FINAL REPORT

Project Title: P73 Review of Pavement Support Conditions under Heavy-duty Asphalt Pavements

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SUMMARY

National and international pavement design guidelines have varying requirements for what constitutes adequate supporting conditions underneath asphalt pavements. Supporting requirements specified by the Queensland Department of Transport and Main Roads (TMR) are currently inconsistent for full-depth, deep-strength and high-modulus (EME2) asphalt pavements. The objective of the *Review of Pavement Support Conditions under Heavy-duty Asphalt Pavements* project is to recommend changes to TMR guidance documents to adopt a consistent approach that provides adequate support to asphalt pavements.

This report summarises the literature review of current practices in Australia and internationally for specifying minimum supporting conditions underneath asphalt pavements. It is envisaged that the findings from the literature review will contribute towards changes to TMR practices and guidance documents.

Key findings from the literature review include:

- TMR is the only Australian state road agency that typically adopts a lightly-bound granular subbase below heavy-duty asphalt pavements.
- TMR has different supporting requirements for EME2 pavements compared to 'conventional' asphalt pavements.
- Current practice by TMR results in thinner pavement support structures compared to Roads and Maritime Services (RMS) for all subgrade strengths, and thinner support structure compared to DPTI for subgrade strengths with CBR ≤ 10%.
- Provision of a 150 mm thick granular subbase is sufficient support when subgrades of adequate long-term bearing capacity are utilised by the Department of Planning, Transport and Infrastructure (DPTI), Main Roads Western Australia (MRWA) and VicRoads. For DPTI, this may require additional fill or subgrade stabilisation, while for MRWA it is common to utilise sand subgrades.
- Support requirements below EME2 pavements in the UK typically result in marginally thicker pavement support.
- Current practice by TMR results in thinner pavement support structures than practice adopted in South Africa, the UK, Florida and New York. Furthermore, French subgrades with a design CBR ≤ 10% result in thicker pavement support than those specified by TMR.

Findings indicate that TMR requirements for support below heavy-duty pavements are generally less than other road agency requirements for highly trafficked roads.

Following consultation with TMR, it is recommended that TMR requirements for support conditions under EME2 be adopted for other heavy-duty asphalt pavements.

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1 INTRODUCTION

1.1 Background

Asphalt pavements should be designed while considering the appropriate minimum supporting conditions below the asphalt base layer. Adequate supporting conditions enable compaction during construction and provide a platform for optimal structural performance. This is particularly important in regions with soft and/or expansive subgrades that could have a detrimental impact on the performance of the structural asphalt layers.

Pavement support conditions have become increasingly important, as pavement thicknesses have reduced considerably in Queensland, with recent updates to pavement design procedures. These changes are leading to thinner bound layers, which are likely to be more susceptible to changes in support conditions, compared to the thicker bound layers determined using previous methods. Hence, it has become increasingly important to ensure adequate supporting conditions are provided.

Pavement design guidelines across Australia and internationally have varying requirements for what constitutes adequate supporting conditions. Asphalt pavement designs have been shown to deliver a longer service life and a reduced risk of premature failure when constructed with structurally sound supporting layers, particularly when adopting a long-life or perpetual pavement philosophy.

Furthermore, the Queensland Department of Transport and Main Roads (TMR) currently has inconsistent supporting requirements for full-depth, deep-strength and high-modulus (EME2) asphalt pavements. Consistent application of supporting condition requirements is required for efficiently-designed and structurally sound asphalt pavements in Queensland.

TMR will realise the greatest benefit from the investment in innovative asphalt pavement technologies when there is consistent and easily-applicable guidance available to road designers across the TMR regions and industry.

1.2 Purpose

The purpose of this project, *Review of Pavement Support Conditions under Heavy-duty Asphalt Pavements,* was to recommend changes to TMR guidance documents to adopt a consistent approach that provides adequate support to asphalt pavements. Improving the consistency of the supporting conditions will allow the equitable comparison of alternative designs and subsequently ensure efficiently-designed and structurally sound pavements.

1.3 Approach

The objective to develop consistent, easily-applicable guidance for road designers operating across TMR regions and industry was accomplished through:

- reviewing existing guidelines and documents in relation to recommended supporting conditions for asphalt pavements
  This was done to determine current practice, both nationally and internationally – Section 2.
- documenting any recommended changes to guidance documents – Section 3.

2 OVERVIEW OF ROAD AGENCY SPECIFICATIONS

This section provides a comprehensive review of the existing documents and guidelines used by national and international road agencies in relation to the recommended supporting conditions for asphalt pavements.

2.1 Australian Practice

The Austroads *Guide to Pavement Technology (AGPT) Part 2: Pavement Structural Design* (Austroads 2012; 2017) contains guidance on pavement supporting conditions. Currently, most of the Australian state road agencies (SRAs) have developed their own supplements to the Austroads guidelines. The relevant Austroads guidelines and each of the relevant Australian SRAs were reviewed to determine best practice, and these documents are listed in Table 2.1. It is important to note that Austroads has recently published an update to *AGPT Part 2* (2017), however, the SRA documents reviewed were based upon the *AGPT Part 2* (2012).

Table 2.1: Australian SRA documents reviewed

Jurisdiction	Documents reviewed
Austroads	*Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2012) *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2017)
Queensland	*Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology* (TMR 2017) Technical Note 142, *High Modulus Asphalt (EME2) Pavement Design* (TMR 2015)
New South Wales	*Austroads Guide to Pavement Technology Part 2: Pavement Structural Design (Supplement)* (RMS 2015)
South Australia	*Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design* (DPTI 2014)
Victoria	Code of Practice RC 500.22, *Selection and Design of Pavements and Surfacings* (VicRoads 2013)
Western Australia	Engineering Road Note 9: *Procedure for the Design of Road Pavements: Western Australia Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design* (MRWA 2013)

2.1.1 Austroads

AGPT Part 2 (2017) (Section 3.2.5) states that an in situ subgrade California bearing ratio (CBR) greater than 10% is required at the time of construction to achieve adequate compaction of the asphalt layers in a full-depth asphalt (FDA) pavement.

Austroads (2017) states that deep strength asphalt (DSA) pavements and FDA pavements are typically used for heavily trafficked roads in urban areas, where granular subbases and/or selected subgrade materials may be utilised below bound layers to provide additional support, known as improved layers. These layers are typically at least 150 mm thick and are used to protect the subgrade and enable adequate compaction of the bound layers.

When normal standard base materials are used, the maximum subbase modulus may be determined using the modulus and thickness of the overlying bound layer in accordance with Table 2.2. The maximum moduli assigned for subbase materials with a soaked CBR > 30% may be the lesser of the value from Table 2.2 and 210 MPa. For a soaked CBR < 30%, a value of 150 MPa may be used.

Table 2.2: Suggested vertical modulus of top sublayer of normal standard base material

Thickness of overlying bound material (mm)	Modulus of overlying bound material (MPa)				
	1000	2000	3000	4000	5000
40	350	350	350	350	350
75	350	350	340	320	310
100	350	310	290	270	250
125	320	270	240	220	200
150	280	230	190	160	150
175	250	190	150	150	150
200	220	150	150	150	150
225	180	150	150	150	150
≥ 250	150	150	150	150	150

Source: Austroads (2017).

2.1.2 Department of Transport and Main Roads (TMR)

Pavements typically used for heavy-duty applications (i.e. > 1000 equivalent standard axles (ESAs)/day in design lane in opening year) in Queensland include DSA pavements, FDA pavements and FDA pavements incorporating an EME2 base, as summarised in Table 2.3.

