REAAA Technical Report

Compendium on Pavement Structural Design and Rehabilitation Methods Adopted by Member Countries

Working Group/Review Panel on QA of Pavement Structures on behalf of REAAA Pavement Technology Committee

Dr Keizo Kamiya & Kieran Sharp

REAAA Technical Report TC-11

REAAA Project: QA of Pavement Structures

REAAA Technical Report TC-11 – October 2021

Compendium on Pavement Structural Design and Rehabilitation Methods Adopted by Member Countries

First Published 2021

Compendium on Pavement Structural Design and Rehabilitation Methods Adopted by Member Countries

ISBN

REAAA Project: QA of Pavement Structures

REAAA Technical Report TC-11

Prepared by

Dr Keizo Kamiya**,** NEXCO Central, Japan

Kieran Sharp, Chair of REAAA Technical Committee

Working Group: QA of Pavement Structures

on behalf of REAAA Pavement Technology Committee

Reviewed and Edited by

Kieran Sharp, Chair of REAAA Technical Committee

Published by REAAA
46B Jalan Bola Tampar 13/14, Section 13
40100 Shah Alam
Selangor, Malaysia
Phone: +603 553 6380
Fax: +603 553 9390
E-mail: reaaa@po.jaring.my
www.reaaa.net

COMPENDIUM ON PAVEMENT STRUCTURAL DESIGN AND REHABILITATION METHODS ADOPTED BY MEMBER COUNTRIES

REAAA 2021
Kuala Lumpur, Malaysia

REAAA Profile

REAAA is the Road Engineering Association of Asia and Australasia. The association promotes the science and practice of road engineering and related professions in the Asia-Pacific region through the development of professional and commercial links within and between countries in the region. REAAA Chapters have been set up in Australia, Brunei, Korea, Malaysia, New Zealand and the Philippines. REAAA is also active in Indonesia, Japan, Singapore, Taiwan and Thailand.

REAAA was established in June 1973 with a permanent secretariat in Malaysia. Currently there are more than 1,200 members in 23 countries. It holds regular events including two Governing Council meetings each year, business forums, a quadrennial international conference, technical visits and study tours, trade exhibitions, seminars, forums and workshops. It also publishes a Journal and a Newsletter. The most recent initiative is a series of technical reports addressing issues of concern in the region.

REAAA Technical Reports

This is the eleventh in the series of Technical Reports since the first report was published in 2008. The following Technical Reports have been published to date.

TC-1 Guide to privatisation of expressways and highways

TC-2 Disaster risk management

TC-3 Efficient operation of the road network

TC-4 Road safety – make it happen

TC-5 Pavement durability

TC-6 Guide to the public-private partnership of road and highway projects

TC-7 Incorporating Japanese pavement design practice for a community road in Mongolia

TC-8 Pavement maintenance and rehabilitation practices

TC-9 Compendium on pavement recycling

TC-10 Report on FEHRL scanning tour to South Korea and Japan: infrastructure resilience

TC-11 Compendium on pavement structural design and rehabilitation methods adopted by member countries

REAAA Technical Sub-Committee: Pavement Technology

The REAAA Pavement Technology Committee (PTC) is one of the three sub-committees reporting to the Technical Committee. It was established at the 108th Governing Council meeting in Brisbane, Australia, in May 2018. The first meeting focussed on the topics to be dealt with by the sub-committee. At the same time, cooperation with, and reference to, the relevant PIARC pavement committee has been maintained so that collaborative activities of mutual interest to both REAAA and PIARC are maintained.

Membership of REAAA Working Group: QA of Pavement Structures

Member	Organisation
Dr Keizo Kamiya	NEXCO Central (Chair)
Mr Kieran Sharp	Chair REAAA Technical Committee
Mr Kazunari Hirakawa	Japan Road Association
Mr Masahiko Iwama	NIPPO Corporation
Mr Atsushi Kawakami	Public Works Research Institute
Mr Yasumasa Torii	Japan Road Association
Mr Toshiyuki Nakamura	Japan Road Association

Membership of REAAA Pavement Technology Committee

Including Cooperation with PIARC Committee: TC.4.1 – Pavements

(New PIARC cycle commenced in October 2019 and will run until October 2022)

Chapter/Country	Member	Organisation
Chair	Dr Keizo Kamiya	NEXCO Central
Australia	Mr Kieran Sharp	Chair REAAA Technical Committee
	Dr Michael Moffatt	Australian Road Research Board
	Mr Andrew Beecroft	HDR
	Dr James Grenfell	Australian Road Research Board
Brunei	Mr Rafitra Razak	Public Works Department
Indonesia	Mr Hedy Rahadian	Ministry of Public Works
Japan	Mr Kazunari Hirakawa	Japan Road Association
	Mr Masahiko Iwama	NIPPO Corporation
	Mr Atsushi Kawakami	Public Works Research Institute
	Mr Yasumasa Torii[1]	Japan Road Association
	Mr Toshiyuki Nakamura[1]	Japan Road Association
Korea	Dr Sueng-Hwan Han	Korea Expressway Corporation
	Dr Junyoung Park	Korea Expressway Corporation
	Mr Insoo Yeo	Korea Road Association
Malaysia	Mr Hamzah bin Hashim	Public Works Department
New Zealand	VACANT	
Philippines	Mr Abdulfatak A Pandapatan	Department of Public Works and Highways
Singapore	Ms Leong Yin Fong	Land Transport Authority
	Ms Nyunt Than	Land Transport Authority
Taiwan	Professor Yu-Min Su	NKUST / CRF
	Mr Jiun-Lue Gau	Freeway Bureau / CRF
Thailand	Dr Montri Dechasakulsom	Department of Highways
	Dr Auckpath Sawangsuriya[2]	Department of Highways
REAAA Secretariat	Ms Zalilahwati bt Latif (Ila)	REAAA
PIARC	Mr Shigeki Takahashi[2]	NEXCO Research Institute

1 Advisor. 2 Member of PIARC Committee TC.4.1 (Pavements).

ACKNOWLEDGEMENTS

The input from the member countries who responded to the questionnaire and provided additional information is gratefully acknowledged.

