drawings, contractor prequalification system and supporting materials and construction expertise. All other SRAs refer to the RMS specification for detailing and construction requirements. New South Wales generally allows the use of rigid pavements as an option to flexible pavements on its major heavy-duty projects without any bias between either type.

Queensland has used rigid concrete pavements recently in Brisbane for tunnels and busways. It broadly estimated it has built at least 50 carriageway-kilometres over the last ten years, with no major performance issues on these pavements. Queensland staff did note that the 16-year-old plain concrete pavement used on the Pacific Motorway south of Brisbane has had some isolated slab replacements and some surface wear, but otherwise maintenance has been minimal. Additionally, there are several 20-year-old projects which have performed relatively poorly and are now needing significant slab replacements. However, these pavements are much thinner than current designs in terms of both base and subbase thickness.

The use of rigid concrete pavements in Victoria, Western Australia and South Australia has been limited. The reasons provided for this included a lack of experience and local industry capability, as well as the lower economic benefit of this pavement type at lower traffic levels. Recently, South Australia has awarded the contract for its first major concrete freeway pavement – on the Northern Connector – which will be a 15 km of dual carriageway freeway constructed with plain concrete pavement. The NSW approach is being adopted.

Western Australia is alone in utilising thin asphalt on granular pavements in heavily-trafficked applications. Other states believe the risk of premature asphalt fatigue is too high, with the subsequent financial, social and political problems being unacceptable. The other states generally do not have the favourable conditions that have allowed this configuration to work well in Western Australia under heavy loadings (e.g. a strong, free-draining sand subgrade and good-quality crushed rocks). That said, it is understood that some recent projects in WA using this configuration have experienced premature asphalt fatigue, requiring the shift towards other heavy-duty pavement types.

Some pavement practitioners in WA believe that the recent failures observed in thin asphalt on granular pavements occurred because the material used as the basecourse in these cases was ferricrete, and the failures might not have occurred if other granular basecourse materials were used. Theories postulated for the failures include small quantities of water infiltrating the ferricrete basecourse and not being dissipated as fast as it could be dissipated in other granular basecourse materials, and the possible debonding between the ferricrete and the asphalt layers. These hypotheses have not yet been fully investigated by Main Roads WA.

For completeness, it is also worth mentioning sprayed seal on granular pavements. These are generally not allowed in urban motorway projects, but they are a commonly used pavement type in heavily-trafficked rural applications in all states, providing good performance.

Table 5.1: Heavy-duty pavement types used on major projects

Pavement type	WA	NSW	Qld	Vic	SA
Full depth asphalt	Commonly used	Commonly used	Commonly used	Commonly used	Commonly used
Deep strength asphalt	Not used	Commonly used	Selectively used, previously most common type > 10 years ago	Commonly used	Rarely used, previously common type > 8 years ago
Thin asphalt on granular	Commonly used	Not permitted as a heavy-duty pavement type	Not permitted as a heavy-duty pavement type	Not permitted as a heavy-duty pavement type	Not permitted as a heavy-duty pavement type
Thick asphalt over lean mix concrete (composite pavement)	Not used	Commonly used	Rarely used	Not used	Not used
Hydrated cement-treated crushed rock base (HCTCRB)	Selectively used if prerequisites satisfied	Not used	Not used	Not used	Not used
Concrete pavements – PCP, CRCP, JCRP, SFRC	Limited use	Commonly used	Selectively used, particularly in tunnels and busways	Rarely used	Rarely used, but first major use underway
Spray seal on granular (1)	Commonly used on rural freeways; not permitted on urban projects	Commonly used on rural freeways; not permitted on urban projects	Commonly used on rural freeways; not permitted on urban projects	Commonly used on rural freeways; not permitted on urban projects	Commonly used on rural freeways; not permitted on urban projects

- Spray seal on granular is not allowed on urban major projects, due to road user expectations and higher maintenance requirements and costs. It was included in this Table as a pavement type that is used extensively in heavily-trafficked rural applications, and to identify all heavy-duty pavement types used in Australia.

5.3 Recommendations

The review of heavy-duty pavement types used on major projects across Australia identified deep strength asphalt pavements and composite pavements as the two types used in other states that could be further investigated in WA.

It is understood that deep strength asphalt was used in the Geraldton Southern Transport Corridor Stage 1 project (opened in 2005). The use of deep strength asphalt in the project allowed a slightly reduced capital cost but incurred an increased expenditure in maintenance of the as-constructed pavement, which discouraged Main Roads WA in the use of this type of pavement. More investigation is required to understand if this type of pavement could be successfully implemented in WA.

The workshops identified a lack of understanding from contractors and designers on the reasons why Main Roads WA mandates specific pavement types and very rarely allows innovative solutions that can result in reduced construction costs. Main Roads WA specifies pavement types that it considers have been proven to minimise WOLCCs based on Western Australian experiences. Contractors bidding on D&C tenders generally focus on capital costs and pavement performance only during the defects correction period. There is, therefore, a gap between what Main Roads WA is seeking and the way D&C tenders are considered and awarded. The current D&C tender framework does not give any advantages to contractors proposing pavement solutions with an optimised WOLCC if the proposed solution does not represent a reduced capital cost. Consideration should be given to the development of a standard methodology to calculate WOLCC that can be used by contractors when proposing innovative solutions and incorporation of WOLCC in the tendering process.

6 PAVEMENT MATERIALS

6.1 Introduction

Workshop participants raised several alternative material types which could be suitable for use in heavy-duty pavements in Western Australia. This section of the report discusses the current use of these materials nationally as well as providing recommendations for further studies.

6.2 Construction and Demolition Waste including Crushed Recycled Concrete

Construction and demolition (C&D) waste materials can provide good-quality pavement layers and minimise environmental impact from the production of virgin aggregates. Additionally, when the recycling plants are located near the construction site, C&D materials can bring considerable economic benefits (Leek 2008). A summary of the engineering and environmental aspects of developing fill from construction and demolition waste is reported in Andrews et al. (2008).

The use of C&D materials not only reduces the carbon footprint associated with the extraction of virgin aggregates, but also contributes to the conservation of natural resources and reduces the amount of material going to landfill. Additionally, if the high modulus that can be achieved with the use of recycled materials is considered in the design, thinner pavements can be obtained, reducing the quantities of aggregates that need to be transported and damage to existing pavements.

In 2014, WA produced approximately 4.4 Mt of C&D waste materials, with more than 3 Mt sent to landfill and less than 0.5 Mt recycled. The main concerns hindering the more widespread use of C&D materials in WA are the potential presence of asbestos, which has been an issue in the past, and the risk of cracking associated with rehydration of old cementitious binders (Austroads 2014b).

The most common C&D material used in pavements is crushed recycled concrete (CRC), which is considered a good quality C&D material. Limited amounts of foreign materials such as ceramics, glass and organics are allowed in CRC specifications, resulting in a more homogeneous product when compared to general C&D materials.

Studies conducted in WA indicate that CRC used as basecourse and subbase pavement layers can achieve very high modulus of elasticity values. Back-calculated layer moduli from Welshpool Road (City of Canning) indicated modulus values in excess of 1 000 MPa when CRC was used as basecourse, and in excess of 500 MPa when used as subbase (Leek & Hubbard 2010).

6.2.1 Main Roads Western Australia

The current version of Main Roads WA *Specification 501: Pavements* (Main Roads WA 2012) only includes compaction requirements for CRC subbase. The document contains a subtitle on ‘Crushed recycled concrete subbase supplied by the contractor’ and indicates that this section is under review.

In the past, Main Roads WA allowed CRC to be used as basecourse for low-traffic volume roads. The 2006-09 version of Main Roads WA *Specification 501* included material property requirements for CRC, such as limits on foreign materials, particle size distribution (PSD) and other mechanical properties. However, these requirements were withdrawn from the specifications in 2011, mainly due to issues related to the presence of asbestos (Marchant 2013).

Trial sections on the Kwinana Freeway extension project in 2009 with different materials including crushed rock basecourse (CRB), bitumen-stabilised limestone (BSL), hydrated cement-treated crushed rock basecourse (HCTCRB) and CRC indicated that the CRC had the lowest measured maximum deflection and curvature. In the project, CRC was used as basecourse under thin asphalt and no reflective cracking was observed at the surface.

However, some local road sections in the City of Canning and City of Gosnells, where CRC was used as basecourse under thin asphalt, resulted in reflective cracking. This led Main Roads WA to limit the use of CRC to subbase layers under full depth asphalt pavements on Alliance contracts.

ERN9 (Main Roads WA 2013a) states that the modulus of CRC may increase for 12 months or longer after construction, and that the risk of premature failure in fatigue must be considered.

ERN9 also cites the use of in situ cement-stabilised crushed recycled concrete as subbase under full depth asphalt or HCTCRB, although this practice is not common in WA. In this case, the vertical modulus of the CRC subbase used in the mechanistic design procedure is limited to 500 MPa.

Leek & Siripun (2010) reported a material characterisation study that was conducted with CRC from the main suppliers in WA: All Earth, C&D Recycling and Capital Demolition. The following parameters were tested: PSD, Atterberg limits, linear shrinkage, Los Angeles (LA) abrasion value, maximum dry compressive strength (MDCS), CBR, maximum dry density (MDD) and optimum moisture content (OMC). The test results were compared to the limits in the 2009 version of Main Roads WA *Specification 501*. The results indicated the following (Leek & Siripun 2010):

- PSD: non-compliances were minor
- Liquid limit: generally exceeded the specification limit
- Linear shrinkage: generally low
- LA abrasion: most results around the maximum specified value
- MDCS: most results below the minimum specified value
- CBR: most results above the minimum specified value.

Despite deviations of WA materials in relation to the 2009 version of Main Roads WA *Specification 501*, especially regarding liquid limit and MDCS limits, the performance of CRC in WA has been exceptional.

Recently, CRC has been used as subbase in two major Main Roads WA projects: Great Eastern Highway between Graham Farmer Freeway and Tonkin Highway in 2012–13 and Gateway WA in 2013–16. Issues with asbestos were encountered in the Gateway project, where independent audit testing indicated that two out of eight samples tested contained asbestos.

6.2.2 Western Australian Local Governments

The Western Australian Local Government Association (WALGA), in conjunction with the Institute of Public Works Engineering Australasia (IPWEA) has published a specification document for the supply of recycled road base (IPWEA/WALGA 2016). The document divides recycled concrete materials in two classes. Different material constituents, PSD, LA abrasion and performance test requirements apply for these two classes of materials. The specification allows the use of recycled materials as basecourse, but stresses that when the recycled material layer is thin, fatigue may occur and lead to block cracking. According to this document, when recycled materials are laid in thick layers with good dry-back and a primer seal, minor transverse cracking may occur, but the asphalt fatigue life is considerably extended.

A survey conducted in 2013 among 42 Local Government Authorities (LGAs) throughout Australia indicated that 58% of the metropolitan LGAs and 20% of the non-metropolitan LGAs surveyed use C&D materials. However, where implemented, C&D materials only represent a small proportion of the utilised pavement materials. Most of the survey respondents identified cost, quality concerns and standardisation as the main barriers to the use of C&D materials, followed by insufficient volume, incompatible construction needs, access and availability of infrastructure for recycling (Municipal Waste Advisory Council 2013).

Major LGA investigations with C&D use include Gilmore Avenue (Town of Kwinana), constructed in 2003; Welshpool Road (City of Canning), constructed in 2007-08; and Warton Road (City of Gosnells), constructed in 2009. These trials concluded that C&D materials provide a high-strength basecourse, but there is a risk of rehydration and subsequent cracking. The investigations concluded that 28-day UCS may not adequately predict the risk of rehydration (Leek et al. 2011).

Any cracks that have developed in the basecourse, although visible, have not negatively affected the pavement serviceability (personal communication, Colin Leek, January 2017). The City of Canning had not repaired cracked sections and no pumping had been observed. However, the City of Gosnells sealed cracks in the Warton Road pavement.

6.2.3 Roads & Maritime Services, New South Wales

NSW recycled materials requirements are set out in RMS *Specification 3051: Granular base and sub-base materials for surfaced road pavements* (RMS 2014). Recycled materials can be used as an unbound or bound basecourse or subbase. Unbound or modified CRC must be sourced from recycled structural concrete (concrete containing reinforcement or from rigid pavements) for use in freeways, major highways and rural highways. For arterial, collector and lower trafficked rural or urban local roads, CRC may be sourced from structural, non-structural and concrete washouts.

Recycled materials used in NSW include slag, fly ash and recycled concrete. The use of recycled materials depends on the project location and viability of using these materials (material availability, costs, etc.). In Sydney, recycled concrete is commonly used as a subbase and basecourse in granular and asphalt pavements. In personal communication in February 2017, James Allen of RMS stated that:

- RMS has not experienced issues regarding the appearance of reflection cracking when using recycled concrete as basecourse.
- Environmental aspects are controlled by the NSW Environmental Authority.
- RMS does not get involved with specifying or testing of asbestos or other contaminants.

The Institute of Public Works Engineering Australia NSW Division has a *Specification for supply of recycled material for pavements, earthworks and drainage* (IPWEA NSW 2010), for use in light to medium traffic roads (design traffic no greater than $4x10^6$ ESAs). This specification allows recycled materials to be used as basecourse and subbase layers, although it states that when high percentages of crushed concrete are present the rehydration potential should be taken into consideration.