Table 2.3: Typical heavy-duty pavements used by TMR

Course	Description (typical)		
	DSA	FDA	FDA (with EME2)
Surfacing	DGA or OGA	DGA or OGA	DGA, OGA or SMA
Intermediate	DGA	DGA	DGA
Base	DGA	DGA	EME2
Subbase	150–200 mm category 1 or 2 cementitiously stabilised granular material	–	–
Improved layer	Min. 150 mm Type 2.3 cementitiously treated unbound granular material	Min. 150 mm Type 2.3 cementitiously treated unbound granular material	Min. 150 mm Type 2.3 cementitiously treated unbound granular material

Note: DGA = dense graded asphalt, OGA = open graded asphalt, SMA = stone mastic asphalt.

Sources: TMR (2015; 2017).

The TMR *Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology* (TMR 2017) states that pavements used for heavy-duty applications typically include a cementitiously stabilised improved layer, with a minimum thickness of 150 mm and an unconfined compressive strength (UCS) of 1.0 to 2.0 MPa at seven days. The cementitious stabilising agent is included to reduce the sensitivity of the subbase to moisture, therefore reducing construction delays and rework that may be caused by rainfall at critical stages of the construction. However, when the in situ strength of the subgrade is less than CBR 7%, TMR advises that a more substantial treatment may be needed. It is important to note that in practice a more substantial treatment is rarely adopted.

Pavements containing an EME2 asphalt base typically require an additional supporting layer below the improved layer if the subgrade design CBR is found to be less than 7%. The additional supporting layer may be comprised of unbound granular material with a variable thickness based on the subgrade bearing capacity, ensuring the modulus at the top of the improved layers' modulus is at least 150 MPa (using Equations 19 and 21 of Austroads 2012) (TMR 2015).

The presence of soft subgrades is a problem that is commonly encountered in Queensland. Soft subgrades are typically defined as those with an in situ subgrade CBR less than 3% at the time of construction, and/or those with a design CBR less than 3%. Typical soft subgrade treatments include covering the soft material with a geotextile-wrapped coarse granular material or rock-fill of varying thickness, according to the subgrade CBR, as presented in Table 2.4.

Table 2.4: Typical minimum cover to provide a stable construction platform and provide design CBR of 3%

In situ subgrade CBR at time of construction or design CBR (%)	Minimum thickness (mm) of coarse granular or rock-fill required to provide a stable construction platform or for the adoption of a presumptive design CBR of 3%
1.0–1.4	400
1.5–1.9	300
2.0–2.4	200
2.5–2.9	150
3.0 +	0

Source: TMR (2017).

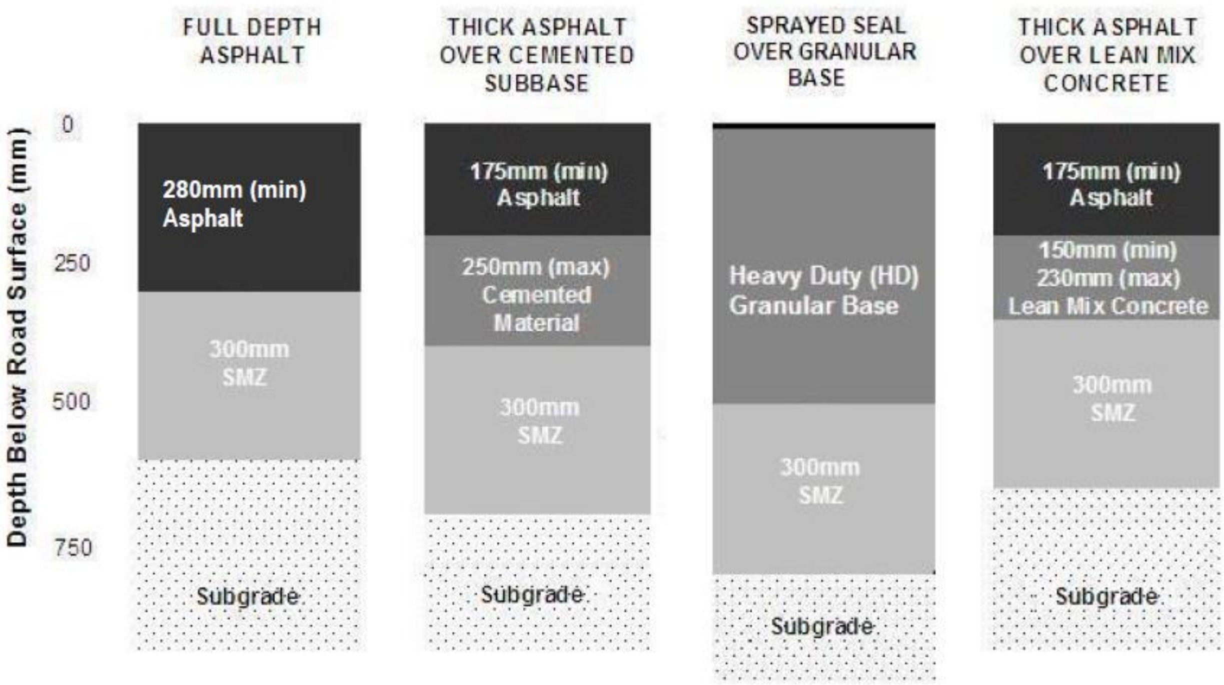
Flexible pavements designed mechanistically must adopt a minimum presumptive CBR of 3%. Where the subgrade CBR is less than 3%, the pavement design must adopt a presumptive value for a semi-infinite layer that accounts for the combined strength of the soft subgrade and the treatment. The presumptive CBR value for the semi-infinite layer is typically 3%, when the following treatments are adopted (TMR 2017):

- the minimum thickness of cover is determined using Table 2.4
- a minimum of 200 mm thick layer of Category 1 or 2 cemented material over the subgrade material with a design CBR of 2-3%
- a minimum thickness of 150 mm of mass concrete (either lean concrete or no fines concrete with geotextile) or sand/cement (12:1) mix over subgrade material with design CBR of 2-3%.

2.1.3 Roads and Maritime Services (RMS)

The New South Wales Roads and Maritime Services (RMS) considers heavy-duty pavements to have a design traffic loading of at least 10^7 ESAs per lane in the first 20 years of service (RMS 2015). There are four typical flexible heavy-duty pavement configurations used by RMS. These are FDA, thick asphalt over cemented subbase, sprayed seal over heavy duty granular base and thick asphalt over lean mix concrete, as presented in Figure 2.1.

Figure 2.1: Examples of heavy-duty flexible pavement configurations used in NSW



Source: RMS (2015).

The earthworks located directly beneath flexible and rigid pavements is defined by RMS as the select material zone (SMZ), which forms the topmost part of the upper zone of formation. RMS requires that all heavy-duty pavements include a 300 mm thick SMZ, as illustrated in Figure 2.1. FDA pavements require a 7 mm low cutter seal on top of the SMZ, while thick asphalt over cemented subbase and thick asphalt over lean-mix concrete subbase require a 7 mm sprayed seal over the SMZ. However, a 7 mm spray seal over the SMZ is optional for the sprayed seal over granular base configuration.

The minimum requirements of the material used in the SMZ are given in RMS *QA Specification 3071: Selected Material for Formation Layers* (2017) as follows:

- The fraction passing the 19.0 mm AS sieve must have a characteristic (4-day soaked, and compacted to 100% maximum dry density with standard compactive effort) CBR value of:
  - 33% for the upper 150 mm of the SMZ
  - 19% for the lower 150 mm of the SMZ.
- A maximum plasticity index (PI) value of 15%
  - if PI is < 3 then the minimum maximum dry compressive strength is 2 MPa.
- Must be free from stones larger than 100 mm maximum particle dimension.
- Must have no less than 50% passing the 19.0 mm AS sieve.
- The unconfined compressive strength (UCS) must not exceed 1.5 MPa.