SUMMARY

The REAAA Technical Sub-committee on Pavements (Pavement Technology Committee, PTC) commenced its activities by conducting a PTC members' meeting in May 2018 when the 108th REAAA Governing Council was held in Brisbane, Australia. Collaboration talks on relevant technical fields between REAAA and PIARC had taken place since the early stage of REAAA's current cycle (2017-2021). The first PTC meeting and the exchange of opinions among the members led to the selection of the theme of 'pavement design' in the REAAA member countries,

The goals of the REAAA Pavement Technical Committee (PTC) reflect issues of major concern in REAAA member countries and also the need to be in line with the PIARC Strategic Plan:

1. Investigate the challenges and incentives used in different countries to encourage the use of methods and materials that minimize the use of natural resources, reduce energy consumption and emissions, and improve health impacts during the lifetime of pavements (recycling, low temperature mixes/warm mix asphalt, new binders/aggregates).
2. Evaluate available technologies and practices for better sustainability and management of low-cost pavement systems.
3. Review the use of technology such as laser, image processing, etc. in pavement monitoring and evaluation techniques; ideally, contribute to state-of-the-art report on road condition monitoring and road/vehicle interaction to be presented at SURF 2017 Symposium in Brisbane in May 2017.

In line with this goals, the PTC sought approval from the REAAA Technical Committee and the REAAA Governing Council to develop a compendium on the current procedures used by each member country for the structural design and rehabilitation of their highway pavements.

It was agreed that the best way to derive the information sought was to develop a questionnaire on the current procedures being used for the design and rehabilitation of pavements in each member country. The contests of the survey covered a wide range of issues, ranging from general issues to structural design to road surface distress to repair methods.

This report presents details of the questionnaire, the responses and an analysis of the results in terms of consistency, or variations, in current practice.

It was confirmed that there is some consensus in terms of practice with similar procedures being used to manage pavements. These similarities are very important, because this assures that all members can easily benefit from the application of promising design or repair methodologies in the future without the need for unnecessary trials. By sharing knowledge and experience, implementation of a new technology can be steadily achieved in each country.

One possible avenue for future work could be to prepare a set of design criteria, with members asked to use their guidelines to develop a range of pavement scenarios which meet these criteria. The resulting pavement designs could then be compared.

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

The REAAA *Pavement Technology Committee* (PTC) was formed in January 2018. It arose out of REAAA Technical Sub-Committee TC-2 (Pavements), which was one of eight Technical sub-committees established at the 90th meeting of the REAAA Governing Council in April 2010 when it authorised its *Strategy Map & Initiatives (2010-2012)*.

During its first cycle from 2010 to 2013, Committee TC-2 addressed the issue of 'pavement durability' and organized a workshop on that theme during the 14th REAAA Conference in Kuala Lumpur in March 2013. The Sub-committee published a *Compendium on pavement durability* (TC-5) in July 2015 and joined the compilation of an REAAA technical report (TC-7) titled *Incorporating Japanese pavement design practice for a community road in Mongolia*, which was lodged on the REAAA website in November 2015.

During its second cycle from 2013-2017 the Sub-committee addressed 'Pavement maintenance and rehabilitation practices' as its main theme, with 'recycling of pavement materials' included as a sub-theme. An REAAA technical report *Pavement maintenance and rehabilitation practice* (TC-8) was published in August 2017, and a *Compendium on recycling of pavement materials* (TC-9) was also published in 2017.

Dr Keizo Kamiya was appointed Chair of the PTC in 2018 as he had been a member of the previous Technical Sub-Committee TC-2 (Pavements), which was led by Japan, and also because he was the Japanese member of PIARC Committee TC D.2 (Pavements).

The goals of the PTC reflect issues of major concern in REAAA member countries and also the need to be in line with PIARC Strategic Theme D (Infrastructure) which was operating at that time (2018):

1. Investigate the challenges and incentives used in different countries to encourage the use of methods and materials that minimize the use of natural resources, reduce energy consumption and emissions, and improve health impacts during the lifetime of pavements (recycling, low temperature mixes/warm mix asphalt, new binders/aggregates).
2. Evaluate available technologies and practices for better sustainability and management of low-cost pavement systems.
3. Review the use of technology such as laser, image processing, etc. in pavement monitoring and evaluation techniques; ideally, contribute to the state-of-the-art report on road condition monitoring and road/vehicle interaction to be presented at the SURF Symposium in Brisbane in May 2018.

In line with these goals, the PTC sought approval from the REAAA Technical Committee and the REAAA Governing Council to develop a compendium on the current procedures used by each member country for the structural design and rehabilitation of their highway pavements.

To this end, it was agreed that the best way to derive the information sought was to develop a questionnaire on the current procedures being used for the design and rehabilitation of pavements in each member country. This proposal was accepted and a questionnaire was developed, mainly by the Japanese members of the PTC, but with input from other members.

This report presents details of the questionnaire, the responses, and an analysis of the results in terms of consistency, or variations, in current practice.

2 QUESTIONNAIRE ON PAVEMENT STRUCTURES

In developing a questionnaire, a template needed to be developed so that all members could report their information in a consistent way. After some discussion, it was agreed that the formation of the Austroads *Guide to Pavement Technology, Part 2: Pavement structural design* (Austroads 2019a), would be adopted as the model for the template.

2.1 Format of Questionnaire

The format of the questionnaire was as follows. Note that, in several cases, examples of pavements, or pavement cross-sections, were shown to assist the respondent:

Part One: General

1.1 What is the percentage of sealed pavements on your major roads?

1.2 What is the major type of pavement used on major roads in your country?
- 1.2.1 If both asphalt & concrete, what percentage is asphalt and what percentage is concrete?

1.3 What is the major application of concrete pavements in your country?
- 1.3.1 If outside tunnels, what is the most common application?

1.4 What pavement design guide do you use when designing your pavements (AASHTO, Austroads, TRL, etc.)?

Part Two: Pavement Structure

1.1 Asphalt Pavements
Please highlight the road classes which apply to each of the three asphalt pavements described in the questionnaire.

1.2 Concrete Pavements
Please highlight the road classes which apply to each of the following four concrete pavements described in the questionnaire.

Part Three: Pavement Design

3.1 Asphalt Pavements
- 3.1.1 What design period is generally adopted for asphalt (highway) pavements?
- 3.1.2 When calculating future traffic, which traffic is multiplied by the design period?
- 3.1.3 What method is used to determine subgrade strength?
- 3.1.4 What method is used in the thickness design of asphalt pavements?

3.2 Concrete Pavements
- 3.2.1 What design period is generally adopted for concrete (highway) pavements?
- 3.2.2 When calculating future traffic, which traffic is multiplied by the design period?
- 3.2.3 Which method is used to determine subgrade strength?
- 3.2.4 What method is used in the thickness design of concrete pavements?