6.2.4 Queensland Department of Transport and Main Roads

Queensland recycled material requirements are set out in TMR MRTS35, *Recycled materials for pavements* (TMR 2016). The specification divides recycled materials in two categories: nominated recycled material blends (NRMBs) and bound recycled crushed concrete (BRCC).

NRMB is an unbound material which can be used as a basecourse immediately below a thin asphalt layer if the 20-year design traffic is less than 10^6 ESAs. If the 20-year design traffic is more than 10^6 ESAs, on national network roads, state strategic roads or regional roads, then NRMB can only be used below an asphalt layer at least 100 mm thick (dense-graded asphalt and/or stone mastic asphalt (SMA)). TMR does not allow the use of NRMB on unsealed roads, heavy-duty pavements or below sprayed seal surfacings trafficked for longer than three months.

BRCC is a mixture of CRC, water and granular additives stabilised using cementitious modification to form a stabilised material. It is produced at a mixing plant to close tolerances of grading, moisture content and stabilising agent content for improved strength, stiffness, density and/or durability. BRCC can be used in temporary pavements, service roads, and in through/main carriageway and ramp pavements with a 20-year design life greater than 10^6 ESAs below at least 175 mm of dense-graded asphalt and/or stone mastic asphalt.

Although the specification allows the use of recycled materials directly under relatively thin layers of asphalt, in practice, recycled materials have only been used for lower layers, such as improved subgrades or lower subbase layers. The thickness of the asphalt above the CRC is typically 300 to 400 mm. TMR has not encountered any issues with cracking originating from the CRC layer propagating through to the surface (personal communication, Peter Bryant, January 2017).

6.2.5 Department of Planning, Transport and Infrastructure, South Australia

The SA *Pavement design supplement to AGPT 2* (DPTI 2014) allows the use of recycled demolition waste as an alternative for quarry products. Recycled materials can be used as Class 1 (basecourse), Class 2 (subbase in heavily- and moderately-trafficked roads and basecourse for lightly-trafficked roads) and Class 3 material (lower subbase/select fill materials in lightly-trafficked roads). The supplement states that recycled products require project specific consideration and DPTI approval. Recycled materials can also be used in cement-stabilised (4.5% cement) subbases under an asphalt basecourse. Specification limits are provided in *Specification Part R15: pavement materials* (DPTI 2015a) and *Part R15A* (DPTI 2015b).

In SA, recycled concrete generally has the same opportunity to be used as quarry products. DPTI currently has three companies and four sites that are pre-qualified suppliers of recycled concrete: ResourceCo Lonsdale, ResourceCo Wingfield, Boral Linwood and Adelaide Resource Recovery Wingfield, covering north and south of the metro area and some of the south east (personal communication, Anna Bartel, January 2017). Additionally, SA has experienced blistering of thin asphalt surfacings from aluminium inclusions in the basecourse on car parks, but not on road surfaces.

The use of CRC is generally determined by contractor preferences, supply availability and cost, rather than any technical issues.

6.2.6 VicRoads

VicRoads included specification requirements for CRC in 1993, allowing its use as subbase material. Since then the use of CRC has considerably increased over the years.

Section 820 (VicRoads 2011) specifies requirements for the use of CRC as pavement subbase and light duty basecourse. In heavy-duty pavements, CRC is only allowed as subbase material. In light duty pavements, the specification allows the use of CRC directly below the bituminous surfacing.

VicRoads also allows the use of CRC treated with cement for subbase layers. The requirements for this material are included in *Section 821* (VicRoads 2015). The resulting material is considered to be bound, requiring minimum cementitious binder content and 7-day UCS values.

6.2.7 Discussion and Recommendations

C&D waste, particularly CRC, not only represents a high-performance pavement material but also brings sustainability benefits. There have been extensive efforts in WA to understand the engineering properties and benefits of the use of CRC.

Due to the high risk of C&D waste becoming bound and developing shrinkage cracking, as well as fatigue cracking that reflects to the surface, it is generally considered sensible to limit the use of C&D waste to subbase layers. It is noted, however, that experience from City of Canning shows that even when visible cracks develop within the basecourse, the pavement can remain serviceable.

In 2013, a Western Australian Pavement Asset Research Centre (WAPARC) study suggested a series of strategies to enhance the use of C&D waste in WA (Andrews 2013), including:

- the formation of a consultative group
- the reinstatement of recycled materials specifications in Main Roads WA documents
- the characterisation of WA recycled materials
- formal investigation into the following issues:
  - fatigue failure
  - plastic shrinkage cracking
  - the use of higher proportions of mixed wasted incorporating brick, rubble and glass, as well as asphalt (where it is not more efficiently reused as aggregate in new asphalt)
- development of new products (use of recycled materials within modified and bound materials)
- extending the life of natural limestone sources by blending it with recycled materials to improve its properties for use in heavier-trafficked pavements
- use of recycled aggregates as partial replacement in concrete and asphalt mixes
- development of tools and guidelines on environmental considerations in material selection
- enhancing knowledge of recycled materials technology by providing non-commercial environment information forums on available products, applications, limitations and performance.

In view of the current challenges, the following studies are suggested to allow for a greater utilisation of C&D materials in WA:

- Development of an assessment framework for approval of C&D waste suppliers. This framework would be based on an investigation of the materials and processes used in the production of C&D waste, with the objective of reducing the risk of having asbestos contaminated materials.
- Investigation on the performance of general WA C&D materials in pavements incorporating higher percentages of mixed waste such as ceramics, rubble and glass. This would allow utilisation of a greater quantity of waste materials and could potentially reduce the risk of rehydration and fatigue cracking.

- Review of current Main Roads WA requirements with respect to C&D waste, including CRC, taking into consideration the properties of CRC in WA and previous experiences. It is noted that a similar project was conducted by ARRB in 2010 with the objective of preparing a specification for use by local governments (Leek & Komsun 2010).

The City of Canning regularly uses C&D materials as subbase and basecourse materials under thin asphalt wearing courses. A review of their experiences could also be beneficial to understand if the use of recycled materials in a larger range of applications could be extended to Main Roads projects.

6.3 In Situ Foamed Bitumen Stabilisation (FBS)

In situ foamed bitumen stabilisation (FBS) is a process where foamed bitumen is mixed with aggregate in situ using a stabilisation machine. Foamed bitumen is created by injecting cold water into hot bitumen, resulting in a less viscous material that can be more easily mixed with aggregates. Some of the advantages of the use of FBS are the ease and speed of construction and its compatibility with a wide range of aggregate types (Kendall et al. 2001). FBS can also be undertaken off site, by mixing the materials in a batch plant and hauling it to site.

FBS is primarily used in rehabilitation works when (Griffin et al. 2015):

- the pavement has been repeatedly patched and repairs are no long cost-effective
- weak granular basecourse overlies a strong subgrade
- structural overlay is not possible
- conventional reseals are no longer correcting flushing problems

Benefits from the use of FBS include (Griffin et al. 2015):

- increased shear strength and reduced moisture susceptibility
- similar strength to cement-treated materials but more flexible
- low moisture content required during construction
- increased construction efficiency due to expedient process
- ability to immediately open to construction traffic
- all weather construction.

FBS layers have higher modulus of elasticity values than conventional granular material layers, which would allow for thinner pavement designs.

A national design procedure for foamed bitumen stabilised pavements is still being developed. However, an interim method is presented in Austroads *Guide to Pavement Technology Part 5: Pavement evaluation and treatment design* (Austroads 2011). This method is being reviewed by Austroads project TT1825 *Improving the design and performance of foamed bitumen stabilised pavements*. As part of this project, recent field performance data from under-designed FBS trial sections is being taken into consideration to allow more accurate performance predictions in the design method. The project is still not finalised, but the following progress reports are available:

- AP-T247-13: *Design and Performance of Foamed Bitumen Stabilised Pavements: Progress Report 1* (Austroads 2013)
- AP-T275-14: *Design and Performance of Foamed Bitumen Stabilised Pavements: Progress Report 2* (Austroads 2014c) and

- AP-T303-15: *Design and Performance of Foamed Bitumen Stabilised Pavements: Progress Report 3* (Austroads 2015).

Current mix design methods are presented in the Austroads report AP-T178-11: *Review of foamed bitumen stabilisation mix design methods* (Austroads 2011b). Austroads project TT1825 is preparing an updated guidance on FBS mix design, which will be included in a future update of the Austroads *Guide to Pavement Technology Part 4D: Stabilised materials* (Austroads 2006). The following test methods are currently under development:

- T301: *Determination of foaming properties of bitumen*
- T305: *Mixing of foamed bitumen-stabilised materials (includes method of establishing mixing moisture content)*
- T310: *Compaction of test cylinders of foamed bitumen-stabilised mixtures: part 1 dynamic compaction using Marshall drop hammer*
- T311: *Compaction of test cylinders of foamed bitumen-stabilised mixtures: part 2 gyratory compaction*
- T315: *Compaction of test slabs of foamed bitumen-stabilised mixtures*
- T330: *Resilient modulus of foamed bitumen-stabilised mixtures*
- T340: *Deformation resistance of foamed bitumen-stabilised mixtures by the wheel-tracking test*

It is expected that the final design procedure will provide greater confidence in the design of FBS pavements, allowing this technology to be used more frequently in both new construction and rehabilitation projects.

The use of FBS in Australia is well established in Queensland and WA. In WA, FBS has primarily been used in rehabilitation projects by local government or by Main Roads WA in the Wheatbelt region. The use of FBS treatments in NSW and Victoria is rapidly increasing.

6.3.1 Main Roads Western Australia

Main Roads WA does not currently have a specification for FBS basecourse. The main concern with the use of FBS in WA is a lack of confidence in predicting its fatigue performance.

Main Roads WA constructed a trial section using FBS on Kwinana Freeway, near Mundijong Road, in 2010. The original pavement, constructed using HCTCRB, had developed fatigue cracking that had reflected to the surface. The objective of the trial was to understand how different pavement stabilisation depths and bitumen contents influence pavement performance. The trial used three thicknesses of stabilisation (150, 240 and 290 mm), three foamed bitumen contents (3.0%, 3.5% and 4.0%) and 0.8% quicklime. A geotextile reinforced seal was used between the stabilised layer and the asphalt surfacing. One of the trial sections (3.5% bitumen and 150 mm thickness) is being studied in Austroads project TT1825. Details are included in the Austroads progress reports cited in Section 6.3. Based on the latest report, the trial section is performing well although maximum deflections and curvature values have increased in the last two years – this may be a result of fatigue damage of the stabilised layer.

Most WA regions use cement stabilisation as a rehabilitation treatment to correct rutting and shoving defects. Typically, 1.5% of type LH (low heat) cement is used, with maximum limits on UCS specified to reduce the risk of cracking. However, experience has shown that when the pavement thickness is too low, cracking develops in the cement-stabilised layers. For this reason, Main Roads WA started using FBS in rehabilitation works instead of cement stabilisation in the

Wheatbelt region. This has worked well in terms of stopping the development of cracking on rehabilitated pavements.

It is stated in ERN9 (Main Roads WA 2013) that no reduction in thickness requirements can be made for pavements incorporating granular material modified with bitumen.

6.3.2 Western Australian Local Government

FBS has been used as rehabilitation treatments at various sites in the City of Canning and the City of Gosnells (Jitsangiam et al. 2012).

The City of Canning has been using FBS in rehabilitation projects since 1999, including on some heavily-trafficked roads. Fatigue failure has not been observed, but there have been isolated shear failures (Cocks et al. 2015).

Three of the City of Canning FBS pavement sections on Kewdale Road, Welshpool, are being reviewed in Austroads project TT1825. These sections are performing well, with no indication that the FBS layer has any fatigue.

The asphalt fatigue performance relationship (Austroads 2012) has been used to estimate FBS material performance. The City of Canning have adopted a fatigue relationship based on testing data from flexural beams prepared and compacted in the field and tested in the laboratory as shown in Equation 1 (Jitsangiam et al. 2012):

$$N = \left(\frac{1558}{\mu\epsilon}\right)^6 \qquad (1)$$

Where

N	=	the number of load cycles during the effective fatigue life
$\mu\epsilon$	=	induced horizontal tensile strain at bottom of foamed bitumen layer

6.3.3 Roads & Maritime Services, New South Wales

In the 1970s the (then) Department of Main Roads NSW constructed three unsuccessful FBS trials, which discouraged further utilisation of the technology until the late 1990s. Since then, numerous projects utilising FBS in NSW have been successful (Wilton 2014).

In 2013, RMS constructed an under-designed FBS pavement trial on the Newell Highway, Bellata, which is being studied as part of Austroads project TT1825 (Austroads 2015). The treatment was used to rehabilitate a pavement presenting rutting and shoving defects. At the time the Austroads (2015) report was written, there was no fatigue cracking in this pavement. Back-calculation results indicated that the moduli of the pavement layers and subgrade under the FBS layer were high and the strains under the FBS layer were low, and therefore, fatigue cracking was not expected (Austroads 2015).

An RMS Technical Direction document contains the directions for the use of FBS: RMS *PTD 2015/001 – Foamed bitumen stabilisation* (RMS 2015a). This document states that FBS is suitable to be used in weak granular pavements to improve strength, in rehabilitation of previously cementitious stabilised pavements where the addition of further cementitious binder is not feasible, as an alternative to full depth asphalt in low to moderately trafficked roads, and to improve resistance to moisture. It also contains factors to consider prior to selecting a FBS treatment. These include:

- cost (FBS has a higher initial cost than cementitious stabilisation but lower than asphalt)
- required compaction vibration (heavy vibratory rollers are required for deep lifts of FBS)
- suitability of the granular materials to be stabilised
- the presence of existing bound layers (which need to be pulverised).