On the condition that the selected material conforms to the SMZ lower layer requirements, the selected material may be modified using hydrated lime or other approved binders to comply with the upper layer requirements. It is important to note that the SMZ may be comprised of granular material, modified granular material, slag and other recycled materials.

The minimum allowable subgrade CBR at the time of construction that may be adopted in RMS controlled pavements is 2%. Any natural subgrade with a CBR less than 2% requires the construction of a stable working platform, bridging layer or other adequate treatment to ensure sufficient support is provided to the layers above for compaction. This working platform is in addition to the SMZ. Working platforms must be constructed using bound material with a minimum thickness of 200 mm with a presumptive semi-infinite subgrade CBR of 3%. However, it is important to note that although the inclusion of a working platform may improve the short-term constructability over weak subgrade (i.e. in situ CBR < 2%), long-term durability of the working platform and settlement due to subgrade consolidation should be considered.

2.1.4 Department of Planning, Transport and Infrastructure (DPTI)

Pavements with a design traffic load exceeding 10^7 ESAs during their service life are considered heavy-duty, in accordance with the DPTI, *Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design* (2014). Typical flexible heavy-duty pavements include thick asphalt (> 175 mm) on 150–200 mm cemented subbase and FDA. Table 2.5 shows the minimum support requirements for heavy-duty pavements by DPTI, where the requisite support conditions decrease as the subgrade CBR value increases. It should be noted that PM2 is an unbound granular material used for subbase, while Type A or B fill is typically quarry or natural sand.

Table 2.5: DPTI minimum support requirements for heavy-duty pavements

Subgrade design CBR (%)	Support treatment options and material quality requirements (1) (CBR)	Minimum thickness (mm) (4)
> 10	PM2 or characteristic strength (2) ≥ 30	150
3–10	In situ lime stabilisation (3)	250
	150 mm PM2 or characteristic strength (2) ≥ 30 over 150 mm Type A or B and characteristic strength (2) ≥ 15	300
< 3	150 mm PM2 or characteristic strength (2) ≥ 30 over 250 mm in situ lime stabilisation (3)	400
	150 mm PM2 or characteristic strength (2) ≥ 30 over 350 mm Type A or B and characteristic strength (2) ≥ 15	500

1 Shall comply with Part 210 and Part 215 DPTI Master specification for roadworks.
2 Characteristic strength is defined in Section 5.9 of DPTI (2014) (i.e. equal to 10th percentile of 4-day soaked CBR).
3 Laboratory investigation of binder content to ensure long-term characteristic strength ≥ 30.
4 Geofabric or geogrids and subsoil drainage may also be needed for weak or wet subgrades. Reactive soils require a minimum pavement support thickness of 600 mm and/or other appropriate moisture control measures.

Source: DPTI (2014).

Where soft subgrades are present, it may be necessary to provide select fill materials over the in situ subgrade. This will provide a working platform to facilitate the compaction of pavement layers (DPTI 2014). The select fill materials must meet the following requirements in accordance with DPTI (2014, Section 5.9):

- characteristic strength of fill material is the tenth percentile value (mean – 1.3 * standard deviation) of the lab 4-day soaked CBR results (design CBR shall not be greater than two-thirds of the characteristic strength)
- the top 150 mm of fill shall have characteristic strength of CBR 15% and a maximum vertical design modulus of 100 MPa
- fill materials with a weight plasticity index (WPI) greater than 1200 shall not be used directly below pavements
- swell values determined with 4.5 kg surcharge and 98% standard compaction should be less than 1% where possible.

2.1.5 VicRoads

VicRoads typically uses two types of pavements for design traffic loadings greater than 3.0×10^6 ESA; namely FDA (comprising an asphalt wearing, intermediate and base course placed on a layer of unbound subbase material) and DSA (comprising an asphalt wearing, intermediate and base course placed on a layer of cementitiously-treated subbase material) (VicRoads 2013).

FDA pavements require a minimum 150 mm thick Class 4 crushed rock subbase placed immediately below the asphalt base, whereas DSA pavements must include a cementitiously-treated subbase (CTS) above a minimum 150 mm thick unbound granular layer. Subbase supporting requirements for FDA and DSA are summarised in Table 2.6.

Table 2.6: VicRoads minimum support requirements for FDA and DSA pavements

Pavement type	Subbase support requirements	Minimum thickness (mm)
Full depth asphalt	Class 4 crushed rock(1)	150
Deep strength asphalt	Cementitiously-treated subbase with a design modulus > 500 MPa; or Cementitiously-treated subbase with a design modulus ≤ 500 MPa for major works(2)	–
	Type A material with an assigned CBR ≥ 10%; or Class 4 crushed rock(1)	150

1 Crushed concrete meeting VicRoads specifications can be used in lieu of Class 4 crushed rock.
2 New carriageways or for the addition of lane(s) over a significant length located on roads with a DESA ≥ 7.0×10^6 ESA.
Source: VicRoads (2013).

The maximum allowable CBR that can be adopted for pavements with a design traffic greater than 1.0×10^6 ESA is 10%. Subgrades that have been identified as weak and/or prone to swelling may require lime stabilisation at a minimum depth of 150 mm.

2.1.6 Main Roads Western Australia (MRWA)

MRWA typically utilises full depth asphalt pavements consisting of an asphalt wearing, intermediate and base course over granular subbase and subgrade for roads subject to heavy traffic (i.e. 40-year design traffic > 3.0×10^6 ESA) in accordance with Engineering Road Note 9 (ERN9) (MRWA 2013).

ENR9 does not specify minimum requirements for a subbase below the FDA. The subgrade CBR is typically assumed as 12% for Perth sands. The design CBR adopted for pavement design purposes must not be greater than 15%, even if imported materials have a higher soaked CBR. However, when natural materials in cuttings or embankments have a low CBR, imported materials may be required below the pavement. Layers constructed using imported materials must be at least 150 mm thick, and the combined thickness of the pavement and imported layer must provide adequate cover to the material with low CBR (MRWA 2013).

Although ERN9 does not state that there is a minimum subbase thickness, the project Scope of Works and Technical Criteria (SWTC) provided to designers typically requires a minimum subbase thickness of 150 mm below FDAs.

It is important to note that MRWA does not allow any reduction in thickness to be made for pavements incorporating granular material modified with cement, lime, bitumen or similar materials.

2.1.7 Comparison of Australian Practice

A summary of the minimum support requirements below heavy-duty asphalt pavements used by each of the Australian SRAs reviewed is presented in Table 2.7.