Part Four: Road Surfacings

4.1 Asphalt Pavements
- 4.1.1 Please highlight road classes which apply to each type of road surface (do not highlight any class if a surfacing type is not used in your country).
- 4.1.2 Please identify other surfacing types which are used in your country.

4.2 Concrete Pavements
- 4.2.1 Please highlight which construction method is most commonly used in your country.
- 4.2.2 Please highlight road classes which apply to each type of road surface. (do not highlight any class if a surfacing type is not used in your country)
- 4.2.3 Please identify other surfacing types which are used in your country.

Part Five: Surface Distress

5.1 Asphalt Pavement

5.1.1 Please highlight the types of surface distress commonly encountered in your country

1 Abrasion or ravelling by studded tyre
2 Rutting or plastic flow
3 Partial rutting or plastic flow
4 Cracking in wheelpath
5 Reflective cracking
6 Reflective cracking on asphalt overlay of concrete
7 Thermal cracking
8. Ageing
9 Corrugations
10 Faulting at bridge joints
11 Faulting on soft soil areas
12 Aggregate stripping
13 Fatigue cracking

5.1.2 Please highlight other distress types that are observed in your country.

5.2 Concrete Pavements

5.2.1 Please highlight the types of surface distress commonly encountered in your country.

1. Abrasion or ravelling by studded tyre
2. Longitudinal cracking
3. Transverse cracking
4. Punch out
5. Joint loss

Part Six: Rehabilitation Methods

6.1 Asphalt Pavement

6.1.1 What is the typical time, in years, that national or State highways operate before they need repair?

6.1.2 Which method is used to rehabilitate an asphalt pavement?

6.2 Concrete Pavement

6.2.1 What is the typical time, in years, that national or State highways operate before they need repair?

6.2.2 Which method is used to rehabilitate a concrete pavement?

3 RESPONSES TO QUESTIONNAIRE

The responses are presented under each question according to each country as follows:

AU Australia
ID Indonesia
JP Japan
KR Korea
MY Malaysia
NZ New Zealand
PH Philippines
SG Singapore
TW Taiwan
TH Thailand

Where relevant, notes to the tables were provided, e.g. definitions. Comments were also provided.

Unfortunately, no response was received from the Brunei Chapter.

3.1 General

3.1.1 Percentage of sealed pavements on major roads

The percentage of sealed pavements on major roads in each country is shown in Table 3-1. In summary:

- Over 90% of major roads in all countries are sealed.
- Over 60% of Australia's roads are unsealed. Whilst few are applied to major roads they are the most significant pavement type in rural areas, including linking regional centres.

Table 3-1: Percentage of sealed pavements on major roads

	AU[1]	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. 90% or higher	✓	✓	✓[2]	✓[2]	✓	✓	✓	✓	NF, UR, Exp	✓
2. 60% to 90%										
3. 30% to 60%										
4. less than 30%										

NF: National Freeway; UR: Urban Road; Exp: Expressway & Provincial Highway.

1 Over 60% of Australia's roads are unsealed but they are not used on National highways.

2 Japan: 99%; Korea: 94.1%.

3.1.2 Major pavement types used on main roads

The main pavement types used on main roads in each country are summarised in Table 3-2, whilst a summary of the split between asphalt and concrete – when both pavement types are used – is shown in Table 3-3.

Comments

- Both asphalt and concrete pavements are used in most countries, with asphalt being by far the most dominant type.
- Only the Philippines has a higher ratio of concrete pavements (60-70%) than asphalt pavements. Concrete pavements are favoured on expressways in Korea.
- Taiwan reported a detailed road classification according to national freeways, urban roads and expressways.
- Australia and New Zealand are unique, with sprayed bituminous surfacings representing 90% of sealed road applications.

Some examples of typical pavement types are shown in Figure 3-1.

Table 3-2: Major pavement types used on main roads

Pavement type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Asphalt pavement	✓		✓	✓	✓	✓		✓	NF, UR	✓
2. Concrete pavement	✓		✓	✓[1]						
3. Both asphalt & concrete	✓[1]	✓					✓		NF	
4. Unknown										
5. Sprayed bituminous seal	90%					✓				

NF: National Freeway; UR: Urban Road.

1 Assumed to mean asphalt surfacing on concrete base (62%).

Table 3-3: Percentage of asphalt and concrete pavements when both pavement types are used

	AU[1]	ID	JP	KR	MY	NZ	PH	SG	TW	TH
Asphalt (AS)	70-75%	93.5%	90&	98%[2]	99%	100%		95%	90%[3]	>90%
Concrete (CO)	5%	3.8%	10%	2%	1%	–	60-70%	5%	10%[2]	<10%

1 The majority of sealed pavements are sprayed bituminous seals.

2 National Expressway.

3 National Freeway.

Asphalt pavement – Japan ***Concrete pavement – Japan*** ***Sprayed/chip seal pavement – Australia***

Figure 3-1: Typical pavement types

3.1.3 Major applications of concrete pavements

A summary of the major applications of concrete pavements is presented in Table 3-4, while the main applications used outside tunnels are shown in Table 3-5.

Comments

The main findings are as follows:

- The major application of concrete pavements is heavily-trafficked pavements, including tollways, expressways and national highways.
- The only country that uses concrete pavements exclusively in tunnels at present is Malaysia. However, they want to extend the use of concrete pavements to both inside and outside tunnels.
- Concrete pavements are used both inside and outside tunnels in most countries.
- Concrete pavements are used for junction access and applications such as busways in Singapore and Taiwan.
- There are no concrete pavements in New Zealand.

Table 3-4: Main applications of concrete pavements

Application	AU	ID	JP	KR	MY	NZ	PH	SG[1]	TW	TH
1. Only inside tunnels					✓	None				
2. Mostly inside tunnels			Exp	NH					Exp	
3. Both inside and outside	✓	Toll/NH	NH	Exp					NF	✓
4. Unknown										

NH: National Highway; NF: National Freeway; Exp: Expressway & Provincial Highway.

[1] Concrete pavements are only used at the approaches to junctions and bus bays.

Table 3-5: Main application of concrete pavements outside tunnels

Application	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Exp. or Motorway	✓	✓		✓	✓	✓	✓			✓
2. National or State Highway	✓	✓	✓		✓	✓	✓		NF	
3. Provincial or Prefectural Road									Exp	
4. Municipal Road										
5. Junction access, bus bays								✓	✓	

Examples of concrete pavements in tunnel applications are shown in Figure 3-2.