The RMS Technical Direction document (RMS 2015a) contains instructions for a preliminary thickness design, to be carried out to assess the feasibility of using FBS, and for the final pavement thickness design.

Using these directions, the preliminary thickness design is carried out in accordance with Austroads (2011c). The FBS layer is modelled as a bound layer using the Austroads asphalt fatigue relationship and the parameters shown in Table 6.1.

Table 6.1: Parameters for FBS layer preliminary thickness design

Parameter	FBS material
Sub-layering	No
Design modulus of FBS material (E_v)	2000 MPa
Lower interface (Lower I/F)	Rough
Ratio of vertical to horizontal modulus of FBS material (E_v/E_h)	1.0
Poisson's ratio of FBS material	0.4
Volume of bitumen binder (%)	7 (assuming 3.5% bitumen by mass)

Source: RMS (2015b).

The final pavement thickness design is similar to the preliminary thickness design, except that the design modulus is adjusted based on laboratory testing results of the actual material to be used limited to a maximum of 2500 MPa (and the volume of binder is adjusted to reflect the final material mix design).

FBS is mainly used in NSW for rehabilitation projects, although there have been cases of plant mix FBS for construction in flood-prone areas. Currently, maintenance works involving FBS are not as prevalent as the use of cementitious binders. Typically, granular pavements are initially rehabilitated using cementitious binders and FBS is used at a later stage to rehabilitate heavily-bound pavements (personal communication, James Allen, February 2017).

6.3.4 Queensland Department of Transport and Main Roads

FBS is widely used in rehabilitation works in Queensland. TMR started trialling FBS as a rehabilitation treatment in 1997, with the objective of obtaining a more flexible and fatigue-resistant stabilisation treatment compared to cement stabilisation. The use of FBS for rehabilitation works is becoming more common than the use of cement stabilisation (personal communication, Peter Bryant, January 2017).

FBS has typically been used in low to moderately-trafficked volume roads with weak and expansive subgrades. In the future, it is expected that FBS will be used in heavily-trafficked roads. Most of the sections where FBS was used were reported to be in good condition in 2015. Back=calculated in situ moduli of FBS layers varied from 700 MPa to 9 000 MPa (Ramanujam & Jones 2000; Kendall et al. 2001).

Although historically FBS has been mostly used on in situ stabilisation works, Queensland is starting to produce plant-mixed FBS materials for use in new construction (personal communication, Peter Bryant, January 2017).

TMR use of FBS is stipulated in specification TMR MRTS07C, *In situ stabilised pavements using foamed bitumen* (TMR 2014) and TMR MRTS09, *Plant-mixed pavement layers stabilised using foamed bitumen* (TMR 2015a) which includes materials and construction requirements.

TMR adopts the Shell asphalt fatigue relationship for FBS structural layers (the same approach used for the design and modelling of asphalt pavement layers) as presented in Equation 2. The fatigue relationship is limited to less than 8% binder content by volume and stiffness values less than 2 500 MPa. Griffin et al. (2015) state that this equation results in slightly thicker pavements compared to the City of Canning method (Section 6.3.2).

$$N = \frac{6918(1.08 + 0.856V_b)}{S_{mix}^{0.36} * \mu\epsilon} \qquad 2$$

where

N	=	number of load cycles during the effective fatigue life
V_b	=	volumetric bitumen content (normally between 6% and 8%)
S_{mix}	=	stiffness of foamed bitumen mix, measured using the ITMr (MATTA testing) on soaked specimens
$\mu\epsilon$	=	induced horizontal tensile strain at bottom of foamed bitumen layer

6.3.5 Department of Planning, Transport and Infrastructure, South Australia

FBS is rarely used on DPTI roads and it is not a favoured option, although DPTI have a specification document for FBS (*Specification Part R24: Construction of foamed bitumen stabilised pavement*, DPTI 2007a). This document contains requirements regarding materials and construction of FBS pavements. DPTI does not have any specific instruction regarding the design of pavements using FBS (personal communication, Anna Bartel, January 2017).

6.3.6 VicRoads

VicRoads' experience with FBS commenced in 1993, when three trial sections were constructed in major roads in Melbourne (Lancaster et al. 1994). After these initial trials, the use of FBS was not continued as it was not considered a treatment that provided a desirable cost-benefit ratio.

Recently, however, VicRoads has been actively involved in Austroads project TT1825 (Austroads 2015), by constructing experimental trial sections on the Calder Freeway, Woodend (constructed in 2013) and the Western Freeway, Ballan (constructed in 2015).

VicRoads expects that the Austroads study will enable the use of FBS as a cost-effective solution for future rehabilitation works when current crushed rock pavements start presenting defects.

Material and construction requirements for the use of FBS are addressed in VicRoads *Technical Note 8: Foam bitumen stabilised pavements* (VicRoads 1993) and *Section 308, In situ stabilisation of pavements with foamed bitumen binder* (VicRoads 2016a).

6.3.7 Discussion and recommendations

The use of FBS in Main Roads WA roads is currently limited to rehabilitation works, particularly in the Wheatbelt region. Based on the experience to date, FBS appears to be a good alternative to cement stabilisation rehabilitation works when the pavement thickness is less than (cementitious) design requirements, as bitumen-stabilised pavements are less prone to cracking than cement-stabilised pavements.

It is expected that the findings of Austroads project TT1825 will allow a better understanding of the material properties and failure modes, providing more confidence in the design of cost effective FBS pavements.

6.4 Bitumen-Stabilised Limestone (BSL)

BSL consists of crushed limestone stabilised with bitumen emulsion. It is usually used as basecourse on granular pavements with thin bituminous surfacings. The bitumen emulsion treatment increases the stiffness of the crushed rock limestone, reduces moisture sensitivity and provides a cohesive layer on top of the pavement, facilitating adherence with bituminous surfacings. BSL treatments can be used to reduce construction time, as they reduce the time associated with dry-back requirements.

Main Roads WA does not allow the use of non-stabilised crushed limestone as basecourse.

Some proposed advantages of a BSL treatment are that it can be trafficked during construction, construction time is reduced compared to other granular pavement alternatives, and it provides a more suitable surface for the subsequent seal to adhere to. Cocks and Hillman (2003) suggested that there was evidence that BSL, when used as basecourse, inhibits the rate of oxidation of bitumen in the overlying seal, although the mechanism is not fully understood.

6.4.1 Main Roads Western Australia

BSL has been used in WA for over 50 years. It was first used as an alternative to crushed rock basecourses which were failing under load. The first large-scale use of BSL basecourse was in 1965: an 8 km long section of a rural road in the southwest of WA (Harmony & Ladner 1976). By about 2000-01, BSL was the preferred material for use in intersections, prior to FDA becoming the preferred approach.

BSL basecourse requirements are included in Main Roads WA *Specification 501: Pavements* (Main Roads WA 2012). Although Main Roads WA allows the use of BSL, it is currently not often used in Main Roads WA projects.

In the past, Main Roads WA has used BSL for heavily-trafficked roads (sections of the Kwinana Freeway). The typical pavement configuration comprised 225 mm of crushed limestone subbase, underlying 75 mm of BSL under a thin bituminous surfacing. BSL has generally performed well, with only a few cases of failure. It is believed that the failures resulted from the use of an inappropriate type of emulsion (personal communication, Geoff Cocks, December 2016).

The main reasons for Main Roads WA stopping the use of BSL were the increase in the cost of bitumen and the implementation of FWD performance requirements in D&C projects. The maximum deflection and curvature performance criteria are considered to be difficult to meet with BSL, as it takes a longer time to cure and achieve the same level of stiffness as crushed rock basecourse.

6.4.2 Western Australian local government

BSL is generally allowed by LGAs in WA; it is commonly used by the City of Wanneroo and the City of Joondalup.

The *IPWEA Local Government Guidelines for Subdivisional Development* (IPWEA 2011) contains BSL specification requirements.

6.4.3 Other States

BSL is not used in other states as the supply of limestone is not as abundant as in WA.

6.4.4 Discussion and Recommendations

One of the main advantages of using BSL rather than CRB is that BSL basecourses can be readily opened to traffic. However, although the use of BSL is covered in Main Roads WA specifications, the current FWD performance requirements associated with D&C projects discourages its use. Further studies could be carried out to assess if lower FWD performance requirements could be used in D&C projects where BSL is used as a basecourse – considering that BSL takes longer to cure. This could allow the use of BSL in D&C projects, especially where construction expediency is imperative.

Additionally, further studies could be carried out to understand and quantify the benefit of BSL to the aging of subsequent bituminous layers.

6.5 Lime-Stabilised Subbase and Subgrade

Lime stabilisation is generally used with high-plasticity materials containing a high proportion of fines. The lime reacts with the clay fraction to reduce plasticity and the affinity of the material to swell with water addition, as well as increasing strength. As with the use of cement, lime can be used to produce unbound or bound layers. When used to produce an unbound layer, the lime is added to reduce moisture susceptibility and increase bearing capacity. When used as a bound layer, the lime is used to significantly increase the structural capacity of the pavement; however, the pavement becomes susceptible to developing shrinkage and fatigue cracking (Vorobieff 1997; Austroads 2006).

6.5.1 Main Roads Western Australia

Lime stabilisation of pavement layers and subgrades is not extensively used in WA though there is some use in some regions.

The depth of stabilisation in a basecourse layer is typically 150 to 200 mm. Experience in the Kimberly region has shown that lime can be used on heterogeneous natural gravels to improve the fraction of the material that presents high plasticity without influencing the fraction that presents low plasticity. When limiting the UCS, lime stabilisation generally represents a low risk of the material becoming bound and developing fatigue cracking. Lime stabilisation of pavement layers is addressed in Main Roads WA *Specification 501: Pavements* (Main Roads WA 2012).

The depth of lime stabilisation in the subgrade is typically 150 mm. Main Roads WA does not allow any reduction in pavement thickness when the subgrade layers are stabilised with lime, although it allows a reduction in the thickness of cover over reactive materials if the lime stabilisation reduces swell. Lime stabilisation of subgrades is covered by Main Roads WA *Specification 302: Earthworks* (Main Roads WA 2015a). Recent tests performed with soft clay soils along the Kwinana Freeway indicated that no CBR improvement is obtained with lime stabilisation unless very high contents of lime are used (personal conversation with Geoff Cocks, December 2016).

The lime content, both for pavement and subgrade stabilisation, is determined by undertaking the ‘Lime Demand’ tests as per VicRoads *Manual of Testing method RD 131.01: Lime saturation point* *of soil (pH Method)* (VicRoads 2013a). The UCS is limited to a maximum of 1.5 MPa, to reduce the risk of the lime stabilisation resulting in a bound layer, subjected to shrinkage and fatigue cracking.

6.5.2 Roads & Maritime Services, New South Wales

In NSW, lime stabilisation can be used in different layers, including in situ clayey subgrades, select material zone (SMZ) and pavement layers (granular subbase and basecourse). When used to stabilise in situ subgrades, RMS does not have clear guidelines regarding the allowance of any increase in design CBR to be accounted for in pavement design thickness procedures. Currently, the designer can decide whether to account for any gain in strength. In SMZ layers, lime stabilisation is used to improve the CBR when the proposed imported material cannot achieve the minimum required value of 30% (RMS 2013a). It is noted, however, that for pavement design purposes, when a SMZ layer is used, the design subgrade CBR is only allowed to be increased from less than 2% to 3% (RMS 2015b). Lime stabilisation of pavement layers is typically limited to rehabilitation and patching works (personal conversation with James Allen, February 2017).

6.5.3 Queensland Department of Transport and Main Roads

Lime stabilisation of soft subgrades is commonly used in Queensland, particularly in southern Queensland (from Toowoomba to Brisbane) and up the east coast. Its use is not prevalent in western Queensland due to lower traffic volumes. Lime stabilisation of subbases is not a common treatment in Queensland (personal conversation with Peter Bryant, January 2017).

TMR *Technical Note 74 Structural design procedure of pavements on lime stabilised subgrades – TN74* (TMR 2012) provides guidance on pavement design requirements when using lime-stabilised subgrades. This document was prepared based on a three-year investigation of lime-stabilised subgrades in projects in Queensland. It is stated that the desirable thickness of lime-stabilised subgrade is 300 mm, with a minimum of 250 mm. The target 28-days UCS is 1.5 MPa, with the range of accepted UCS values being between 1.0 and 2.0 MPa. The lime content is determined as the greatest of the lime demand test results (according to Test Method Q133 (TMR 2017)) and the lime required to achieve the target UCS, with the UCS limited to 1.0 to 2.0 MPa (28 days).

Stabilised subgrade layers are considered to behave as an unbound material with improved stiffness. The maximum allowed design modulus of the top sub-layer of subgrade stabilised with lime is 200 MPa, which is the design value when the material complies with the UCS and lime demand test requirements. No modulus testing is required to verify the 200 MPa value when the material complies with the UCS and lime demand test requirements.

In the mechanistic design model lime-stabilised layers are sub-layered, with decreasing modulus values assigned to each sub-layer. The sub-layering differs from the Austroads sub-layering methodology in that the modulus is not restricted by the strength of the underlying subgrade. TN74 (TMR 2012) also specifies the minimum thickness of unbound granular pavement on top of lime-stabilised subgrades based on the average daily traffic in the year of opening, varying from 150 mm for less than 100 ESAs/day to 250 mm for more than 1000 ESAs/day.