Table 2.7: Comparison of state road agency minimum support requirements for heavy-duty asphalt pavements

SRA	Minimum pavement support requirements	Comments
TMR	Improved layer: FDA and DSA: Minimum 150 mm cement modified granular layer (1.0 to 2.0 MPa at 7 days) FDA (EME2): FDA requirements with layer of varying thickness below improved layer based on bearing capacity of subgrade, top of the improved layer must achieve minimum 150 MPa modulus Subgrade: CBR ≥ 3%: FDA and DSA requirements CBR 2.5 to 2.9%: 150 mm geotextile wrapped granular fill CBR 2.0 to 2.4%: 200 mm geotextile wrapped granular fill CBR 1.5 to 1.9%: 300 mm geotextile wrapped granular fill CBR 1.0 to 1.4%: 400 mm geotextile wrapped granular fill	Specified in TMR (2017) supplement Specified in TMR (2015) technical note Specified in TMR (2017) supplement
RMS	300 mm select zone material: Top 150 mm CBR 33% Bottom 150 mm CBR 19% Material can be unbound or modified quarry product, recycled or slag. CBR < 2%: Working platform CBR ≥ 2%: No working platform/capping layer required unless material is expansive	SMZ specified in RMS (2014) supplement, Earthworks specification provides detailed requirements
DPTI	CBR > 10%: 150 mm granular subbase CBR 3 to 10%: 150 mm granular subbase on 150 mm Type A Fill, or 250 mm lime-stabilised subgrade CBR < 3%: 150 mm granular subbase on 250 mm lime stabilised subgrade, or 150 mm granular subbase on 350 mm Type A or B Fill	Specified in DPTI (2014) supplement Earthworks design supplement has additional requirements, which may exceed these minimums in Austroads (2012)
VicRoads	150 mm Class 4 (min. CBR 15 %) crushed rock subbase	Specified in VicRoads (2013) supplement
MRWA	150 mm granular subbase	Specified in SWTC. Not specified in MRWA (2013) supplement ERN9

The minimum support requirements below heavy-duty pavements vary between each of the SRAs, which may be attributed to varying local conditions and materials.

The TMR requirement of a minimum 150 mm thick improved layer is similar to DPTI, MRWA and VicRoads. However, TMR is comparatively unique in that the improved layer is usually cementitiously-treated (lightly bound) to reduce water sensitivity. Furthermore, TMR is the only SRA that has requirements for FDA containing an EME2 base layer. Subgrades with a design CBR less than 3% require additional fill below the improved layer to achieve the TMR minimum of CBR 3%, similar to the practice adopted by RMS and DPTI.

The DPTI supports requirements, directly below the asphalt layer, vary based on the underlying strength of the subgrade, but always require a minimum of 150 mm thick granular subbase and may require an additional 150 mm to 350 mm of select fill. Therefore, for an in situ subgrade with a CBR 1.0% to 1.4%, DPTI requirements would decrease the minimum total thickness by 150 mm compared to current TMR requirements.

RMS require a 300 mm thick select material zone below heavy-duty pavements that may be comprised of granular, modified, recycled or slag materials provided the minimum strength requirements are satisfied. This approach taken by RMS for the selection of constituent materials of the pavement supporting layers is comparatively non-prescriptive compared to the other SRAs.

2.1.8 Comparison of Support Requirements

A comparison of the support requirements for various levels of subgrade support, based upon the pavement design supplements of the state road agencies reviewed in Section 2.1 is presented in Table 2.8.

General observations from design comparisons between current TMR requirements and other Australian road agency practices include:

- TMR is the only Australian SRA that typically adopts a lightly bound granular subbase below heavy-duty asphalt pavements.
- TMR has different requirements for EME2 pavements compared to conventional asphalt pavements.
- Provision of a 150 mm thick granular subbase is sufficient support when subgrades of adequate long-term bearing capacity are utilised by DPTI, MRWA and VicRoads. For DPTI, this may require additional fill or subgrade stabilisation, while for MRWA it is common to utilise sand subgrades.
- Current practice by TMR results in thinner pavement support structures than RMS for all subgrade strengths, and thinner than DPTI for subgrade with a CBR ≤ 10%.

The design comparisons indicate that TMR requirements are generally less than RMS and DPTI.

Table 2.8: Support comparison of pavement support thicknesses for Australian practice

Design CBR (%)	TMR (FDA)	TMR (EME2)	RMS	DPTI	VicRoads	MRWA
3.0	150 mm improved layer	300 mm subbase, or 150 mm subbase over 170 mm CBR7 select fill	150 mm CBR 33% SMZ over 150 mm CBR 19% SMZ	150 mm subbase over 250 mm stabilised subgrade, or 150 mm subbase over 350 mm Type A or B Fill	150 mm subbase (CBR15)	150 mm subbase
5.0	150 mm improved layer	200 mm subbase	150 mm CBR 33% SMZ over 150 mm CBR 19% SMZ	150 mm subbase over 150 mm Type A Fill, or 250 mm lime stabilised subgrade	150 mm subbase (CBR15)	150 mm subbase
7.0	150 mm improved layer	150 mm subbase	150 mm CBR 33% SMZ over 150 mm CBR 19% SMZ	150 mm subbase over 150 mm Type A Fill or, 250 mm lime stabilised subgrade	150 mm subbase (CBR15)	150 mm subbase
10.0	150 mm improved layer	150 mm subbase	150 mm CBR 33% SMZ over 150 mm CBR 19% SMZ	150 mm subbase over 150 mm Type A Fill or, 250 mm lime stabilised subgrade	150 mm subbase (CBR15)	150 mm subbase
12.0	150 mm improved layer	150 mm subbase	150 mm CBR 33% SMZ over 150 mm CBR 19% SMZ	150 mm subbase	150 mm subbase (CBR15)	150 mm subbase

Note: Support comparisons are based upon jurisdictional pavement design supplements.

2.2 International Practice

The relevant guidelines of each of the international road authorities reviewed are presented in Table 2.9

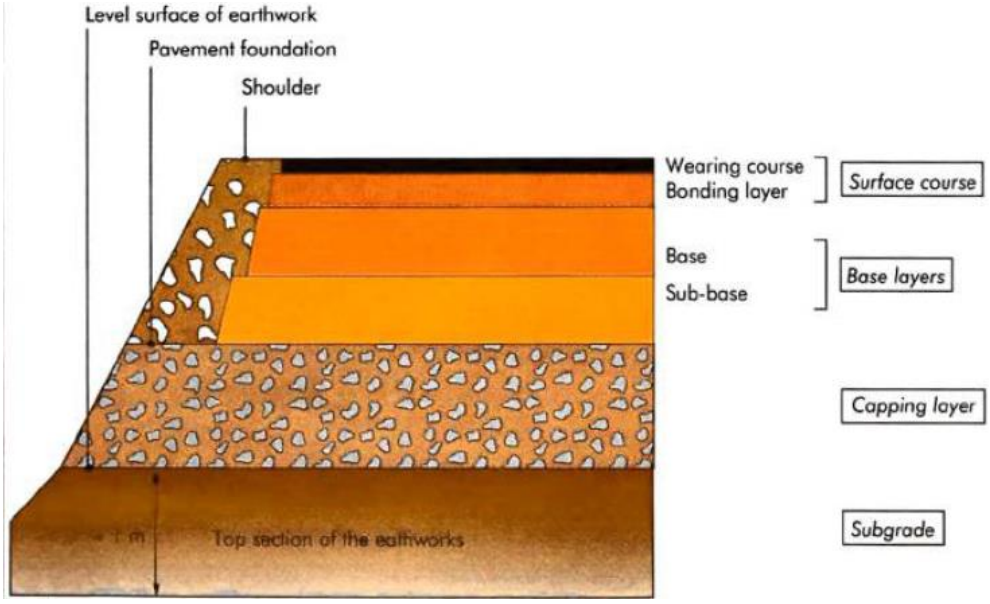
Table 2.9: International road authority documents reviewed