Figure 3-2: Examples of a concrete pavement in tunnel applications (Source: Japan)

3.1.4 Guides used for the structural design of road pavements

The guides used as the basis for the structural design of road pavements in each country are shown in Table 3-6.

In summary:

- Australia uses the Austroads series of guides for the structural design and rehabilitation of pavements (e.g. Austroads 2019a and b). The various states and territories issue supplements to take account of local conditions.
- New Zealand practice is also based on Austroads. However, they have also published a supplement to take account of local conditions in that country (NZTA 2017).
- Japan imported the Structural Number policy from the AASHO Road Test (CBR 3) and modified it so it would be usable for a wide range of CBR values to match the operating conditions in that country. Manuals are published and revised by the Pavement Committee of the Japan Road Association.
- Practice in Korea, the Philippines and Taiwan is also based on AASHTO (1993) although Korea has developed its own guidelines based on mechanistic-empirical pavement design guide (MEPDG) concepts. However, AASHTO is also referenced when finalising the design.
- Practice in Malaysia and Singapore is based on UK practice (Transport Research Laboratory 1970) though Malaysia (JKR) has developed its own guidelines (Public Works Department Malaysia 2017). TRL have issues several supplements since Road Note 29 was published.
- Practice in Thailand is based on the US Asphalt Institute (1970) guidelines.

Table 3-6: Guides used for the structural design of road pavements*

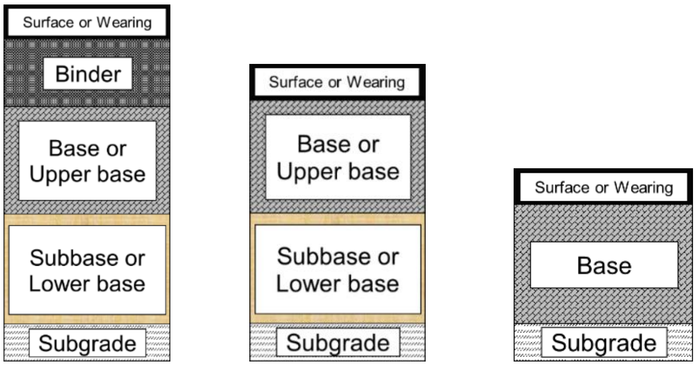
AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
Austroads	Austroads, AASHTO	AASHO arranged	AASHTO MEPDG KPRP (Korean pavement research Program) guidelines	ATJ 5/85, JKR	Austroads	AASHTO, ASTM, ACI	TRL Road Note 29	AASHTO, California, R-value	Asphalt Institute, PCA

* Most countries have developed supplements to reflect local conditions.

3.2 Pavement Structure

3.2.1 Asphalt pavements

In terms of asphalt pavement usage, countries were asked which road classes were applied to each of the three asphalt pavement types shown in Figure 3-3. The results are shown in Table 3-7. Some typical examples of asphalt pavements in use are shown in Figure 3-4.



4-Layer-System 3-Layer-System 2-Layer-System

Figure 3-3: Typical asphalt pavement cross-sections

Table 3-7: Asphalt pavement cross-sections typically adopted in member countries

4-Layer System	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway	✓	✓	✓	✓	✓	✓	✓	✓	NF	✓
2. National Highway or State Highway	✓	✓	✓	✓	✓		✓	✓	NF	✓
3. Provincial or Prefectural Road		✓		✓				✓		
4. Municipal Road		✓		✓				✓	UR	

3-Layer System	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway						✓			Exp	
2. National Highway or State Highway	✓	✓	✓			✓	✓			✓
3. Provincial or Prefectural Road		✓	✓	✓	✓		✓		Exp	✓
4. Municipal Road		✓		✓					UR	

2-Layer System	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway						✓			Exp	
2. National Highway or State Highway	✓	✓				✓				
3. Provincial or Prefectural Road	✓	✓	✓				✓		Exp	✓
4. Municipal Road	✓	✓	✓	✓			✓		UR	✓

NF: National Freeway; UR: Urban road; Exp: Expressway.

Japan *Indonesia* *Australia*

Figure 3-4: Typical examples of asphalt pavement use in the region

Summary/Comments

- Thicker pavement structures such as the four-layer-system tend to be used on toll roads or national highways. However, they may be widely use at the local level in Indonesia and Singapore. The thinner structures tend to be used in provincial or municipal roads.
- Malaysia is working towards adopting the three-layer system into municipal roads.
- Comment from Australia: It is unclear whether the base and subbase layers refer to asphalt or granular. Other configurations could have been added, e.g. the minimum subgrade support conditions/select fill requirements. Another of way of illustrating would be to set a design example for each road class with supplied design CBR and ESAs and compare configurations. This approach has been used in European comparisons of design codes.

3.2.2 Concrete pavements

Countries were asked to nominate the use of concrete pavements with and without asphalt intermediate layers but with steel mesh (see Figure 3-5), and the results are shown in Table 3-8 and Table 3-9.

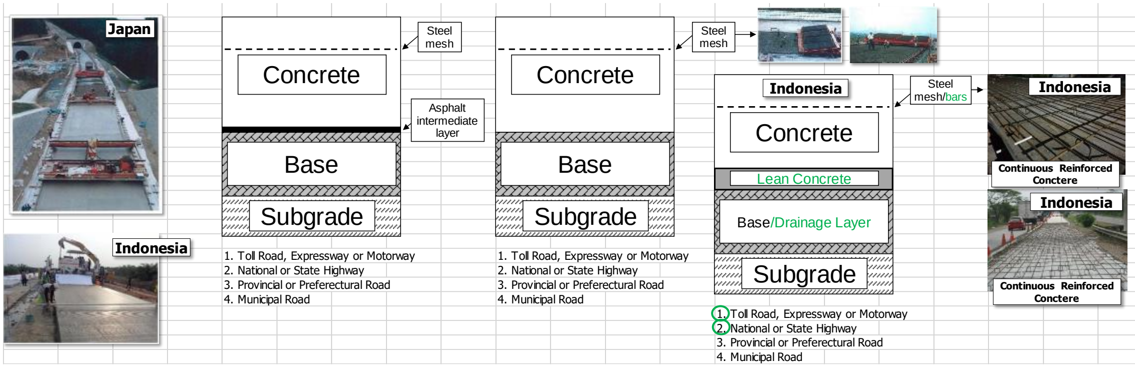


Figure 3-5: Concrete pavements, without asphalt intermediate layers but with steel mesh

Table 3-8: Usage of concrete pavements: with steel mesh & with asphalt intermediate layers

With asphalt intermediate layer	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway										
2. National Highway or State Highway			✓							
3. Provincial or Prefectural Road										
4. Municipal Road										

Table 3-9: Usage of concrete pavements: with steel mesh & without asphalt intermediate layers

Without asphalt intermediate layer	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway		lean concrete	✓	✓	✓				NF	✓
2. National Highway or State Highway			✓	[1]					NF	✓
3. Provincial or Prefectural Road			✓						Exp	✓
4. Municipal Road										
5. Junction access, bus bays								✓		

[1] Not much. NF: National Freeway; Exp: Expressway.