TMR *Specification MRTS07A, In situ stabilised subgrades using quicklime or hydrated lime* (TMR 2015b) describes the Queensland requirements for the lime stabilisation of subgrades.

6.5.4 Department of Planning, Transport and Infrastructure, South Australia

Lime stabilisation of pavement layers in SA is usually adopted for reasons of construction expediency rather than to improve material properties. High-plasticity clays are common in SA. Additionally, lime stabilisation of soft clay subgrades with 3% to 5% hydrated lime is often used in rural projects to expedite construction. Lime stabilisation is predominantly used for major roads rather than on remote areas or lane widening. However, approximately 10 years ago, lime stabilisation was extensively used in the construction of rural overtaking lanes (personal communication, Anna Bartel, 25 January 2017).

DPTI *Pavement design supplement* (DPTI 2014) includes a minimum lime stabilisation depth of 250 mm as one of the support treatment options for heavy-duty pavements when CBR values are between 3 and 10% and a minimum lime stabilisation depth of 250 mm underlying 150 mm of fill when the CBR is less than 3%. The design supplement only allows a higher subgrade strength to be used in the design if thorough field and laboratory testing has validated the long-term properties of the stabilised material. The increased strength subgrade can be considered as a selected subgrade material when appropriate site investigations and laboratory tests are conducted, including lime demand and UCS tests. The design CBR value is limited to a maximum of 15%.

DPTI *Specification Part R23: In situ stabilisation* (DPTI 2007b) is used for in situ stabilisation of layers using lime.

6.5.5 VicRoads

Lime stabilisation by VicRoads is mostly used on expansive clay subgrades. *Code of Practice RC 500.22* (VicRoads 2013b) states that lime stabilisation can be used to improve the strength of clay at or below the subgrade level and that *Code of Practice RC 500.23* (VicRoads 2016b) is to be used to assign CBR values. RC 500.23 refers to RC 301.04 (VicRoads 2016c), which assigns CBR values based on stabilised samples. The depth of stabilisation must not be less than 150 mm (VicRoads 2013b) and the stabilised layer CBR is limited to a maximum of 6%.

VicRoads *Standard Specification Section 290: Lime stabilisation of earthworks materials* (VicRoads 2013c) covers the use of lime stabilisation in subgrades. VicRoads Standard Specification *Section 307 – In situ stabilisation of pavements with cementitious binders* (VicRoads 2008) covers the use of lime stabilisation in pavement layers, including material and construction requirements.

6.5.6 Discussion and Recommendations

Lime stabilisation is more commonly used on clay subgrades with the aim of reducing plasticity, reducing swell and increasing the strength of soft subgrades.

The practice to account for the allowance of strength gain from the lime stabilisation of subgrades in pavement thickness design procedures considerably varies between SRAs. In Queensland, TMR allows a maximum design modulus of the upper sub-layer of the stabilised material of 200 MPa, which corresponds to a CBR value of more than 15%. The lime-stabilised layer is divided into five sub-layers with decreasing modulus, without being limited by the modulus of the subgrade underneath. In SA, DPTI only allows a higher CBR to be considered if thorough field and laboratory investigation validates the long-term properties of the stabilised material. The maximum allowed design CBR value for the stabilised layer is 15%. In NSW, RMS does not have a clear position regarding the use of a higher CBR value when the in situ subgrade is stabilised with lime. The contractor is left to decide if they want to consider any gain in strength. When lime stabilisation is used in SMZ layers constructed on top of very soft subgrades (CBR less than 2%), RMS allows the combined design subgrade CBR to be increased to 3%. In Victoria, VicRoads state that the design CBR can be derived from CBR testing of stabilised samples, but the maximum allowed design CBR is limited to 6%. Main Roads WA does not allow any consideration of the increase in strength from lime stabilisation in the thickness design procedure, although it allows reduction in the required cover over reactive materials.

Main Roads WA has one of the most conservative approaches among the SRAs investigated. Although not a large proportion of Main Roads WA network lies on soft clayey subgrades, it is believed that significant savings could be achieved should further studies demonstrate that some gain in strength can be considered in the pavement thickness design. Further studies could concentrate on a review of past experiences in WA with the use of lime-stabilised subgrades, including field testing, sampling and laboratory testing to verify the strength and composition of the stabilised layers.

6.6 Reclaimed Asphalt Pavement in Stabilised Pavements

RAP is a high-quality recycled material, as it incorporates old binder that is added to new asphalt mixes, thus reducing new binder content requirements. Therefore, to take full advantage of this material, it is generally preferred that, when viable (i.e. where there are asphalt plants in the proximity), RAP is used in asphalt rather than in stabilised pavements.

Most states allow significant quantities of RAP to be utilised in asphalt layers, depending on the mix type, use and the level of testing proposed. TMR allows up to 40%, VicRoads allows up to 30%, RMS allows up to 40% and DPTI allows up to 50% in structural asphalt layers (although most asphalt mixes in SA have only incorporated between 20% and 30% RAP to date, and only 10% is allowed in wearing course mixes). Main Roads WA currently only allows a maximum of 10%. WARRIP project number 2017-002, currently in progress, is aimed at implementing the use of higher quantities of RAP in asphalt in WA.

When it is not economically viable to transport RAP to an asphalt plant, consideration should be given to the use of RAP in stabilised pavements. The current Main Roads WA specification for granular and modified pavement materials (Specification 501, Main Roads WA 2012) does not include any clauses addressing the use of RAP.

6.7 Geosynthetics

Geosynthetics are used in pavements to stop reflection cracks, to improve the bearing capacity of soft layers and to separate materials. Geosynthetics can be geofabrics, geogrids or a combination of both (composite).

Geofabrics are commonly used in sprayed seals to stop the propagation of reflection cracking through the surfacing, and as filters, to separate layers, to stop the migration of fines. Geogrids and composites are more commonly used on soft subgrades to allow construction on top of low CBR soils and to increase bearing capacity. The increase in strength is attributed to the interlock of particles at the geogrid level, which increases confinement and minimises lateral displacement.

The two main suppliers of geosynthetics in Australia are Geofabrics and Global Synthetics. Both companies have in-house pavement design methodologies to account for the structural capacity of geosynthetics in the design procedure. However, these methodologies are not incorporated in the Austroads design procedures and have not been extensively used and proven by Australian road agencies.

6.7.1 Main Roads Western Australia

Main Roads WA uses geotextiles in seals (geotextile reinforced seal – GRS) in rehabilitation works to reduce the risk of reflective cracking where it is believed that the basecourse has become bound and may develop shrinkage and fatigue cracking. Historically, it has been extensively used in rehabilitation works over HCTCRB pavements. GRS is included in Specification *503, Bituminous surfacing* (Main Roads WA 2015b).

Geogrids, or a composite, have been used on occasions to deal with soft soil problems, although they were not part of the original designs (personal communication, Geoff Cocks, December 2016).

Main Roads WA specifies the use of geosynthetics in some projects as a filter to separate coarser material layers from finer material layers. However, this does not allow for a reduction in pavement thickness when using geosynthetics.

Requirements for the use of geotextiles in drainage layers are included in *Specification 501: Pavements* (Main Roads WA 2012).

Recently, a geotextile has been specified in a principal shared path along Safety Bay Road to stop longitudinal cracking associated with wet-dry variations.

6.7.2 Roads & Maritime Services, New South Wales

Geotextiles are typically used by RMS in seals for asphalt rehabilitation treatments where the pavement presents cracking (personal communication, James Allen, February 2017). Specification requirements for geotextile reinforced seals can be found in RMS QA Specification R106: *Sprayed bituminous surfacing (with cutback bitumen)* (RMS 2012a) and RMS QA Specification R107: *Sprayed bituminous surfacing (with polymer modified binder)* (RMS 2012b).

RMS does not allow any reduction in pavement thickness from the use of geosynthetics. Therefore, the use of geosynthetics to mechanically stabilise subgrades and pavement layers, are not very commonly used in NSW (personal communication, James Allen, February 2017).

RMS QA Specification R67 (RMS 2010) contains requirements for the supply and installation of geosynthetics to be used under road embankment fills constructed over soft ground. It specifies select material above the geosynthetic reinforcement to have a minimum CBR of 15% and the compacted thickness of select material above and below the geosynthetic to be between 300 and 350 mm.

6.7.3 Queensland Department of Transport and Main Roads

Geosynthetics are used by TMR mainly in seals to inhibit crack propagation, or to wrap granular fill materials used to cover soft subgrades. The use of geotextile reinforced seals in the rehabilitation of cracked pavements is fairly common. The use of geosynthetics over soft subgrades has only recently begun to increase in popularity.

TMR design supplement (TMR 2013) states that geosynthetics are to be considered non-structural, and therefore should not be included in the pavement thickness design. The Nation Asset Centre of Excellence (NACOE) project P49 *Quantifying the benefits of geosynthetics for the mechanical stabilisation of subgrade soils* is currently investigating if any reduction in pavement thickness can be made with the use of geosynthetics in the stabilisation of subgrade layers.

Geotextiles for use in seals are addressed in TMR Technical Specification MRTS57: *Geotextiles for paving applications* (TMR 2015c). Geosynthetics for use in subgrade improvement are covered in TMR *Technical Specification MRTS58: Subgrade reinforcement using pavement geosynthetics* (TMR 2015d).

6.7.4 Department of Planning, Transport and Infrastructure, South Australia

DPTI regularly uses geosynthetics on soft subgrades, if they are a cheaper alternative to boxing out and replacing materials – this generally occurs at locations that would otherwise require replacement depths greater than 150 mm.

Geotextile reinforced seals are typically used on unbound granular base and cement-treated subbases for pavement widenings on heavily-trafficked rural roads to inhibit reflection cracking.

The DPTI Supplement to AGPT Part 2 (DPTI 2014) also mentions the use of geotextile reinforced seals on full depth granular configurations to improve performance on rural roads and on seals with low binder application rates to mitigate aggregate embedment.

The Supplement also states that geotextiles and geosynthetics that reinforce pavement layers or have load-spreading properties are excluded from the mechanistic modelling procedures; therefore, reductions in pavement thickness are not allowed with the use of geosynthetics.

Technical guidelines on the use of GRS is provided in DPTI *Technical Note No. 22: Geotextile reinforced sprayed seals* (DPTI 2000).

DPTI Standard Specification *Part R85: Supply of geotextiles* (DPTI 2007c) includes requirements for the supply of geotextiles.

Typical failures and challenges observed by DPTI include failures resulting from construction issues such as insufficient overlapping requirements, edge distance (vehicle wander), road repair and dragging when one section is ’picked up‘ by water (personal communication, Anna Bartel, 25 January 2017).

6.7.5 VicRoads

In Victoria, geosynthetics are typically only used in seals as a mean of reducing the risk of reflective cracking (personal communication, Klaus Kiesel, December 2016).

Guidance on geotextile reinforced seals are provided in VicRoads *Technical Bulletin No 38 – Guide to geotextile reinforced sprayed seal surfacing* (VicRoads 2001), VicRoads *Technical Bulletin No 45 – Bituminous sprayed surfacing manual* (VicRoads 2004) and *Technical Note 14 – Geotextile reinforced seals* (VicRoads 2014).

6.7.6 Discussion and Recommendations

The main uses of geosynthetics in Australia are in sprayed seals to inhibit the propagation of cracks from underlaying layers or for the mechanical stabilisation of soft subgrades. The use of geosynthetics may rarely include the separation of coarser materials from finer materials, such as in drainage layers.

Although several studies overseas indicate that the use of geosynthetics can reduce pavement thickness requirements, currently-accepted design methods in Australia do not allow any structural gain from the use of geosynthetics. NACOE project P49 (*Quantifying the benefits of geosynthetics for the mechanical stabilisation of subgrade soils)* is currently investigating if any reduction in pavement thickness can be made with the use of geosynthetics in subgrade layers. The project is currently looking at setting up trial sections and/or undertaking laboratory loading tests to quantify the benefit of geosynthetics for pavement design purposes. Once available, the findings of this project and its applicability to WA conditions should be reviewed to determine if any savings from thickness reduction can be realised in Main Roads WA projects.

6.8 High-Performance Asphalt Materials in Addition to EME2

During the workshop conducted with designers, the use of high-performance asphalt materials in addition to EME2 was cited. No details were given in relation to what type of asphalt mixes were being referring to. It is understood that 'high-performance' asphalt materials relate to the use of PMBs that are not already specified by Main Roads WA.

6.8.1 Main Roads Western Australia

The use of PMBs in WA is limited to where Main Roads WA specifies it. The polymer used is typically A15E; it is used both in asphalt surfacing layers and intermediate layers, whereas A20E is typically used in open-graded asphalt (OGA).

ERN9 (Main Roads WA 2013a) does not allow designers to account for the effect of polymers in the rutting and fatigue resistance of asphalt. Therefore, the use of PMBs does not allow for a reduction in pavement thickness.

It is understood that Main Roads WA is considering the use of A35P mixes on thin asphalt pavements and FDA pavements in regions with warmer climates. Preliminary laboratory testing carried out by Main Roads WA indicates that the resilient modulus and wet tensile strength of the A35P asphalt mix is similar to asphalt produced with Class 600 binder. This suggests that A35P could be used for intermediate courses in FDA pavements. Preliminary wheel tracking test results indicate that the deformation resistance of the A35P mix is similar to that of the A15E mix. It also suggests that A35P also represents benefits when used in asphalt wearing courses (personal communication, Ross Keeley, December 2016).