Jurisdiction	Documents reviewed
France	*French Design Manual for Pavement Structures* (Laboratoire Central des Ponts et Chausees (LCPC) 1997)
New Zealand	*New Zealand Guide to Pavement Structural Design* (NZ Transport Agency (NZTA) 2017)
South Africa	*Structural Design of Flexible Pavements for Interurban and Rural Roads* (Republic of South Africa Department of Transport (RSA DOT) 1996) *South African Pavement Engineering Manual* (SAPEM) (South African National Roads Agency (SANRAL) 2014)
United Kingdom	*Design of Long-life Flexible Pavements for Heavy Traffic (*Nunn et al. 1997) *Design Manual for Roads and Bridges, Volume 7: Pavement Design and Maintenance, Section 2: Pavement Design and Construction* (Highways Agency 2006) Interim Advice Note 73/06: *Design Guidance for Road Pavement Foundations (Draft HD25)* (Highways Agency 2009)
United States of America	*AASHTO Guide for Design of Pavement Structures* (American Association of State Highway and Transportation Officials (AASHTO) 1993) *Comprehensive Pavement Design Manual, Chapter 6: Materials* (New York Department of Transportation (NYDOT) 2014) *Flexible Pavement Design Manual* (Florida Department of Transportation (FDOT) 2016) *Highway Design Manual* (California Department of Transportation (Caltrans) 2017) *Pavement Manual* (Texas Department of Transportation (TxDOT) 2017)

2.2.1 France

The *French Design Manual for Pavement Structures* (LCPC 1997) defines structures consisting of an asphalt wearing course over one bituminous layer as flexible pavements. If the asphalt wearing course is over two bituminous layers, they are called ‘thick bituminous pavements’. The asphalt layers are placed directly on the pavement foundation (i.e. capping layer and subgrade) for thick bituminous pavements, whereas flexible pavements typically utilise a subbase layer comprised of unbound granular material below the asphalt layers. The French pavement terminology is presented in Figure 2.2.

Figure 2.2: French pavement layer terminology



Source: LCPC (1997).

The capping layer in French pavement structures can only be constructed on subgrades with a minimum long-term bearing capacity of at least 20 MPa. The structural requirements of the capping layer vary depending on the constituent materials and the long-term bearing capacity of the subgrade. The capping layer is not required to provide structural support where the subgrade bearing capacity is greater than 120 MPa. However, subgrades with a bearing capacity less than 50 MPa will always require a structural capping layer. The capping layer, when required to provide structural support, is typically used to increase the pavement support to 120 MPa (LCPC 1997). Table 2.10 presents the required thicknesses of the capping layers to improve the long-term bearing capacity of the pavement foundation.

Table 2.10: Conditions for upgrading the long-term bearing capacity of the pavement foundation

Long-term bearing capacity of subgrade (MPa)	Minimum thickness of unbound granular capping layer (mm)	Minimum thickness of modified capping layer (mm)
20–50	800(2)	350 (treated with lime and cement)(1) 500 (treated with lime only)(1) 500 (treated with lime and cement)(2) 700 (treated with lime only)(2)
50–120	500(2)	350 (treated with lime and cement)(2) 500 (treated with lime only)(2)

1 To obtain pavement foundation (capping layer and subgrade) long-term bearing capacity of 50 MPa.
2 To obtain pavement foundation (capping layer and subgrade) long-term bearing capacity of 120 MPa.

Source: LCPC (1997).

Flexible pavements utilising a subbase comprised of unbound granular materials have fixed thicknesses to suit the bearing capacity of the underlying layers to ensure adequate compaction of the overlying asphalt base layer may be achieved. The minimum thicknesses are presented in Table 2.11. It is important to note that the subbase may be comprised of bituminous materials in thick bituminous pavements, and as such, the thickness will be determined using mechanistic design procedures.

Table 2.11: Minimum thickness of unbound granular subbase

Long-term bearing capacity of capping layer and subgrade (MPa)	Minimum thickness of unbound granular subbase (mm)
20–50	450
50–120	250
120–200	150

Source: LCPC (1997).

2.2.2 New Zealand

The New Zealand Transport Agency (NZTA) is a member of Austroads, and as such, its design practice generally reflects AGPT Part 2 (Austroads 2012). The *New Zealand Guide to Pavement Structural Design* (NZTA 2017) typically uses structural asphalt when the 25-year design traffic volume is greater than 5 x 10^7 ESAs to minimise the risk of premature failure. Structural asphalt used by the NZTA include FDA (asphalt layers founded directly on subgrade), DSA (asphalt layers founded on an unbound or stabilised aggregate layer) and perpetual pavements (asphalt wearing, intermediate and base course).

Subgrades with an in situ CBR not greater than 3% (soft subgrades) require either reinforcement or establishment of a working platform to facilitate adequate compaction in the overlying granular layers and to ensure fines do not infiltrate the pavement structure. The preferred methods for establishment of a working platform are to (NZTA 2017):

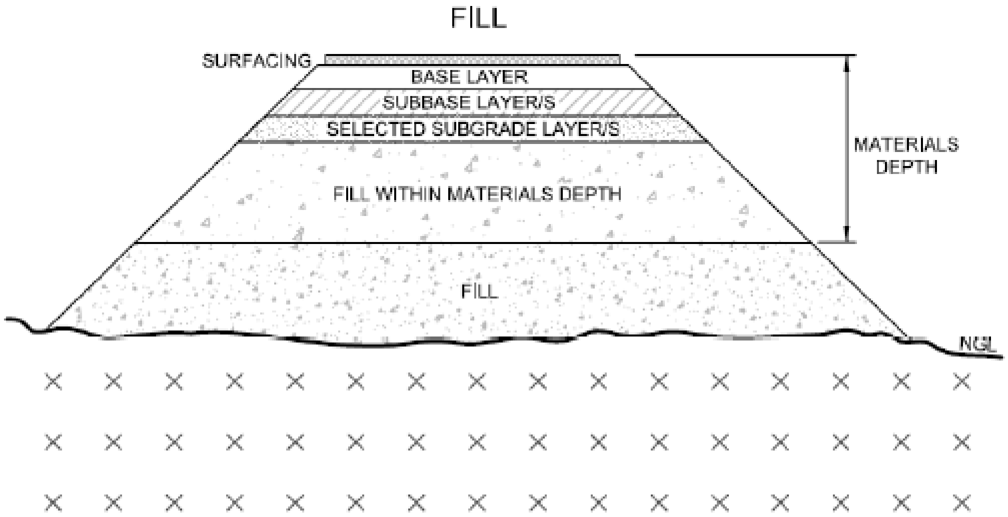
- stabilise the subgrade to a depth of at least 180 mm
- incorporate reinforcing geosynthetic material between the subgrade and the subbase (and elsewhere as required)
- allow a sacrificial depth of 150 mm of granular material and design the pavement assuming no improvement to the subgrade CBR or modulus.

It is important to note in areas prone to expansive soils or a high water table, the provision of adequate drainage may result in improved subgrade conditions; however, no anticipated improvements may be factored into the subgrade design (NZTA 2017).

2.2.3 South Africa

South African road pavements are typically comprised of a surface course supported by several granular layers designed to carry the design traffic loading, as illustrated in Figure 2.3. Highly trafficked roads require the construction of selected subgrade layers to provide additional support to the structural layers of the pavement (SANRAL 2014). Typical material depths for each road category are presented in Table 2.12.

Figure 2.3: Materials depth in a fill



Source: SANRAL (2014).

Table 2.12: Typical material depths

Road category	Materials depth (mm)
A (freeways, 3–100 x 10^6 ESA)	1000–1200
B (inter-urban collectors, rural roads, 0.3–10 x 10^6 ESA)	800–1000
C (low volume roads, < 3 x 10^6 ESA)	800
D (rural access roads, < 1 x 10^6 ESA)	700

Source: SANRAL (2014).

The material used for the base and subbase is dependent on the expected traffic over a 20-year design period, where an asphaltic base course may be used for design traffic exceeding 1 x 10^6 ESAs (SANRAL 2014). On roads with a design traffic greater than 1 x 10^6 ESAs, the subbase is typically comprised of cement-stabilised gravel with an elastic design modulus of 2000 MPa.