Countries were then asked to nominate the use of concrete pavements without asphalt intermediate layers and without steel mesh (see Figure 3-6), and the results are shown in Table 3-10 and Table 3-11.

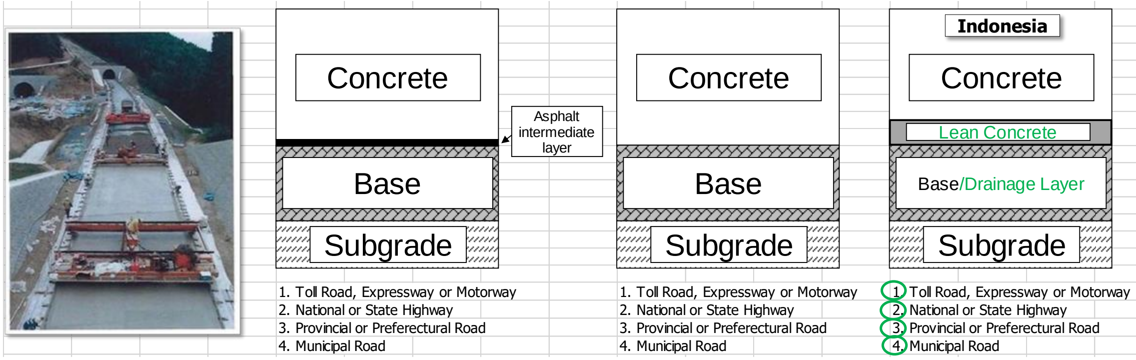


Figure 3-6: Concrete pavements, without asphalt intermediate layers and without steel mesh

Table 3-10: Usage of concrete pavements: asphalt intermediate layers & without steel mesh

With asphalt intermediate layer	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway							✓			
2. National Highway or State Highway							✓			
3. Provincial or Prefectural Road										
4. Municipal Road										

Table 3-11: Usage of concrete pavements: without asphalt intermediate layers &without steel mesh

Without asphalt intermediate layer	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway	✓	✓		✓						
2. National Highway or State Highway	✓	lean concrete		✓			✓			
3. Provincial or Prefectural Road		✓								
4. Municipal Road		✓			✓					

Summary/Comments

- Concrete pavements with steel mesh and with asphalt intermediate layers are only used on National highways in Japan.
- Concrete pavements without asphalt intermediate layers but with steel mesh are mostly used on toll roads, and national or provincial highways. Indonesia adopts a lean mix concrete interface to provide a levelling layer with the concrete slab above it. A drainage base layer is used, which may be suitable for use in countries with high annual rainfall. Continuously reinforced concrete is also used for longer durability. Korea uses a lean concrete base for both jointed pavements and continuously reinforced concrete pavements. A plastic sheet is applied over the lean concrete base of jointed pavements.
- Concrete pavements without steel mesh are used in Indonesia on all road classes, including municipal roads. Other countries mostly use steel mesh on toll roads or National highways.
- Concrete pavements without steel mesh and without intermediate layers are only used in the Philippines.
- Malaysia is working towards increasing the usage of concrete pavement into its National highway or State highway system.
- Comment from Australia: Similar comments to Table 3-7. The use of case studies would have enabled Australia to illustrate the widespread use of lean mix concrete subbases and also the use of undowelled jointed pavements, neither of which is provided for in the question.

3.3 Pavement Design

3.3.1 Asphalt pavements

Design period and traffic multipliers

The design period generally adopted for asphalt (highway) pavements is summarised in Table 3-12, whilst the category of traffic that is multiplied by the design period when calculating future traffic is shown in Table 3-13.

Table 3-12: Design period generally adopted for asphalt (highway) pavements

Design period	AU[1]	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. 10 years			✓				✓		UR	✓
2. 20 years		✓		✓	✓			[1]	NF, Exp	
3. 30 years	✓									
4. 40 years	✓									

UR: Urban road; NF: National Freeway; Exp: Expressway.

1 Cumulative number of standard axles (ESAL).

Table 3-13: Traffic multiplied by the design period when calculating future traffic

<table>
<tr><th>Traffic</th><th>AU</th><th>ID</th><th>JP</th><th>KR</th><th>MY[2]</th><th>NZ</th><th>PH</th><th>SG</th><th>TW</th><th>TH</th></tr>
<tr><td>1. Annual Average Daily Traffic (AADT)</td><td></td><td>LT</td><td></td><td></td><td></td><td></td><td>✓</td><td></td><td rowspan="3">NF, UR, Exp</td><td>N, P</td></tr>
<tr><td>2. Estimated number of heavy vehicles*</td><td></td><td></td><td>NH</td><td></td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3. Equivalent Single Axle Load (ESAL)</td><td></td><td>Exp, NH</td><td>Exp</td><td></td><td></td><td></td><td></td><td>✓[3]</td><td>N, P, M</td></tr>
<tr><td>4. Other</td><td>✓[1]</td><td></td><td></td><td>✓[4]</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

LT: low traffic; NF: National Freeway; Exp: Expressway; N: National highway; P: Provincial highway; M: Motorway.

* In this context, 'heavy vehicles' can be considered to be the same general classification as 'commercial vehicles'.

1 Number of load repetitions of each axle load on each axle group type, together with a load-damage exponent.

2 10 years design life for traffic category 30 million standard axles (MSA) and below, and 20 years design life for traffic category 30 MSA and above.

3 Cumulative number of Standard Axles (ESAL).

4 Structural analysis is performed using a combination of vehicle type (12 classes) and a load spectrum.

Summary

- The design period generally adopted for the design of asphalt pavements is between 10 and 20 years. A range of traffic options are used, including AADT, the estimated number of heavy vehicles and equivalent standard axle loads (ESAL).
- Australia adopts a design period of 30 years and uses the number of load repetitions of each axle load on each axle group type, together with a load-damage exponent, for calculating traffic. The design period is presumably selected in line with the recommendations in the design guide.
- Passenger vehicles are not considered in any of the guidelines for estimating design traffic.