Although A35P is not currently in common use, one heavily-trafficked intersection in Port Hedland (WMAPT of about 40 ºC) was constructed about three years ago using A35P binder in all asphalt layers of a FDA pavement. Additionally, A35P binder was used in the overlay of an airstrip in Barrow Island (WMAPT of about 40 ºC) about three years ago. In this project the asphalt was constructed with thicknesses varying from about 100 to 250 mm, as the overlay was also used to correct crossfall issues. The asphalt was prepared by in situ mixing of EVA, more specifically 5% (by mass of binder) of Polybilt 101 grade. Both the Port Hedland and Barrow Island sections are performing well to date. There was some breaking at the edge of the grooving on the runway at Barrow Island where the airplanes land, but no significant rutting defects have been observed (personal communications, Ross Keeley, December 2016 and Geoff Cocks, January 2017).

The aim of WARRIP project 2017-005 is to characterise the modulus and fatigue properties of 14 mm and 20 mm A35P mixes, including an investigation of the influence of rest periods on asphalt fatigue behaviour.

Additionally, WARRIP project 2016-011 is investigating the use of crumb rubber modified bitumen in WA. A recent NACOE project showed that the use of crumb rubber can benefit durability and crack resistance.

6.8.2 Roads & Maritime Services, New South Wales

RMS typically uses C450 binder, whilst A15E PMB is used for high-stress situations. A5EP (see Section 6.8.4) is also used in certain circumstances (personal communication, James Allen, 21 February 2017).

6.8.3 Queensland Department of Transport and Main Roads

TMR has been extensively using A15E binder (called 'A5S' in Queensland) for all major projects for at least the last decade. A15E is used in surfacing and intermediate layers, as well as in stone mastic asphalt (SMA).

Recently, TMR began investigating the use of crumb rubber modified binder in OGA and the use of high binder content asphalt in OGA.

6.8.4 Department of Planning, Transport and Infrastructure, South Australia

DPTI uses a high-performance PMB (A5EP) asphalt, which provides high modulus, high flexural fatigue and high rut resistance. A5EP is produced by pre-blending a minimum of 7.5% of polymer imported by Kraton Australia with standard bitumen on site. It was developed as a solution to continuous rutting problems from heavy vehicles at road intersections. DPTI has been using A5EP for the last five years in a variety of products, with satisfactory performance observed to date. A5EP is believed to provide a more fatigue resistant asphalt than EME2 at a lower cost (personal communication, Anna Bartel, January 2017).

DPTI *Specification R25* (DPTI 2016a) includes requirements for A5EP binders. DPTI *Specification R27* (DPTI 2016b) includes instructions on where A5EP is to be used, including very heavy-duty, coarse dense-graded asphalts and SMA.

6.8.5 VicRoads

VicRoads does not extensively use asphalt with PMBs or other high-performance asphalt materials, such as EME2. FDA pavements are generally constructed using Class 320 bitumen, as the lower pavement temperatures do not justify the use of stiffer binders.

VicRoads *Code of Practice RC 500.22 Selection and design of pavements and surfacings* (VicRoads 2013b) includes heavy-duty and high-performance asphalt with A10E PMB and 500/170 Multigrade binder. A10E binders are commonly used within SMA and OGA layers in the Melbourne metropolitan area. Multigrade binders, although included in VicRoads documents, are not commonly used, as it can only be sourced from Queensland (personal communication, Klaus Kiesel, December 2016 & January 2017).

6.8.6 Discussion and Recommendations

As discussed in Section 6.8.1, the current Main Roads WA ERN9 design guide (Main Roads WA 2013a) does not allow benefits from the use of high-performance asphalt mixes to be accounted for in thickness design procedures. Therefore, there are no incentives for contractors and designers to explore high-performance mixes other than what are specified by Main Roads WA.

The following studies are recommended for further work:

- investigation of high-performance asphalt mixes used by other states and internationally, and their applicability to WA conditions
- laboratory testing program to characterise a wider range of asphalt mixes using the improved Austroads methodology (construction of modulus master curves and 4-point beam fatigue testing)
- implementation of the Austroads improved design procedures for asphalt pavements, allowing the benefits of high-performance mixes to influence pavement thickness design.

6.9 Permeable Pavements

Permeable pavements allow water to infiltrate the pavement and migrate to the subgrade. There are a variety of permeable pavements on the market, including permeable concrete (e.g. Permacrete), permeable pavers and permeable pavement cells which are filled with granular materials.

Main Roads WA do not use permeable pavements. However, cases of permeable pavement use in WA include a carpark at the Perth Airport Domestic Terminal and a carpark at the new Burswood stadium, where permeable pavements were used to reduce drainage requirements.

TMR, VicRoads and RMS do not have experience with the use of permeable pavements (personal communication, Peter Bryant, January 2017, Klaus Kiesel, December 2016 & James Allen, February 2017).

In SA, permeable pavements are only used in lightly-trafficked car parks where tree roots require water.

Currently, permeable pavements are believed to be applicable only for very low traffic applications, such as carparks, shared paths or local roads. It is not envisaged that permeable pavements will be used for major projects such as heavy-duty roads. Additional studies in this area could include a literature search and field trials using permeable pavements in cycle paths, with the objective of reducing drainage requirements.

6.10 Saline Water for Construction

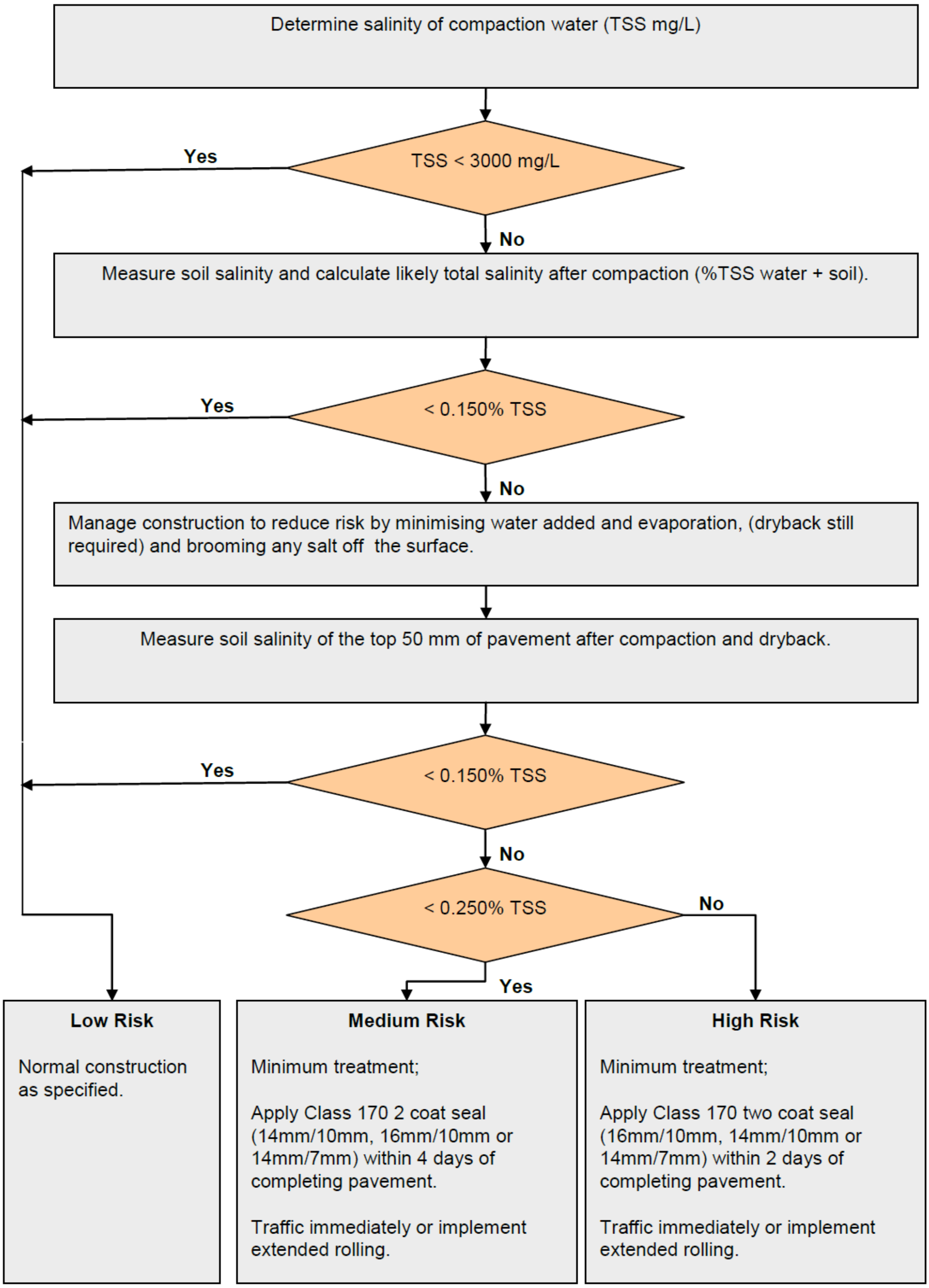
In remote areas of WA, the supply of potable water is not always readily available and the use of bore saline water is often considered as an alternative to avoid the cost of transporting potable water long distances. The use of saline water must be carefully considered, as once the water evaporates, salt crystals can form, the interface between the basecourse and the seal weakens and vapour pressure differences develop, resulting in blistering of the bituminous surfacing and fluffing of the upper part of the basecourse. These defects are explained in detail in Main Roads WA *Engineering Road Note 3* (ERN3) (Main Roads WA 2003).

6.10.1 Main Roads Western Australia

During the workshop conducted with contractors, it was stated that Main Roads WA (in the Wheatbelt region) did not consider published Main Roads WA guidelines in relation to the use of saline water.

Main Roads WA Document No. 6706/02/133 *Water to be used in pavement construction* (Main Roads WA 2013b) sets out a standard for water to be used in pavement construction. The document states that water used for pavement construction shall not contain more than 3000 mg/L of total soluble salts (TSS). If this limit is surpassed, then water may be used, subject to approval from the Superintendent. The document contains a salinity risk management flowchart, which is reproduced in Figure 6.1.

Figure 6.1: Salinity risk management flowchart



Source: Main Roads WA (2013b).

This flowchart was updated in 2013 to exclude the use of prime when the project falls within the 'Medium Risk' category following experience from a project in Bulyee which fell in the 'Medium

Risk' category; however, when the prime was used, extensive eruptions developed. Once the prime was omitted, the pavement performed well. This was attributed to the medium curing cutter in the prime reacting with the salt, thus negatively affecting adhesion.

It is understood that the comment raised during the workshop referred to Main Roads WA not considering the use of water containing more than 3,000 mg/L of TSS in the Wheatbelt region, even if the recommendations in this flowchart were followed. As per the Main Roads WA document, water containing more than 3000 mg/L of TSS can only be used following approval from the Superintendent.

Water with saline concentrations of up to 8,000 mg/L of TSS has been successfully used at the Eyre Highway. It is believed that the gravel used in the construction was more tolerant to salt concentrations, although the chemistry involved has not been investigated.

Recently, laboratory tests were conducted in the Main Roads WA Materials Laboratory using samples of laterite gravel compacted with water containing varying concentrations of sodium chloride. The objective of the testing was to assess the penetration of binder on samples with varying salt concentrations. The study indicated that the penetration remained within the suggested target range of 5–10 mm (Austroads & AAPA 2010) for samples prepared with salt concentrations of up to 12,000 mg/L. The study suggested that consideration could be given to the use of water with higher saline concentrations than what is currently allowed (3,000 mg/L); however, further testing and validation would still be required (Crew 2014).

6.10.2 Western Australian Local Government

The IPWEA Subdivisional Guidelines (IPWEA 2011) requires that water used in pavement construction contains less than 3,000 mg/L TSS and proposals to use saline water are supported by a geotechnical engineer experienced in pavement construction.

6.10.3 Roads & Maritime Services, New South Wales

RMS *Specification R71: Construction of unbound and modified pavement course* (RMS 2013b) requires that water used in pavement construction must be free from deleterious amounts of materials such as oils, salts, acids, alkalis and vegetable substances. Water taken from other than a town water supply system must contain no more than:

- 600 mg/L of chloride ion
- 400 mg/L of sulfate ion
- 1% by mass of undissolved solids.

RMS does not have extensive experience with problems related to saline water. Water used in construction is usually potable water or within the limits cited in the specifications (personal communication, James Allen, February 2017).

6.10.4 Queensland Department of Transport and Main Roads

There are no currently published documents within TMR that specify saline content limits for water used in pavement construction.

In the past (over five years ago), when there was a shortage of water in Queensland, TMR was forced to use both bore and recycled water. Some documents used at the time are believed to have specified saline content limits; however, these documents have never been published. Currently, TMR is not experiencing issues with the availability of potable water for pavement construction projects.

6.10.5 Department of Planning, Transport and Infrastructure, South Australia

DPTI *Specification Part R15 Pavement materials* (DPTI 2015a) states that potable water must be used in stabilised and wet-mixes materials (plant-mixes).