Selected material layers are incorporated to provide a working platform for the overlying structural layers. The materials used for selected layers are often chosen based on availability and proximity to the project, containing relatively few strength requirements. They commonly have an elastic design modulus in the range of 30 to 160 MPa (SANRAL 2014).

Flexible pavement design in South Africa assumes that all subgrades are brought to class G7 material quality (i.e. 120 MPa) support standards to provide adequate support to the structural pavement layers. Any subgrade that does not meet the minimum requirements may be improved by importing layers of increasing quality, following the recommendations presented in Table 2.13.

Table 2.13: In situ subgrade delineation for flexible pavements

CBR (%) of delineated subgrade sections	Action
> 15	▪ In situ subgrade of a G7(1) standard and of sufficient strength to support structural layers. ▪ Rip and re-compact to 93% of modified (mod.) AASHTO density.
7–15	▪ In situ subgrade of a G9(2) standard. ▪ Rip and re-compact in situ material to 93% of mod. AASHTO density. ▪ Import a 150 mm thick layer of G7(1) standard material.
3–7	▪ In situ subgrade of a G10(3) standard. ▪ Rip and re-compact in situ material to 93% of mod. AASHTO density. ▪ Import a 150 mm thick layer of G9(2) standard material. ▪ Import a second 150 mm thick layer of G7(1) standard material.
< 3	▪ Chemical/mechanical stabilisation. ▪ Or, remove and import new material. ▪ Or, add additional cover to replace poor quality in situ material below material depth.

1 Typical elastic design modulus of 120 MPa.
2 Typical elastic design modulus of 70 MPa.
3 Typical elastic design modulus of 45 MPa.

Source: SANRAL (2014).

2.2.4 United Kingdom

The United Kingdom Highways Agency typically utilises FDA pavements for heavy design traffic, comprising an asphalt surface course, binder course and base course over a pavement foundation (i.e. granular subbase, capping layer and subgrade) (Highways Agency 2009). The pavement foundations are classified into four classes and are defined by the stiffness modulus at the top of the foundation as summarised in Table 2.14.

Table 2.14: Foundation classes

Foundation class	Stiffness modulus (MPa)	Minimum subbase/capping layer thickness (mm)	Notes
1	50–100	150	Capping only design without a subbase layer, must not be used for design traffic in excess of 20 million standard axles (msa)
2	100–350	150	Subbase and capping design or subbase only design, must not be used for design traffic greater than 80 msa unless minimum 150 mm of bound subbase is used
3	200–1000	175	Typically incorporate cement or hydraulically bound mixtures (HBM)
4	400–3500	200	Typically incorporate cement or hydraulically bound mixtures (HBM)

Source: Highways Agency (2006; 2009).

Local experience indicates that for design traffic greater than 80 million standard axles (msa), increasing the design pavement thickness does not provide substantial benefits to the structural integrity of the road, provided the wearing course is sufficiently maintained before it affects the structural integrity of the road. It is important to note that design traffic greater than 80 msa, the asphalt binder course and asphalt base course must contain crushed rock or slag coarse aggregate unless local experience indicates that gravel may be successful (Highways Agency 2006).

The Highways Agency's pavement design standard, HD 26/06 *Pavement Design and Maintenance* (Highways Agency 2006) states that the foundation below an EME2 layer must be a class 3, class 4 or a class 2 foundation that has a surface stiffness modulus of at least 120 MPa at construction.

A subgrade with a CBR of less than 2.5% is considered to provide unsuitable support for a pavement foundation and must be permanently improved. Treatment options include (Highways Agency 2009):

- replacing the top 0.5–1.0 m of soft subgrade with suitable material, however the design CBR may not be greater than 2.5% to account for the long-term potential strength reduction caused by the underlying soft material
- cohesive materials may be stabilised using lime or other suitable stabilising agents to a design CBR no greater than 2.5% even if the material exhibits better properties
- incorporating a geosynthetic material
- adopting a deep drainage system for permeable soils in conjunction with monitoring the expected CBR improvement over time, which may form the basis of the assumed design CBR.

It is important to note that if the materials underlying the subbase are more permeable than the subbase and the water table is more than 300 mm from the underside of the foundation, no drainage is required (Highways Agency 2009).

2.2.5 United States of America

Pavement design practices in the USA are similar to Australia in that each state jurisdiction has adapted the design practice from the national guide, i.e. the American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* (1993). As a result, practice varies between jurisdictions.

The AASHTO Design Guide does not contain specific quality requirements for the subbase or base course of flexible pavements. However, when the design traffic exceeds 5×10^6 equivalent single axle loads (ESALs), the minimum recommended thickness of the aggregate base is 6 inches (approximately 150 mm). It is important to note that base course refers to the layer of the pavement structure beneath the surface course, constructed on the subbase that is typically comprised of treated or untreated aggregates.

The adapted design practice of selected states is discussed below.

California

Pavement design in California is carried out in accordance with the California Department of Transportation (Caltrans) *Highway Design Manual* (2017). Flexible pavements typically comprise an asphalt surface course supported by an asphalt base layer, a granular subbase and subgrade (Caltrans 2017). Caltrans' subbases do not have restrictive quality requirements and are typically comprised of recycled pavement materials; however, cement or lime stabilisation maybe be required where the subbase materials do not meet strength requirements. Typical design modulus values for aggregate subbase range from 70 to 280 MPa (relationship based on AASHTO 1993, pp. II-21) (Caltrans 2017).

Subgrades comprised of low strength soils (CBR < 3%) or moisture-sensitive materials in the presence of high water tables are preferably improved by subgrade enhancing geosynthetic (SEG) fabrics. SEG fabrics are placed between the pavement structure and the subgrade (Caltrans 2017) to increase the design CBR to 3%. It is important to note that very soft subgrades (CBR < 2%) may require construction of a subbase or aggregate base material, a minimum of 6 inches (150 mm) thick, to provide a working platform for construction traffic loading.

Florida

The Florida Department of Transportation (FDOT) *Flexible Pavement Design Manual* (2016) defines flexible pavements as structures comprising a wearing course, structural course (intermediate course), base course, subbase, stabilised subgrade and roadbed soil (natural soil materials). FDOT is non-prescriptive regarding the material that may be used for the base course; however, project conditions may require an asphaltic base.

The base layer for design traffic exceeding 3.5 x 10^6 ESALs must have a design modulus of at least 200 MPa for granular bases, or comprise of an equivalent asphalt base and subbase, if necessary. The required modulus for asphalt bases is not specified (FDOT 2016). Subbases are typically only used below an asphalt base, where the minimum subbase design modulus is 200 MPa.

The stabilised subgrade layer is a structural layer, typically 12 inches (300 mm) thick. It is used as a working platform to enable the construction of the pavement base course, where the constituent materials are not specified and a minimum design modulus of 80 MPa is achieved (FDOT 2016). It is important to note that although the FDOT does not specify a minimum roadbed soil modulus, the design value must not exceed 80 MPa.