Determination of subgrade strength

Methods used to determine subgrade strength are presented in Table 3-14. The most commonly-used method is the CBR method though back-calculation of resilient modulus based on deflection testing is used in Australia and Korea. Various methods are used in Taiwan depending on the class or road being considered.

Table 3-14: Methods used to determine subgrade strength

Traffic	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. California Bearing Ratio (CBR)	✓	✓	✓		✓	✓	✓	✓	UR	Constr.
2. Resilient modulus (laboratory)									NF	
3. Resilient modulus (back-calculated)	✓			✓[1]						Rehab.
4. Other									Exp[2]	

UR: Urban road; NF: National Freeway; Exp: Expressway.

1 Laboratory resilient modulus is used during the design stage. Modulus is also back-calculated using the results of deflections measured using the Plate Bearing test. It is commonly used for field QA/QC testing.

2 Cal. R-value.

Summary

- The most commonly-used method is the CBR method though back-calculation of resilient modulus based on deflection testing is used in Australia and Korea. Various methods are used in Taiwan depending on the class or road being considered.

Thickness design

The methods used to conduct thickness design of asphalt pavements are shown in Table 3-15.

Summary

- Various thickness design methods are used, with the use of design curves based on design traffic and subgrade strength (empirical methods) common.
- Australia uses a mechanistic-empirical thickness design method with the ability to design to a selected project reliability level as shown in the footnote to the Table. Reliability factors are also used in Korea, New Zealand and Taiwan.

Table 3-15: Thickness design methods: asphalt pavements

Traffic	AU[1]	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Chart based on design traffic & subgrade strength		✓								✓
2. Above design chart + reliability factor			NH				✓			
3. Design curves based on design traffic & subgrade strength		✓	Exp		✓		✓	✓	UR	
4. Above design curve + reliability factor						✓			NF, UR, Exp	
5. Other		✓[2]		✓[3]						

UR: Urban road; NF: National Freeway; Exp: Expressway.

1 Suggested project reliability levels depending on road class are as follows:

Road class	Project reliability (%)
Freeway	95–97.5
Highway: lane AADT > 2000	90–97.5
Highway: lane AADT ≤ 2000	85–95
Main road: lane AADT > 500	85–95
Other roads: lane AADT ≤ 500	80–90

2 Design catalogue and pavement deflection.

3 Performance indices are used when determining the design period.

3.3.2 Concrete pavements

Design period and traffic multipliers

The design period generally adopted for highway pavements is summarised in Table 3-16, whilst the category of traffic that is multiplied by the design period when calculating future traffic is shown in Table 3-17.

Table 3-16: Design period generally adopted for concrete (highway) pavements

Design period	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. 10 years										
2. 20 years			✓	NF			✓			✓
3. 30 years				Exp[1]	✓				NF	
4. 40 years	✓	✓				–[2]		✓		

NF: National Freeway; Exp: Expressway.

1 Recent expressways.

2 There are no heavily-trafficked concrete pavements in New Zealand.

Table 3-17: Traffic multiplied by the design period when calculating future traffic: concrete pavements

Traffic	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Annual Average Daily Traffic (AADT)							✓		NF	
2. Estimated number of heavy vehicles			✓		✓				NF	✓
3. Equivalent Single Axle Load (ESAL)								✓[1]	NF	
4. Other	✓[2]	✓[2]		✓[3]					NF, Exp	

NF: National Freeway; Exp: Expressway.

1 Heavy Vehicle Axle Groups (HVAG) x damage exponent.

2 Number of load repetitions of each axle load on each axle group type, together with a load-damage exponent.

3 Structural analysis is performed using a combination of vehicle type (12 classes) and a load spectrum.

Summary

- The design period for concrete pavements varies from 20 or 30 years and can be higher than that adopted for asphalt pavements. Most countries use AADT or the estimated number of heavy vehicles, or ESAL, when calculating future traffic. Both Australia and Indonesia adopt a design period of 40 years and use HVAG and damage components in traffic estimation.

Determination of subgrade strength

Methods used to determine subgrade strength are presented in Table 3-18.

Table 3-18: Methods used to determine subgrade strength: concrete pavements

Method	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. California Bearing Ratio (CBR)	✓	✓		for QA	✓	✓	✓	✓	UR	✓
2. Resilient modulus (laboratory)				✓					NF	
3. K value (K75 or K30)			✓	for QA						
4. Other				✓[1]					NF[2]	

UR: Urban road; NF: National Freeway; Exp: Expressway; QA: Quality Assurance.

1 Laboratory resilient modulus is used during the design stage. Modulus is also back-calculated using the results of deflections measured using the Plate Bearing test. It is commonly used for field QA/QC testing.

2 →Cal. R-value.

Summary

- The most commonly-used method is the CBR method though resilient modulus testing in the laboratory is used in Korea.
- Various methods are used in Taiwan depending on the class or road being considered.
- Australia used the number of load repetitions of each axle load on each axle group type together with a load-damage exponent.

Thickness design

The methods used to conduct thickness design of concrete pavements are shown in Table 3-19.

Table 3-19: Thickness design methods: concrete pavements

Design method	AU[1]	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Chart based on design traffic & subgrade strength										✓
2. Above design chart + reliability factor						–				
3. Design curves based on design traffic & subgrade strength		✓	✓		✓			✓		
4. Above design curve + reliability factor				✓[2]					NF[3]	

1 Based on US Portland Cement Association (PCA) method (Packard 1984).

2 Performance indices are considered when determining the design period.

3 AASHTO Guide. NF: National Freeway.

Summary

- Various design methods are used, with the use of design curves based on design traffic and subgrade strength (empirical methods) commonly used. Reliability factors are used in Korea and Taiwan.
- The method used for the determination of the design thickness of rigid pavements in Australia is based on the USA Portland Cement Association (PCA) method (Packard 1984). There is also the ability to design to a ‘selected project reliability level.

3.4 Road Surfacings

3.4.1 Asphalt pavements

Each country was asked to select which various asphalt surfacing types were used in the following classes of road:

- Toll road, expressway or motorway
- National or state highway
- Provincial or Prefectural road
- Municipal road.

The asphalt types offered were:

- dense-graded asphalt
- porous asphalt
- stone mastic asphalt
- gap-graded asphalt
- semi-flexible asphalt
- double bituminous surfacing treatments, including sprayed/chip seals.

Countries were given the option of nominating other asphalt surfacing types.