Water used for construction is generally potable water although saline water has been used on occasions. These include shoulders along the Nullarbor and Eyre Highway near Ceduna. The appearance of blisters is managed by applying a heavy spray seal and ensuring that the salt is not exposed to water. The techniques described in Pavement Work Tip No. 47 (Austroads & AAPA 2008) are used to assist in sealing (personal communication, Ian Alright, January 2017).

6.10.6 VicRoads

Victoria does not typically use bore water for road construction projects.

Technical Report TR 209 (Midgley 2010) states that care needs to be taken to ensure that the quality of water used in the construction of granular pavements is clean and substantially free from impurities such as oils, salts, acids, alkalis and vegetable substances.

Technical Specification *Section 307 – In situ stabilisation of pavements with cementitious binders* (VicRoads 2008) states that water used in the construction of stabilised layers shall also be clear and substantially free from sediments and detrimental impurities such as oils, salts, acids, alkalis and vegetable substances. The specification requires that water supplied from sources where dissolved salts are unknown or likely to be present are tested for electrical conductivity. The electrical conductivity shall not be more than 3,500 µS/cm and the amount of chloride and sulphate in any water used shall each be no greater than 300 ppm. Water sources classified by the relevant water authority as potable water are exempt from this requirement.

6.10.7 Discussion and Recommendations

Main Roads WA's current approach to the use of saline water for pavement constructions appear to be working well, although there are cases where water with a much higher saline concentration than that specified has resulted in successful outcomes. Additional studies in this field could include:

- Revisiting the current limit in saline concentrations accepted by Main Roads WA: this could include a similar testing program to the tests conducted by Crew (2014) at the Main Roads WA Materials Laboratory but with additional variables, such as other types of materials and dry-back levels, as well as a field validation component (Crew 2014).
- A study of the chemistry between different natural aggregates and salts aimed at understanding successful projects where construction water contained a very high salinity content.

6.11 Emerging Technology and Future Innovations

There were various ongoing developments and emerging technologies identified nationally. Table 6.2 presents a summary of the main emerging technologies identified; some of them are already being investigated as part of other WARRIP projects.

Table 6.2: Emerging technology and future innovations

Item	Description	Status	Main Roads WA
EME2 Asphalt	EME2 is a high-modulus, high-fatigue structural asphalt mix. This can achieve the same performance with reduced asphalt thickness.	Ongoing Austroads / NACOE / AAPA / WARRIP projects. AAPA has released a generic model specification. Queensland TMR have a draft mix and design rules. QLD & NSW have built some short trials.	WARRIP project 2016-001 is developing guidelines for the design of pavement structures containing high modulus asphalt layers with EME2. WA's first trial is scheduled for May 2017.
High Reclaimed Asphalt Pavement (RAP)	RAP recovered from existing road pavements is blended with virgin asphalt, for environmental benefits. Trend is to seek higher RAP percentages.	Ongoing NACOE / WARRIP projects. Main Roads WA currently allows 10% RAP in its specification. Other SRAs allow higher RAP contents. Depending on the asphalt mix, asphalt layer and expected traffic, TMR allows up to 40%, VicRoads allows up to 30% (which can be potentially increased subject to additional testing), RMS allows up to 25% and DPTI allows up to 50%.	The opportunity to increase the RAP content is being investigated as part of WARRIP project 2017-002, which aims at increasing the maximum RAP content allowed in asphalt mixes to about 20 to 25%.
Crumb rubber asphalt	Crumb rubber is blended with the bitumen, creating a binder with improved durability and fatigue characteristics. In addition to improved performance, recycling ground tyre rubber reduces landfill volumes and preserves natural resources.	Ongoing NACOE / WARRIP projects. Crumb rubber modified bitumen has been used in Australia for many years for sprayed seal applications, but it is still uncommon in asphalt mixes although some SRAs have specification requirements for the use of crumb rubber in asphalt.	The use of crumb rubber modified bitumen in sprayed seals has been routine practice in WA for over 30 years. WARRIP project 2016-11 is currently investigating the opportunity to increase the utilisation of crumb rubber modified binder in OGA mixes. Main Roads WA is planning to place trials during summer of 2017–18.
Stone mastic asphalt (SMA)	SMA was developed as a 'premium' wearing course mix, with high durability, fatigue and sufficient texture for use on high speed roads. SMA has improved durability compared to OGA.	The use of this mix is well established in Vic, SA & NSW. It is typically used as freeway wearing course unless drainage or noise concerns warrant OGA.	The use of SMA in WA is being investigated as part of WARRIP project 2016-002. Main Roads WA has recently specified SMA in two sections, however in one of them, due to poor quality of the placed SMA, the works continued with OGA.
Performance based specifications	Performance-based specifications can offer opportunity for innovation and reduced costs at same performance level.	See Section 4.4.2. Still in development in Australia (ongoing Austroads project APT1953).	Continue to monitor and participate in development.
Foamed bitumen stabilisation	Foamed bitumen stabilisation is a technique where foamed bitumen is created by injection of cold water into hot bitumen and then mixed with aggregate to produce a high modulus pavement material that is generally less susceptible to cracking than cement stabilised materials.	Austroads project TT1825 is currently investigating improved procedures for mix design and structural design of foamed bitumen stabilised materials. For more information, refer to Section 6.3.	Continue to monitor and participate in development.

Item	Description	Status	Main Roads WA
A5EP binder	A5EP is a plastomeric elastomer product used to produce high performance asphalt mixes in South Australia. For more information, refer to Section 6.8.4.	Currently only used in NSW and SA.	Investigation on this type of binder and its applicability to WA conditions is suggested.
Potential use of nanotechnology	Nanotechnology is a term broadly used to describe the manipulation of matter at an extremely fine scale (1–100 nm). It is believed that the use of nanotechnology can potentially allow improved strength, stiffness, cohesion, durability and workability in asphalt mixes.	Ongoing NACOE project is researching the strength and durability benefits of modifying bitumen using spinifex nanofibers.	WARRIP project 2018-005 is currently underway, which will include characterisation and evaluation of nanosilica-modified asphalt.

6.12 Recommendations

Based on a review of the different pavement materials cited in the workshop and other emerging technologies nationally, and considering the work that is already being carried out as part of other WARRIP projects and proposals, the following recommendations are suggested for Main Roads WA to consider:

- Investigate ways to increase the utilisation of C&D recycled materials, including the development of an assessment framework for approval of suppliers and further investigation on the risk of rehydration and fatigue cracking of these materials.
- Continue to monitor and participate on the Austroads project TT1825 *Improving the design and performance of foamed bitumen-stabilised pavements* and move to implement the test methods and design procedures that arise from the project.
- Investigate the long-term performance of BSL and its potential to replace FDA pavements if used as basecourse over high stiffness subbase materials such as recycled concrete.
- Monitor learnings from the NACOE project P49: *Quantifying the benefits of geosynthetics for the mechanical stabilisation of subgrade soils*.
- Investigate the A5EP binder used in NSW and SA and determine its suitability for WA conditions.
- Continue to monitor and participate in the development of performance-based specifications.

7 SUMMARY AND RECOMMENDATIONS

To explore ways to extend the range of pavement/materials options considered by Main Roads WA the types of pavements and materials used in major projects in Western Australia, two workshops were held with key members of the Western Australian pavements industry – one for contractors and another for pavement designers. At these workshops, views were sought on current Main Roads WA practices and a range of issues were raised.

Workshop attendees expressed a need for contract frameworks that allow and encourage innovation. It is recommended that Main Roads WA undertake an investigation into contract models with more risk sharing and flexibility for change. Suggested contract frameworks that could be investigated further include: Early Contractor Involvement (ECI) contracts, a three-party procurement model (design-construct-owner), a staged construction model, and an improved Alliance model.

It is recommended that further refinement in acceptance criteria and penalties/bonuses are considered, to encourage contractors to deliver better outcomes rather than just focusing on minimum requirements. Additionally, it is recommended that further investigation be carried out on the development of performance-based specifications, which would give contractors/designers more flexibility to achieve cost-effective pavement solutions.

The review of heavy-duty pavement types used on major projects across Australia identified deep strength asphalt pavements and composite pavements as the two types used in other states that could be further investigated in WA.

The workshops identified a lack of understanding from contractors and designers for the reasons why Main Roads WA mandates specific pavement types and very rarely allows innovative solutions that can result in reduced construction costs. Main Roads WA specifies pavement types that it considers have been proven to minimise WOLCCs based on Western Australian experiences. Contractors bidding on D&C tenders generally focus on capital costs and pavement performance only during the defects correction period. There is, therefore, a gap between what Main Roads WA is seeking and the way D&C tenders are considered and awarded. The current D&C tender framework does not give any advantages to contractors proposing pavement solutions with an optimised WOLCC if the proposed solution does not represent a reduced capital cost. Consideration should be given to the development of a standard methodology to calculate WOLCC that can be used by contractors when proposing innovative solutions and incorporation of WOLCC in the tendering process.

Based on a review of the different pavement materials cited in the workshop and other emerging technologies nationally, and considering the work that is already being carried out as part of other WARRIP projects and proposals, the following recommendations are suggested for Main Roads WA to consider:

- Investigate ways to increase the utilisation of C&D recycled materials, which may include the development of an assessment framework for approval of suppliers and further investigation on the risk of rehydration and fatigue cracking of these materials.
- Continue to monitor and participate in the Austroads project TT1825 *Improving the design and performance of foamed bitumen stabilised pavements* and move to implement the test methods and design procedures that arise from the project.
- Investigate the long-term performance of BSL and its potential to replace FDA pavements if used as basecourse over high stiffness subbase materials such as recycled concrete.

- Monitor learnings from the NACOE project P49: *Quantifying the benefits of geosynthetics for the mechanical stabilisation of subgrade soils*.
- Investigate the A5EP binder used in NSW and SA and determine its suitability for WA conditions.
- Continue to monitor and participate in the development of performance-based specifications.

Workshop participants and Main Roads WA staff recognised that the information exchange undertaken during the workshops was excellent and that there were benefits to be realised in more open-forum discussion. As a result of the workshops it became apparent that industry needs to better understand the technical and historical background of Main Roads WA decisions and its prescriptive pavement requirements, in order to be able to collaborate with Main Roads WA in developing new solutions.

It is recommended that Main Roads WA develop a rolling timetable of events to actively engage with industry outside specific contract processes. These events could comprise a combination of workshops, Main Roads WA TechXchange presentations and webinars.

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APPENDIX A WORKSHOP PARTICIPANTS

The participants at the Contractors Workshop held on 20 April 2016 from 9 to 11 am at the Don Aitken Centre, West Perth were:

Doug Morgan (Main Roads WA)

Les Marchant (Main Roads WA)

Ross Keeley (Main Roads WA)

Michael Moffatt (ARRB)

Larry Schneider (ARRB)

Jonathon Griffin (ARRB)

Hossein Asadi (ARRB)

Zia Rice (ARRB)

Tony Tufilli (Asphaltech)

Wilfredo Valenzuela (BGC)

Neil Chamberlain (Bituminous Products)

Ray Sputore (CCI)

David Azzam (Clough Projects Australia)

Dirk Taljaard (CPB Contractors)

Jackson Lingwood (CPB Contractors)

Justin Redelinghuys (CPB Contractos)

Peter Hopmueller (Georgiou Group)

William Wallace (Maca Civil)

Leigh Fisher (AustStab)

The participants at the Road Designers Workshop held on 20 April 2016 from 1 to 4 pm at the Don Aitken Centre, West Perth were:

Les Marchant (Main Roads WA)

Ross Keeley (Main Roads WA)

Michael Moffatt (ARRB)

Larry Schneider (ARRB)

Jonathon Griffin (ARRB)

Hossein Asadi (ARRB)

Zia Rice (ARRB)

Michael Bresnahan (AAPA)

Lilian Salupalu (Brierty Limited)

Colin Leek (City of Canning)

Srijib Chakrabarti (Coffey)

Geoff Cocks (Coffey & ARRB)

Fred Verheyde (Douglas Partners)

Craig Hugo (Mining and Civil Geotest)

Con Rimpas (Pavement Analysis)

Paul Bussell (Stabilised Pavements Group)

Thorsten Froebel (WA Stabilising)

Paul Foley (WML Consultants)

Phillip Taylor (Arup)

APPENDIX B WORKSHOP NOTES

The following discussion notes were summarised and displayed during the workshops. Subsequently minor amendments to the text were made to clarify some issues discussed. It is not believed that any substantive change in meaning or intent has resulted from the post-workshop editing.

Each of the opinions raised during the workshops, and summarised here, do not necessarily reflect the views of all workshop participants.

Discussion notes from the contractor's workshop comments are shown in plain text, whereas the notes from the designer's workshop are shown as *italicised text*.

B.1 Form of Contract

- Forms of contract suitable for innovation? – D&C, construct only, Alliance.
- Local capability and experience – readiness for adoption of different technologies – non-local experience and contracting mechanisms.
- Absence of performance history limits implementation of new and innovative approaches. Sharing of associated risk.
- Gateway project good demonstration project for advances in pavement construction and FDA practice.
- Reference alternative contracting mechanisms in other jurisdictions.
- Contracting terms that promote innovation are rare across Australia.
- Alliance and ECI project delivery approaches may offer greater opportunity for implementing innovative approaches.
- Lack of incentives to consider innovative approaches.
- Alliance and ECI project delivery promote contractor-side innovation. D&C project delivery with innovation driven by owner-side.
- Design and construct procurement model stifles innovation. Alternative approaches like Alliances more supportive.
- Benefit-Risk Sharing.
- 3-party procurement model, design-construct-owner, may allow for more innovative approach.
- Alliance framework in WA (Gateway) not reflective of international best practice. Example of procurement model stifling innovation.
- Risk transfer from owner-contractor and transfer from contractor-designer. Significant issues where examples of better models sought.
- Staged construction a proven model in WA in 1980s. Potentially difficult for the designer. Limitation to the approach is the lack of a robust method for assessing WOL cost. Consideration of implementation approach in the current contractual environment.