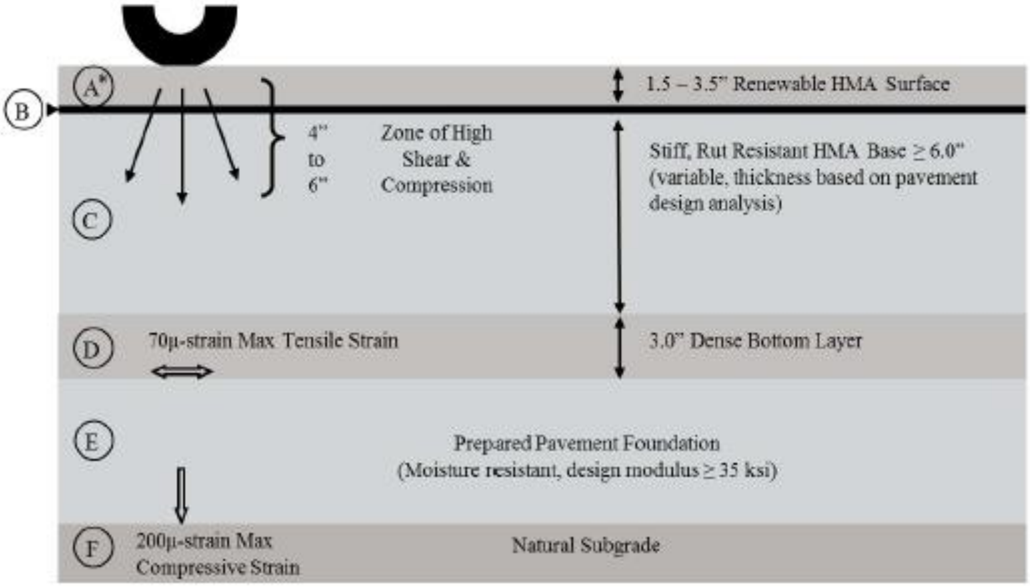
New York

Heavy duty asphalt pavements used by the New York Department of Transportation (NYDOT) consist of an asphalt wearing course, asphalt binder (intermediate) course, asphalt base course with an underlying granular subbase and subgrade (NYDOT 2014). The subbase is typically 300 mm thick and does not have any specific strength requirements. Typical subgrade design moduli range from 34 to 48 MPa, where values below 21 MPa indicate soft soil with poor drainage that may offer weak support and may need to be upgraded through improving drainage, material replacement or stabilisation (NYDOT 2014).

Texas

The Texas Department of Transportation (TxDOT) specifies the use of perpetual pavements for design traffic levels exceeding 3 x 10^7 ESALs over a 20-year design period (TxDOT 2017). The design considerations, including minimum support conditions for TxDOT perpetual pavements are presented in Figure 2.4. The prepared pavement foundation layer specification is relatively non-prescriptive, allowing unbound granular, cement stabilised or lime stabilised materials to be used for construction. The preferred layer thicknesses are 6–12 inches (150–300 mm) for unbound granular materials, 6–12 inches for cement stabilised materials and 8 inches (200 mm) for lime stabilised materials.

Figure 2.4: TxDOT perpetual pavement design



Note: Hot mix asphalt (HMA), kilopound per square inch (ksi), 35 ksi ≈ 240 MPa.
Source: TxDOT (2017).

The TxDOT *Pavement Manual* (2017) recommends the design modulus for natural subgrade to range from 8–20 ksi (55–140 MPa). However, TxDOT frequently encounters in situ material that is inadequate for traffic loading demands and/or is expansive in nature, requiring chemical treatment to obtain the desired properties. Typical treatment options include stabilisation using emulsified asphalt treatment or lime/cement treatment to improve the design modulus to 15–25 ksi (100–170 MPa) or 30–45 ksi (200–310 MPa) respectively (TxDOT 2017). The minimum prepared pavement foundation (used directly above the natural subgrade) must have a design modulus of 35 ksi (240 MPa), as shown in Figure 2.4.

2.2.6 Comparison of International Practice

A summary of the minimum subbase and subgrade requirements below heavy-duty pavements used by each of the international road agencies reviewed is presented in Table 2.15.

Table 2.15: Comparison of international road agency minimum support requirements for heavy duty pavements with TMR

Country	Minimum pavement support requirements		Comments
Australia (TMR)	Improved layer:		
	FDA and DSA:	Minimum 150 mm cement modified granular layer (1.0 to 2.0 MPa at 7 days)	Specified in TMR (2017) supplement
	FDA (EME2):	FDA requirements with layer of varying thickness below improved layer based on bearing capacity of subgrade, top of the improved layer must achieve minimum 150 MPa modulus	Specified in TMR (2015) technical note
	Subgrade:		Specified in TMR (2017) supplement
	<u>CBR ≥ 3%:</u>	FDA and DSA requirements	
	<u>CBR 2.5 to 2.9%:</u>	150 mm geotextile wrapped granular fill	
	<u>CBR 2.0 to 2.4%:</u>	200 mm geotextile wrapped granular fill	
	<u>CBR 1.5 to 1.9%:</u>	300 mm geotextile wrapped granular fill	
	<u>CBR 1.0 to 1.4%:</u>	400 mm geotextile wrapped granular fill	

Country	Minimum pavement support requirements		Comments
France	Subbase: Capping layer: Subgrade:	No min. strength requirements, min. thickness of 150 mm Required to provide structural support if subgrade is less than 50 MPa, typically to increase strength to 120 MPa Minimum long-term bearing capacity of 20 MPa	Specified in LCPC (1997) French design guide
New Zealand	Subgrade:	Minimum CBR 3%	Specified in NZTA (2017) pavement design guide
South Africa	Foundation layers: Subbase: Selected materials: Subgrade:	Freeway materials depth typically 1000–1200 mm No stated minimum, typically provide stabilised subbase with an elastic design modulus of 2000 MPa Selected based on availability, layered to provide support equal to 120 MPa Minimum CBR 15%	Specified in SANRAL (2014) pavement engineering manual
United Kingdom	EME2 foundation: Subgrade:	Cementitiously treated min. design stiffness modulus 200 MPa or unbound granular capping layer min. design stiffness modulus 120 MPa with 150 mm bound subbase Minimum design CBR 2.5%	Specified in Highways Agency (2006) design manual Specified in Highways Agency (2009) design guidance
United States of America	Subbase: Subgrade:	Design modulus for granular subbase typically 70–280 MPa Minimum design CBR 3%, CBR < 2% require 150 mm granular material cover	Specified in Caltrans (2017) highways design manual
	Subbase: Improved layer: Subgrade:	Minimum design modulus 200 MPa Minimum design modulus 80 MPa Maximum design modulus 80 MPa	Specified in FDOT (2016) flexible pavement design manual
	Subgrade:	Minimum design modulus 21 MPa	Specified in NYDOT (2014) pavement design manual
	Perpetual pavements: Subgrade:	150–300 mm subbase (design modulus ≥ 240 MPa) Subgrade min. design modulus not specified, max 200 με Design modulus typically 55–140 MPa	Specified in TxDOT (2017) pavement manual

The international road agencies reviewed adopt different approaches to the specification of minimum supporting requirements below FDA and other heavy-duty asphalt pavements. Differences in supporting conditions may be attributed to the climatic conditions, material availability and cost of labour, thus influencing comparisons between requirements. It is important to note that comparisons in practice between TMR and the international agencies reviewed should undergo careful consideration due to fundamental differences in pavement design practices. For example, the Austroads (2017) mechanistic-empirical pavement design procedure involves sublayering of the granular material whereas France and the USA do not use sublayering.

TMR requirements for minimum support below FDA containing an EME2 base layer were adapted based on the French specifications, which is evident through TMRs inclusion of an improved layer with a minimum design modulus of 150 MPa, where other heavy-duty pavements do not have this requirement. However, the minimum long-term bearing capacity of French subgrade is 20 MPa, compared to the TMR requirement of CBR 3%.

The NZTA pavement design guide is based on AGPT 2 (2012) but does not specify minimum subbase supporting requirements. However, the NZTA specifies that a design subgrade CBR less than 3% requires improvement, which is comparable to TMR.

Heavy-duty pavements in South Africa are typically comprised of several granular material layers, where the required strength and thickness varies with the expected design traffic. The SAPEM minimum strength requirements for subbase or selected material layers vary with the material used (i.e. elastic modulus of 70 MPa for G9 materials). Furthermore, a minimum in situ CBR of 15% is required for the subgrade, which may be achieved by importing layers of increasing quality.