Dense-graded asphalt

The most common type of asphalt is a dense-graded mixture of continuously graded aggregate, sand, filler and bitumen which is mixed and placed hot. By varying the aggregate combination to provide a range of different air voids, and using different grades of binder, asphalt properties can be adapted to suit applications ranging from lightly-trafficked applications such as residential streets to heavily-trafficked applications such as freeways and expressways.

Photographs of typical dense-graded asphalt pavements are shown in Figure 3-7, whilst the applications of dense-graded asphalt pavements in member countries is shown in Table 3-20.

Table 3-20: Applications of dense-graded asphalt pavement surfacings

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway		✓	✓	✓	✓		✓	✓[1]	NF	✓
2. National or State Highway	✓	✓	✓	✓	✓		✓	✓[1]	NF	✓
3. Provincial or Prefectural Road	✓	✓	✓	✓	✓				NF, UR, Exp	
4. Municipal Road	✓	✓	✓	✓		✓			UR[1]	

UR: Urban road; Exp: Expressway.

1 Mainly used for arterial roads with lower traffic speed limits. NF: National Freeway.

Figure 3-7: Dense-graded asphalt

Summary

- Dense-graded asphalt is used in all countries and is by far the most common asphalt surfacing type used.

Porous asphalt

Porous asphalt consists of standard bituminous asphalt in which the fines have been screened and reduced, creating void space to make it highly permeable to water. The air voids content of porous asphalt is approximately 16%, compared to 2-3% for conventional asphalt.

Photographs of typical porous asphalt pavements are shown in Figure 3-8, whilst the applications of porous asphalt pavements in member countries is shown in Table 3-21.

Figure 3-8: Porous asphalt

Table 3-21: Applications of porous asphalt pavement surfacings

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway	✓		✓	✓		✓		✓[1]	NF	
2. National or State Highway			✓			✓		✓[1]	NF	
3. Provincial or Prefectural Road									Exp	
4. Municipal Road				✓						

NF: National Freeway; Exp: Expressway.

[1] Selected stretches of expressways with higher traffic speeds especially at noise hotspots.

Summary

- The use of porous asphalt is becoming more widespread in several countries, with usage the highest in Japan, Korea, New Zealand and Singapore. Porous asphalt is used in Taiwan in higher-speed applications and where the control of traffic noise is an issue.
- Open-graded asphalt is a porous asphalt mix designed to allow surface water to drain away and hence increased driver safety, It is also used as a low traffic noise surfacing, especially in urban areas. Countries were not asked to nominate their usage of open-graded asphalt mixes.

Stone mastic asphalt

Stone mastic asphalt (SMA) is designed to have a large percentage of coarse aggregate with predominantly stone-on-stone contact and the remaining voids partially filled with a mastic comprising fines, filler and bituminous binder. The combination of stone-on-stone contact of the coarse aggregate and stiffening of the binder mastic with fine aggregate and filler provides a mix with good deformation resistance.

Photographs of typical stone mastic asphalt pavements are shown in Figure 3-9, whilst the application of stone mastic asphalt pavements in member countries is shown in Table 3-22.

Figure 3-9: Stone mastic asphalt

Table 3-22: Applications of stone mastic asphalt pavements

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway	✓			✓		✓	✓	✓[1]	NF	
2. National or State Highway		✓	✓	✓		✓	✓	✓[1]	NF	
3. Provincial or Prefectural Road									Exp	
4. Municipal Road					✓					

1 Selected stretches of heavy duty roads. NF: National Freeway; Exp: Expressway.

Summary

- Stone mastic asphalt is used in all countries and its use is increasing, particularly in heavily-trafficked applications.

Gap-graded asphalt

Fine gap-graded asphalt was developed to have good durability in locations such as residential streets and lightly-trafficked roads. It is a variation of dense-graded asphalt, but with some aggregate fractions reduced or omitted. Fine gap-graded mixes have a relatively larger proportion of fine aggregate for improved workability and ease of compaction. When combined with relatively high binder content, they can achieve exceptional durability.

A photograph of a typical gap-graded asphalt pavement is shown in Figure 3-10, whilst the applications of gap-graded asphalt pavements in member countries is shown in Table 3-23.

Figure 3-10: Gap-graded asphalt

Table 3-23: Applications of gap-graded asphalt pavements

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway				✓[2]			✓	✓[1]	NF	
2. National or State Highway		✓	✓	✓[2]	✓		✓		NF	
3. Provincial or Prefectural Road		✓							Exp	
4. Municipal Road										

NF: National Freeway; Exp: Expressway.

1 Limited use.

2 Mainly for Expressways with higher traffic speed limits.

Summary

- SMA and porous asphalt mixes are examples of gap-graded mixes and so there is a wide range of applications.
- Gap-graded asphalt is used in six countries, mainly in heavily-trafficked applications, though they are also used in lightly-trafficked applications in Australia.
- Gap-graded asphalt is used in Japan in higher skid resistance applications, though not widely.

Semi-flexible asphalt

A semi-flexible pavement is a relatively new pavement technology. It is an open-graded asphalt with a high air void content filled by injecting special grouting materials. It is constructed without expansion, contraction, and construction joints. It is resistant to rutting and shoving/corrugation. Semi-flexible asphalt materials possess the flexible characteristics of asphalt materials and the high strength (hardness) of concrete.

A photograph of a semi-flexible asphalt pavement is shown in Figure 3-11, whilst the applications of semi-flexible asphalt pavements in member countries is shown in Table 3-24.

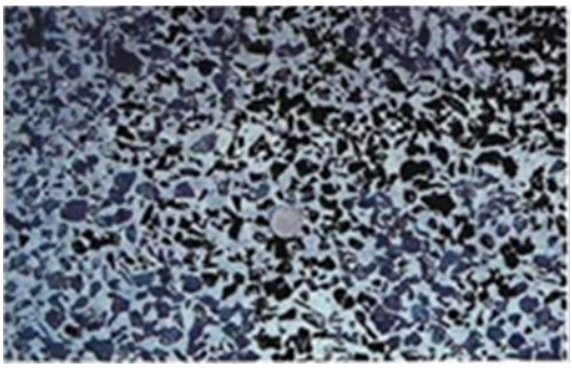


Figure 3-11: Semi-flexible asphalt

Table 3-24: Applications of semi-flexible asphalt pavements

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway			✓				✓			
2. National or State Highway			✓				✓			
3. Provincial or Prefectural Road										
4. Municipal Road										
5. Junction access, bus bays								✓		

[1] Selected stretches of expressways with higher traffic speeds especially at noise hotspots. NF: National Freeway; Exp: Expressway.