B.2 Contract Requirements

B.2.1 SWTC

- Defects correction period discourages innovation.
- SWTC specification of pavement type and minimum thickness as well as performance-based criteria – one or the other, not both.
- Either transfer design risk fully in SWTC or specify minimum requirements.
- Performance-based acceptance criteria: if you want innovation you cannot have some performance criteria.
- Confidence in adhering to SWTC.
- Who wears the risk?
- D&C risk profile is too tight.
- Main Roads in ERN9 and SWTC push the contractor to follow a defined method and still be held responsible for risk of defects.
- Different project delivery methods when “innovative” outcomes desired.
- Main Roads should accept design risk for innovations it wants to be trialled.
- Design options with associated acceptable liability periods.
- D&C encourages contractor to focus on defects period and not Risk to Main Roads beyond defects period.
- Utilisation of appropriate performance criteria leads to the desired outcome.
- SWTC has design life warranties in addition to performance criteria.
- Establishment of clear incentives and disincentives for as-constructed roughness levels, due to impact on long-term performance of built structure.
- Alternatives to reconstruction when non-conformance encountered. (pay factors)
- Conditional performance consideration above and below desired levels.
- NZ experience shows contractors capable of delivering reduced roughness when adequately incentivised.
- Number of D&C projects with nonconforming rutting in defects period (FDA). Methods of measurement and criteria in addition to mixture design issues.

B.2.2 SWTC and ERN9

- ERN9 restricts the use of plain jointed concrete. However, recent projects have utilised. Example of conflict between ERN9 and SWTC. Precedence of documents important.

B.3 Improved Engagement between Parties / Knowledge Transfer

- Performance-based acceptance criteria: Main Roads should make available maintenance records to assist contractors in their decision making.
- Sharing of experiences and learnings from trials and innovative technologies.
- Open access to performance data on existing pavement technologies and trials.
- Appropriate forum for transfer of Main Roads WA learnings, workshops, technical notes, others?

- Sharing of performance data for Main Roads WA pavements.
- Raw data to give people the opportunity to make their own interpretation.
- Interaction, sharing with the road construction and design industry not necessarily only in alliance and contracting environments.
- Utilisation of workshops to discuss changes in practice. Driven by harmonisation efforts in QLD, NSW, etc.
- Western Australia Pavements Group (WAPG) existing forum for exchange of ideas with road design industry. Findings from the group published in journals and position papers.
- Open forum/workshop for pavement design and construction.
- Potential inclusion of construction industry in WAPG.
- Collaboration with contractors and designers to achieve innovation more common than driving through contracting mechanisms.
- Joint meetings optimal for driving to the desired outcomes Design, Delivery, and purchasing.
- The construction approach has a significant impact on the final outcome. Lack of public engagement hindering construction approach.
- Enhanced effort to disseminate recent learnings from Main Roads WA with industry of practice. Workshops and tech exchange.

B.4 Knowledge/Experience

- Local capability and experience – readiness for Adoption of different technologies – non-local experience and contracting mechanisms.
- Performance-based acceptance criteria: lack of available empirical performance data for designers to be confident to ensure criteria can be met
- Risk associated with innovative pavements and correlation with defects correction period.
- Limited familiarity and experience with bitumen stabilised limestone today.
- Does limited technical capability limit innovation?
- Absence of performance history limits implementation of new and innovative approaches. Sharing of associated risk.
- Established technologies referred to as demonstration versus trial. Ambiguity of the term “trial”. Optimal term references the longer term viewpoint of future implementation.
- Whilst it is a trial no one will invest in technology.
- Main Roads WA to explain the desired outcomes of ‘trials and remove some ambiguity of the term.
- Lack of long-term commitment to trials.
- Local governments have numerous trials of innovative materials/techniques with available information. But no design method. Main Roads should test City of Canning pavements.

B.5 Whole of Life Cycle Analysis

- Open up the D&C to specify its own performance criteria that should be adopted for innovations:
    - Main Roads would need to assess the bids whole of life cycle costs

- Understanding of different objectives, early-life versus longer-term costs.
- Consideration of whole-of-life (WOL) cost by designers/constructors when considering pavement options.
- Comparing alternatives: WOL basis. Limitation: Standardised valuation of pavement assets.
- *Furt*her considerations when selecting pavement types like whole-of-life (WOL) and technical capacity to successfully deliver a wide range of pavements.
- WOL key consideration for the selection of pavement types.
- Robust system for valuation of pavement assets.
- Introduction of innovative approaches may rely on consideration of WOL.
- WOL cost not only economic considerations, but also user costs, salvage value, carbon content, emissions, potential rehabilitation options.
- Establishment of discount factor in NZ strongly influenced the uptake of innovative practices.
- Use WOL to determine pavement performance criteria.
- Staged construction a proven model in WA in 1980s. Potentially difficult for the designer. Limitation to the approach is the lack of a robust method for assessing WOL cost. Consideration of implementation approach in the current contractual environment.

B.6 Construction

B.6.1 Specifications

- Placement of asphalt in winter months to open up construction period (consider lower refusal densities).
- In situ air voids have insignificant impact on pavement life.
- Waterproofing approaches for FDA, placing and removing temporary seals expensive.
- Is asphalt stripping as significant an issue as generally thought. Sampling technique? There is a lot of cost for a perceived risk.

B.6.2 SWTC and Specifications

- Minimum requirements should be performance based instead of specifying minimum application rates (tack coats) or minimum binder contents (asphalt).
- Modified materials is <1.0 MPa at 7-days – However, HCTCRB or cementitiously modified pavements specified explicitly.

B.7 Materials

- Increased use of recycled materials, construction and demolition waste.
  - including recycling existing pavement
- Potable water restrictions for rural pavements (e.g. Wheatbelt)
  - Main Roads WA guidance note not considered
- Consideration of foam bitumen stabilised base and lime stabilised subbase.
- Lime stabilised subgrade to allow thinner pavement
- Increased utilisation of reclaimed asphalt pavement in stabilised pavements.

- Bitumen stabilised limestone approximately 30% cheaper than thick asphalt:
  - easy to lay
  - not as moisture sensitive c.f. ferricrete
  - needs skilled placement
  - bitumen stabilised limestone key technology on Gateway to address extended dry-back periods at LG intersections.
- Limited familiarity and experience with bitumen stabilised limestone today.
- Utilisation of recycled materials in pavement base and subbase layers.
- Recycled crushed concrete a premium material that should be reserved for structural pavement layers.
- Consideration of geosynthetic (geogrids and geotextiles) reinforced seals.
- Other high-performance asphalt materials in addition to EME2.
- Some areas of WA have expansive clays and geosynthetics have value in these applications.
- Permeable pavements (concrete) can be used on heavily trafficked roads. No immediate cost savings but potential benefits in drainage structures. Also permeable asphalt pavements.

B.8 Design

B.8.1 General

- Consideration of in situ stabilised subgrade with thin bituminous surfacing. Numerous successful models both WA and international.
- Deep strength asphalt approx. 100 mm may be a viable option.
- Staged approach to pavement construction established international model.
- Staged construction a proven model in WA in 1980s. Potentially difficult for the designer. Limitation to the approach is the lack of a robust method for assessing WOL cost. Consideration of implementation approach in the current contractual environment.
- Staged construction approach potentially very successful in rural WA where routine assessment of roughness conducted.
- Consideration of South African G1 heavy-duty unbound granular pavement with stabilised subbase. Enhanced technical capacity and supervision required.
- Unbound granular pavement options may not be optimal in environments with extremely heavy traffic. High AADT in the year of opening.
- Geosynthetic reinforced seals provide measure of insurance but not directly considered in structural design.
- Different design approaches for rehabilitation versus new pavement. Characterisation of in situ environment. e.g. widening.
- Rapidly changing geometry requirements prevent large number of metro pavements from reaching design life. 20–25 years may be more appropriate.
- Influence of design traffic on the pavement type selection and thickness.
- FDA pavements commonly selected for widenings due to abbreviated construction periods.

B.8.2 SWTC

- Availability of different pavement types in SWTC and limiting criteria:
  - need to open up a larger suite of considered options
- Limited options for widening structures when overlays are not accepted. However, may be some interpretation issues.
- Potential for reducing the design life on widening projects, where additional work is anticipated. Matching the expected life of the adjacent structure.
- Bitumen stabilised pavements (foam bitumen) with sprayed seal or thin asphalt to be added to base SWTC list.
- Allowance of full suite of allowable pavement type sections on every project.
- Remove options for consideration only when unfeasible versus pre-selection.
- Conflicting information between different technical sections of SWTC. Inconsistencies.

B.8.3 ERN9

Traffic

- *Review impact of traffic multipliers and design factors.*
- *Characterisation of design traffic. Analysis of the impact on design thickness (parametric study).*
- *Reference historical traffic patterns for optimisation of design traffic estimates.*
- *Changes in axle loads and tire pressures going in the future.*

Asphalt

- Conflicting information in ERN9 with respect to the application of binder-rich base asphalt layers.
- Review of OGA application. Why are we using? Safety and noise benefits may be worth considering.

Safety Factors/Margins

- *Significant factors of safety built into the design procedure are additional construction tolerances requirements required?*
- *Project specific reliability factors.*
- *10 mm addition for wearing courses. Eliminates unbound granular pavements from consideration.*

Modelling

- Requirements for 3/5 of the total unbound granular pavement structure to be composed of basecourse.
- Potential tensile capacity of self-cementing materials.
- Consider SMA in design.
- Options for inclusion of fatigue endurance limits to limit the design thickness of heavily trafficked pavements.

- No consideration of performance benefits of modified asphalts.
- Utilisation of binder-rich base asphalt layers.
- Allowance for the performance benefits of PMB asphalts. Can be accommodated with express permission from Main Roads WA.

Other

- Do we need to follow ERN9?
- ERN9 difficult to follow and execute reliable designs.
- ERN9 restricts the use of plain jointed concrete. However, recent projects have utilised. Example of conflict between ERN9 and SWTC. Precedence of documents important.
- Utilisation of typical cross sections for unbound granular pavements. Catalog pavements.
- Where subbase CBR is greater than 60% for unbound granular 125–150 mm of basecourse may be acceptable.
- Prescriptive design stifles innovation.
- Significant innovation in pavement practice is most likely via the composing materials.
- ERN9 limits the utilisation of subsurface drainage features forcing the designer to select more expensive pavement alternatives.

B.8.4 SWTC and ERN9

- Main Roads WA technical documents provide limiting values but not options for taking advantage of improved properties (SWTC and ERN9). Benefit of improved CBR not allowed.
- Conflicting requirements for PMB design thickness in SWTC and ERN9.

B.8.5 ERN9 and AGPT2

- Implementation of existing Austroads findings.
- FDA pavements likely very conservative. Potentially long-life structures. ERN9 and AGTPT Part 2 with significant in-built conservatism.
- AGPTP Part 2 and ERN9 design guides may contain inaccuracies. Significant in-built conservatism. Approximate factor of safety of 50 for asphalt fatigue.
- Alternative granular modulus values for FDA where small amounts of cement utilised 150–210 MPa.
- Deep strength asphalt used in other Australian jurisdictions but some differences in the approach (pre vs. post cracking).

B.9 Others

Innovation applied to pavement components in addition to complete pavement cross-section.

APPENDIX C MAJOR PROJECT PAVEMENT TYPE DETAILS

When comparing Queensland design options with practices in other states, it be noted that TMR selects pavements based on average daily ESAs in the design lane in the year of opening. This can be converted to 30 year and 40 year design traffic loading if a growth rate is assumed. For comparison with other states who specify guidelines in terms of cumulative design traffic loading in ESA over a design period, 1,000 ESA/lane is equivalent to a 40 year design traffic of 2.8 x 10^7 ESA with a 3% growth rate, and 3,000 ESA/lane is equivalent to an 8.3 x 10^7 ESA with a 3% growth rate

Table C 1: Major project pavement types for Australian road agencies – flexible pavements – full depth asphalt pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Typically > 250 mm asphalt placed on granular subbase	Commonly used heavy-duty pavement on major projects where the 40-year design traffic exceeds 3×10^7 ESAs.	Accepted heavy-duty pavement on major projects.	Commonly used heavy-duty pavement for urban and rural with ESA/lane > 1000.	Commonly used heavy-duty pavement on major projects.	Commonly used heavy-duty pavement on major projects where design traffic > 10^7 ESA.
Typical configuration & minimum support requirements	▪ 260 – 330 mm asphalt (for recent projects) ▪ Granular subbase typically crushed limestone 200 mm thickness but reduced to 150 mm in the most recent projects. Crushed recycled concrete has also been used as subbase in some alliance projects. Minimum thickness requirements are stated in the SWTC.	▪ > 250 mm asphalt ▪ 7 mm lower cutter seal ▪ 300 mm SMZ. SMZ is select material zone, defined by CBR of upper and lower 150 mm. Can be a quarry product, site won material, recycled material and slag or modified materials.	▪ DG14HS or DG14HP, OG10 or OG14 (or SMA) ▪ Water proofing seal ▪ DG20HM ▪ Prime, spray seal ▪ Minimum 150 mm Type 2.3 unbound granular improved with cement (7 day UCS 1.0–2.0 MPa).	▪ AC typically > 250 mm ▪ Granular subbase 150 mm min ▪ Select fill – as per earthworks specification, or 180 + 150 mm, as per expansive clay rules. – CBR6%. – Inhibit moisture penetration.	▪ > AC 200 mm ▪ Granular subbase 150 mm ▪ Support: Type A select fill 0-150 mm, *or* Lime stabilised subgrade 250-400mm. Thickness of support is a function of subgrade CBR value.
Additional details	Minimum PMB 100 mm (end up 140 mm with prescribed layer thicknesses). High bitumen bottom layer is not allowed due to water retention / stripping risk in overlying layers.	High bitumen bottom layer is not allowed due to water retention / stripping risk in overlying layers.	Emphasis on water proofing seal under wearing course. Prime on modified granular.	Design Supplement provides standard DGA mixes, with DGA, SMA, OGA and UTA wearing courses allowed. Wearing course typically 40 mm DGA, sometimes SMA.	OGA, SMA, DGA wearing course allowed. SMA default choice as high texture, durable mix with some noise benefits on high speed motorways. But OGA still used where higher aquaplaning risk or greater noise mitigation issues. Spray seal required under OGA and SMA, noting DPTI SMA is a relatively coarse mix.