Practice by the Highways Agency in the United Kingdom states that the pavement foundation below an EME2 layer must be cementitiously treated to a minimum design stiffness modulus of 200 MPa or contain an unbound granular capping layer with a minimum stiffness modulus of 120 MPa below a 150 mm bound subbase. Subgrades with a design CBR of less than 2.5% must be permanently improved before they may be used as a pavement foundation.

Similar to Australia, pavement design practices in the USA vary between SRAs. Texas was the only SRA practice reviewed that contained specific guidance on perpetual pavements, where the subbase is required to have a design modulus of at least 240 MPa, with a thickness typically between approximately 150 mm and 300 mm. Although no minimum design modulus is stated, the vertical strains in the natural subgrade must not exceed 200 $\mu\varepsilon$ due to loading.

Furthermore, in Florida, the required design moduli of the subbase and improved layer are 200 MPa and 80 MPa respectively, while the minimum subgrade strength is not stated. Caltrans adopts a similar approach to TMR, specifying a minimum design CBR of 3%, but does not state minimum subbase requirements. The NYDOT allows the weakest design subgrade of the USA road jurisdictions reviewed, with a minimum of 21 MPa.

2.2.7 Comparison of International Support Requirements

A comparison of the support requirements for various levels of subgrade support, based on the selected international practice reviewed in Section 2.2 and TMR is presented in Table 2.16.

General observations from the comparisons between current TMR requirements and international practice include:

- French practice results in thicker support requirements compared to TMR practice for subgrades with a design CBR of less than or equal to 10%.
- NZTA (2017) does not state minimum subbase requirements for DSA or perpetual pavements; however, subgrades with a CBR of less than or equal to 3% require the construction of a working platform, resulting in thinner pavement support structures.
- Practice adopted in South Africa results in thicker pavement support structures compared to TMR practice.
- UK practice results in thicker pavement support requirements compared to TMR practice.
- Practice in the USA varies between state jurisdictions; however, requirements in Florida and New York result in thicker pavement support requirements while requirements in Texas may result in similar outcomes to TMR, depending on subbase constituent materials. Furthermore, subbase requirements in California are limited to subgrades with a design CBR less than 3%, which result in thinner supporting layers.

The support comparisons indicate that TMR requirements are usually less than those of the selected international practice, with exceptions, as outlined above.

Table 2.16: Support comparison of pavement support thicknesses for international practice

Design CBR (%)	TMR (FDA)	TMR (EME2)	France	NZ	South Africa	UK (TRL250)	USA (California)	USA (Florida)	USA (New York)	USA (Texas)
3.0	150 mm improved layer	300 mm subbase, or 150 mm subbase over 170 mm CBR7 select fill	450 mm subbase, or 150 mm subbase over (min.) 500 mm treated capping layer	180 mm stabilised subgrade, or reinforcing geosynthetic, or 150 mm sacrificial depth of granular material	Subbase: 200–450 mm cement stabilised Selected subgrade layers: Upper – 150 mm G7 (120 MPa) Lower – 150 mm G9 Subgrade in situ: Rip and recompact to 150 mm G10	320 mm subbase, or 150 mm subbase over 350 mm capping layer	150 mm subbase	120 mm subbase over 300 mm stabilised subgrade	300 mm subbase	150–300 mm subbase
5.0	150 mm improved layer	200 mm subbase	450 mm subbase, or 150 mm subbase over (min.) 350 mm treated capping layer	–		220 mm subbase, or 150 mm subbase over 250 mm capping	–	120 mm subbase over 300 mm stabilised subgrade	300 mm subbase	150–300 mm subbase
7.0	150 mm improved layer	150 mm subbase	250 mm subbase, or 150 mm subbase over (min.) 350 mm treated capping layer	–		200 mm subbase, or 150 mm subbase over 220 mm capping layer	–	120 mm subbase over 300 mm stabilised subgrade	300 mm subbase	150–300 mm subbase
10.0	150 mm improved layer	150 mm subbase	250 mm subbase, or 150 mm subbase over (min.) 350 mm treated capping layer	–	Subbase: 200-450 mm cement stabilised Selected subgrade layers: 150 mm G7	170 mm subbase, or 150 mm subbase over 190 mm capping layer	–	120 mm subbase over 300 mm stabilised subgrade	300 mm subbase	150–300 mm subbase

Design CBR (%)	TMR (FDA)	TMR (EME2)	France	NZ	South Africa	UK (TRL250)	USA (California)	USA (Florida)	USA (New York)	USA (Texas)
12.0	150 mm improved layer	150 mm subbase	150 mm subbase	–	Subgrade in situ: Rip and recompact to 150 mm G9	160 mm subbase, or 150 mm subbase over 170 mm capping layer	–	120 mm subbase over 300 mm stabilised subgrade	300 mm subbase	150–300 mm subbase

3 CONCLUSIONS AND RECOMMENDATIONS

A review of current national and international guidelines in relation to the recommended supporting conditions for heavy-duty asphalt pavements was undertaken to develop consistent, easily-applicable guidance for road designers operating across TMR regions and industry. General conclusions resulting from the investigation include the following:

- TMR is the only Australian SRA that typically adopts a lightly bound granular improved layer below heavy-duty asphalt pavements.
- TMR has different supporting requirements for EME2 pavements compared to conventional full-depth asphalt pavements.
- Provision of a 150 mm thick granular subbase is sufficient support when subgrades of adequate long-term bearing capacity are utilised by DPTI, MRWA and VicRoads. For DPTI, this may require additional fill or subgrade stabilisation, while for MRWA it is common to utilise sand subgrades.
- Current TMR practice results in thinner pavement support structures compared to RMS for all subgrade strengths, and thinner than DPTI for subgrade strengths with a CBR ≤ 10%.
- NZTA practice does not state minimum subbase requirements for DSA or perpetual pavements; however, subgrade with a design CBR ≤ 3% requires a working platform.
- The South African approach of providing layers of increasing quality over soft subgrades results in thicker support structures to achieve a minimum subgrade design CBR of 15% for pavements.
- Support requirements below EME2 pavements in the UK are typically higher than those specified by TMR.
- California adopts a similar approach to TMR, specifying a minimum design CBR of 3%, but does not state minimum support requirements.
- Florida incorporates both a subbase and an improved layer below heavy-duty asphalt pavement.
- New York incorporates a 300 mm thick subbase; however, there are no strength requirements below asphalt.
- Perpetual pavements in Texas are required to have a minimum design subbase modulus of 240 MPa, where the thickness typically varies based on constituent materials and may result in similar outcomes to TMR.
- Current TMR practice results in thinner pavement support structures compared to South Africa, the UK, Florida and New York. Furthermore, French subgrades with a design CBR ≤ 10% result in thicker pavement support thicknesses than those specified by TMR.

In conclusion, TMR requirements for supporting layer underneath heavy-duty asphalt pavements are generally less than other road agency requirements for high traffic roads, and there is justification to increase the requirements. To achieve this, the practicalities of implementation within an existing established design system, as well as TMR's focus on value-for-money would need to be considered.

Following consultation with TMR, it is recommended that TMR requirements for support conditions under EME2 be adopted for other heavy-duty asphalt pavements in the TMR *Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology*. This approach could be readily adopted within the current Austroads pavement design system and would align TMR's requirements more closely with national and international practices, particularly for subgrades with CBR less than 7%. Most notably, TMR's requirements would be reasonably closely aligned with UK requirements, where there has been a well-documented history of achieving long pavement lives when these requirements have been followed.

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