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
				Intermediate layers 1 (& maybe 2) typically C600 binder for rut resistance (rather than stiffness benefit) as rutting issues in intermediate layers hard to fix. High bitumen bottom layer (SF) is allowed. Minimum subbase Class 4 crushed rock, 150 mm min.	High binder bottom layer has been used on last 5 or 6 major projects, for reduced thickness benefit.

Table C 2: Major project pavement types for Australian road agencies – flexible pavements – deep strength asphalt pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Typically, asphalt wearing course, intermediate course, base course placed on cement-treated subbase (CTSB).	Not typically used (only one project recorded using this type of pavement). Cemented materials excluded from use in flexible pavements, except as CTSB (2% Type LH cement, in situ stabilised) below deep asphalt, or below subgrade level as working platform.	Accepted heavy-duty pavement on major projects.	Selectively used. Was most commonly used type > 10 years ago, but reduced use due to cracking concerns. Allowed for urban and rural with ESA/lane > 1000.	Commonly used heavy-duty pavement on urban freeway projects.	Not used in last 10 years. Is allowed still in some project SWTCs, but not adopted.
Typical configuration & minimum support requirements	Minimum 175 mm asphalt or 230 mm of granular over top of cemented layers.	▪ ≥ 175 mm asphalt ▪ Low cutter seal ▪ ≤ 250 mm CTSB ▪ 7 mm low cutter seal ▪ 300 mm SMZ (as per full depth asphalt).	▪ DG14HS or DG14HP, OG10 or OG14 (or SMA) ▪ Spray seal ▪ DG14HS or DG14HP ▪ DG20H ▪ Prime + SAMI ▪ 150-200 mm CTSB ▪ Prime + 10 or 14 mm seal ▪ > 150 mm unbound granular improved with cement.	▪ ≥ 175 mm asphalt ▪ 100-180 mm CTSB placed in single layer) ▪ ≥ 150 mm Type A, CBR > 10% or Class 4 crushed rock below the CTSB if CTSB design modulus is > 500 MPa, or ≤ 500 MPa for major works.	▪ ≥ 175 mm asphalt ▪ SAMI (if < 200 mm AC) ▪ CTSB 4% GB, 150–200 mm plant mix.

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Additional details	N/A	N/A		Additional subgrade capping layer, typically 400 mm, used on expansive clays sites. CTSB assigned 500 MPa modulus (not sub-layered) in design, considered to be post-cracked. Trafficking limits & moisture requirements in construction specification have limited use of a fully bound layer.	

Table C 3: Major project pavement types for Australian road agencies – flexible pavements – sprayed seal surfaced granular pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Spray seal (and prime) over unbound granular basecourse & subbase.	Commonly used on rural heavy-duty pavements.	Accepted on rural pavements, limited to 5 x 10^7 ESA (20-year life).	Commonly used rural pavements.	Commonly used rural pavement. Can be used beyond 1 x 10^7 ESA. Thin asphalt overlay at intersections. Minimum material CBR for DESA for spray seal surfacing provided.	Commonly used rural pavement, typically up to 4 x 10^7 ESAs.
Typical Configuration & Minimum Support Requirements	▪ Basecourse minimum thickness must be top 3 sublayers, 250 mm max[(1)] Modified materials may need to be greater than 250 mm from fatigue considerations.	Minimum Requirements: ▪ Basecourse: 200 mm ▪ Subbase: As per Fig 8.4 (Austroads 2012) ▪ 300 mm SMZ	▪ Type SG – spray sealed granular, for < 3 000 ESA/lane. or SG(HD) – spray sealed heavy-duty granular, < 3 000 ESA/lane ▪ Basecourse	For greater than 7 x10^6 ESA, minimum requirements: ▪ Basecourse: 200 mm Class 1 ▪ Subbase: 145–220 mm Class 3 ▪ Lower subbase: 100 mm Class 4	Minimum Requirements: ▪ Double Spray seal, S20E ▪ Prime ▪ Basecourse: 250 to 300 mm Class 1 ▪ Subbase: 125 mm Class 2
Additional details	N/A	N/A		Fig 8.4 (Austroads 2012) variant in their supplement includes minimum layer class and thickness requirements versus design traffic & subgrade CBR.	South Australian aggregates are often softer than other states, requiring thicker basecourse layers for equivalent performance to better aggregates.

Table C 4: Major project pavement types for Australian road agencies – flexible pavements – thin asphalt on granular pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Typically, 40–60 mm asphalt on unbound granular basecourse & subbase.	Commonly used in heavily trafficked situations with 40-year design traffic of no more than 3×10^7 ESAs with ≤ 60 mm asphalt on granular.	Not permitted as a heavy-duty pavement type.	Used up to 1000 ESA/lane. Not used in heavy-duty situation.	Used occasionally, typically outer metro region duplication projects. Supplement says generally not considered suitable above 3 x 10^6 ESA due to high risk of premature asphalt fatigue. May be allowed on a project specific basis, following risk assessment (including social, political and WOLC). Expected there will be a reduced initial cost but higher ongoing maintenance requirements and costs and increased social and political risk from public perceptions of a new pavement not performing.	Not used as heavy-duty pavement, typically only considered up to 1 x 10^7 ESA, with minimum of 75 mm of asphalt required.
Typical configuration & minimum support requirements	▪ OGA 30 mm ▪ DGA 30 mm ▪ Spray seal ▪ Prime ▪ Basecourse – min thickness top 3 sublayers (AGPT-2), 250 mm max ▪ Subbase. For lower speeds use thinner 30 mm DGA10 or 40 mm DGA14 (roundabouts and intersections) surfacing.	N/A	AG(B) – Unbound granular pavement with thin AC (DG10 or DG14) surfacing	N/A	N/A

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Additional details	Designed mechanistically using Austroads (2012) but with reduced asphalt fatigue allowable loading requirements for special case of crushed limestone subbase, 40-year design traffic load < 3×10^7 ESAs, Perth sand subgrade, crushed rock base or bitumen stabilised limestone. Modified materials may need to be greater than 250 mm from fatigue considerations.	N/A	N/A	N/A	N/A

Table C 5: Major project pavement types for Australian road agencies – flexible pavements – Thick asphalt on lean mix concrete pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Typically, asphalt wearing course, intermediate course, base course on lean mix concrete (LMC) subbase.	None built in WA.	Commonly used heavy-duty pavement type.	Used as “Flexible Composite” For urban and rural with ESA/lane > 1000.	Never used by VicRoads. Closest would be concrete subbase as a construction expedient, to VicRoads LMC specification, which has a different focus to RMS specification. Would need to use RMS specification if was to be considered in future projects.	Never used by DPTI. No local industry experience in design and construction. No specification for LMC as a pavement Subbase, would need to use RMS specification if being considered for future projects.

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Typical configuration & minimum support requirements	N/A	▪ ≥ 175 mm asphalt ▪ Bitumen emulsion (curing) + low cutter seal (bonding) ▪ 150 – 230 mm LMC ▪ 300 mm SMZ.	▪ DG14HS or DG14HP, OG10 or OG14 (or SMA) ▪ Spray seal ▪ DG14HS or DG14HP ▪ DG20HMI ▪ Bitumen emulsion + SAMI ▪ 150–230 mm LMC ▪ Prime + 10 or 14 mm seal ▪ ≥150 mm unbound granular improved with cement Thickness of HG20HMI is determined using Austroads (2012) and to ensure at least 175 mm total DGA thickness.	N/A	N/A
Additional details	N/A	LMC placed by prequalified contractor, paving workers have grey card certification.	Used on two significant projects, one 5 years old, other 10 years old. Both performing well. Copy of NSW approach.	N/A	N/A

Table C 6: Major project pavement types for Australian road agencies – flexible pavements – hydrated cement treated crushed rock base (HTCRB) pavement

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Pavement contains a hydrated cement treated crushed rock base	HTCRB option only used where Main Roads WA does design (e.g. construct only contracts) until design method validated and released.	Not used	Not used	Not used	Not used
Typical configuration & minimum support requirements	▪ Basecourse: 230 mm HCTCRB ▪ Subbase: 200 mm,	N/A	N/A	N/A	N/A

Description	Western Australia	New South Wales	Queensland	Victoria	South Australia
Additional details	Unique to WA The current proposed design methodology when using HCTCRB is to check the design assuming HCTCRB is unbound (modulus of 1000 MPa) and bound (modulus of 2000 MPa).	N/A	N/A	N/A	N/A

Table C 7: Major project pavement types for Australian road agencies – rigid pavements

Pavement type	Western Australia	New South Wales	Queensland	Victoria	South Australia
Usage	Limited long-term historical use but utilised on selected new junctions at the north of the state (PCP) and in Perth metropolitan area (Gateway Project) between FDA pavement and bath structures in areas prone to inundation (CRCP). Allowed types are nominated within project specific SWTCs	Commonly used pavement type. NSW leads Australia with concrete technology, with other states utilising their design and construction standards and specifications. Contactors must be prequalified to build concrete pavements. Performance is good, provided built to specification and subgrade support is not compromised.	Recent use mainly in tunnels and busways. Broad estimate of 50 carriageway km in last 10 years. No major performance issues. Some 20-year-old projects have poor performance, needing major slab replacements, but deficient design by modern standards. Allowed on urban and rural roads with ESA/lane > 1000.	Pavement design supplement allows use on urban and rural with ESA/lane > 1000 Rarely used in practise.	No substantial concrete pavements built in SA, but ongoing Northern Connector project will have 14 km of PCP freeway, first major concrete pavement in the state. Allowed types are nominated in project specific SWTC. Concrete was allowed on some green fields projects but lost out to full depth asphalt.
Plain Concrete Pavement (PCP)	No typical configurations provided in pavement design supplement. Refers to Chapter 9 of Austroads (2012) and RMS for design, which would allow PCP, JRCP, CRCP.	▪ 220–280 mm concrete ▪ Curing & debonding treatment ▪ 150 mm LMC ▪ 7 mm sprayed seal ▪ 300 mm SMZ Transverse saw-cut joints are typically 4.2 m apart.	PCP allowed, but typical thicknesses not identified in supplement ▪ ≥ LMC subbase 150 mm ▪ Prime + single spray seal ▪ ≥ 150 mm CTSB.	No typical configurations provided in pavement design supplement. CRCP required if pavement is to be surfaced with asphalt, including PGA. Refers to Chapter 9 of Austroads (2012) and RMS for	Refers to Chapter 9 of Austroads (2012) and RMS for design, which would allow PCP, JRCP, CRCP.

Pavement type	Western Australia	New South Wales	Queensland	Victoria	South Australia
Jointed Reinforced Concrete Pavement (JRCP)		▪ 200–250 mm base ▪ Curing & debonding treatment ▪ 150 mm LMC ▪ 7 mm sprayed seal ▪ 300 mm SMZ. Base incorporates SL82 mesh and dowelled contraction joints, 8 m spacing.	JRCP allowed, typical thicknesses not identified ▪ ≥ 150 mm LMC subbase ▪ Prime + single spray seal ▪ ≥ 150 mm CTSB.	design, which allows PCP, JRCP, CRCP.	
Continuously Reinforced Concrete Pavement (CRCP)		▪ 200–250 mm base ▪ Curing & debonding treatment ▪ 150 mm LMC ▪ 7 mm sprayed seal ▪ 300 mm SMZ. Base incorporates 16 mm longitudinal steel reinforcement with a minimum proportion of steel of 0.65%.	CRCP allowed, typical thicknesses not identified ▪ ≥ 150 mm LMC subbase ▪ Prime + single spray seal ▪ ≥ 150 mm CTSB Typically used where an asphalt surfacing is required.		
Steel Fibre Reinforced Concrete Pavement (SFRC)		▪ 250 mm base ▪ Curing & debonding treatment ▪ 150 mm LMC ▪ 7 mm sprayed seal ▪ 300 mm SMZ.	SFCP allowed, typical thicknesses not identified ▪ ≥ 150 mm LMC subbase ▪ Prime + single spray seal ▪ ≥ 150 mm CTSB.		