Summary

- The use of semi-flexible asphalt pavements is limited to heavily-trafficked applications in Japan and the Philippines. They can be used in junctions and bus bays in Singapore.

Double bituminous surfacing treatments (including sprayed/chip seals)

A double bituminous surfacing treatment is a double application of bituminous binder in the form of an emulsion or hot spray or sometimes cutback bitumen, followed by a double application of an aggregate as close to uniform size as possible. Their best application is roads of low- to medium-traffic volumes (AADT < 4,000).

Photographs of typical double bituminous surfacing treatments are shown in Figure 3-12, whilst the usage of these pavement types is shown in Table 3-25.

Figure 3-12: Examples of double bituminous surfacing treatments (not including sprayed/chip seals)

Table 3-25: Applications of double bituminous surfacing treatments

Road type	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway							✓			
2. National or State Highway	✓	✓				✓	✓			
3. Provincial or Prefectural Road	✓	✓			✓	✓			[1]	
4. Municipal road	✓	✓				✓				

[1] Used as rejuvenators.

Other flexible pavement surfacing types (surface treatments)

Taiwan cited the use of recycled asphalt pavement (RAP), a treatment probably used in other countries but not identified in the survey.

Specialised surface treatments include surface enrichment and rejuvenation, high friction surface treatments, and coloured surface treatments. Examples cited in the survey include slurry seals (Australia, Indonesia, Philippines) microsurfacing (Indonesia) and sand sheeting (Indonesia).

Sprayed/chip seals

The sprayed/chip seal is used in multiple applications in Australia and New Zealand. It is the most common surfacing type used in those countries. The principal use of sprayed seals in Australia and New Zealand is in the surfacing of unbound granular pavements and stabilised pavements. Sprayed seals may also be used to restore surface characteristics or provide waterproofing on asphalt and concrete pavements. Polymermodified binders (PMBs) can be used in sprayed sealing applications for high stress seals (HSS), strain alleviating membranes (SAMs) and strain alleviating membrane interlayers (SAMIs).

An example of a sprayed/chip seal pavement is shown in Figure 3-13 (Austroads 2018).

About 60% of the pavements in Australia are unsealed and they form a vital part of the national road network, particularly provincial and municipal road applications in remote areas of the country. Guidelines for the management of unsealed roads have been published by Austroads and other sources (e.g. Austroads 2009). A typical unsealed road is shown in Figure 3-14.

Figure 3-13: Typical sprayed/chip seal surfacing

Figure 3-14: Typical unsealed road

Geotextile reinforced seals

Geotextile reinforced seals (GRS) are used in Australia. They are produced by spraying a layer of bitumen onto a pavement (bond coat), then covering this bitumen with a layer of geotextile and lightly rolling (Figure 4.2). A single/single or double/double seal is then applied over the geotextile. GRS is currently the most effective sprayed sealing technique in SAM and SAMI applications used for treating badly cracked and distressed bound and unbound pavements, particularly when crack movements are slow. It must, however, be recognised that the potential life of the geotextile treatment may be influenced by premature distress in the underlying layers, the poor condition of the original pavement or periodic inundation.

A further application for GRS is as a surfacing treatment on pavements constructed with poor-quality clay materials. This treatment has been successfully used in remote areas where reasonable quality granular pavement materials are unavailable and pavements must be constructed using local clay soils. These materials can provide adequate bearing capacity provided surface cracking is avoided in dry periods and moisture entry is prevented in wet periods. The use of GRS under these conditions has proven to be an economical means of providing low cost, all weather roads in remote areas (Figure 3-15). Guidance for their use is provided in Austroads (2018).

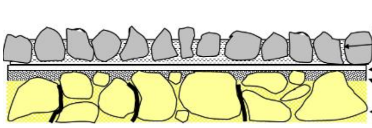


Figure 3-15: Geotextile reinforced seal pavement

Summary

- Taiwan cited the use of recycled asphalt pavement (RAP), a treatment probably used in other countries but not identified in the survey.
- Double bituminous surfacing treatments are used in some applications in Indonesia, Malaysia and the Philippines.
- Sprayed/chip seals are the most common surfacing type used in Australia and New Zealand.
- Geotextile reinforced seals are used as a surfacing in remote parts of Australia.

3.4.2 *Concrete pavements*

Construction method

Common concrete pavement construction methods are shown in Figure 3-16. Countries were asked to nominate which construction method is most commonly used in their country and the results are shown in Table 3-26.

Figure 3-16: Common concrete pavement construction methods

Table 3-26: Concrete pavement construction methods

Construction method	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Setform rail			✓				✓			✓
2. Slipform paving	✓	✓	✓	✓	✓		✓		NF	✓
3. Continuously reinforced concrete		✓?	✓	✓[1]			✓	✓		✓
4. Manual labour		✓								
5. Roller compacted concrete				✓[2]			✓			

NF: National freeway. [1] Use becoming popular. [2] Pilot study.

Summary

- The most common construction method used is slipform paving, with the setform rail method used in Japan, the Philippines and Thailand. There are some roller compacted concrete pavements in the Philippines. There are no concrete road pavements in New Zealand.

Road classes applying to various road surfacings

Countries were asked to nominate which of the surfacing treatments shown in Figure 3-17 were applied to various classes of road. The results are shown in Table 3-27, Table 3-28, Table 3-29 and Table 3-30.

Brushed *Grooved* *Aggregate exposed* *Roller compacted*

Figure 3-17: Concrete pavement surfacing treatments

Table 3-27: Concrete pavement surfacing treatments: brushed surface

Road class	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway					✓		✓		NF	✓
2. National or State Highway			✓				✓		NF	✓
3. Provincial or Prefectural Road	✓									
4. Municipal Road										
5. Junction access, bus bays								✓		

NF: National freeway.

Table 3-28: Concrete pavement surfacing treatments: grooved surface

Road class	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway	✓	✓	✓	✓			✓			
2. National or State Highway	✓	✓		✓			✓			
3. Provincial or Prefectural Road		✓		✓						
4. Municipal Road		✓		✓						
5. Junction access, bus bays				✓				✓		

Table 3-29: Concrete pavement surfacing treatments: aggregate exposed surface

Road class	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway			✓	✓[1]						
2. National or State Highway										
3. Provincial or Prefectural Road										
4. Municipal Road										
5. Junction access, bus bays										

1 Pilot study.

Table 3-30: Concrete pavement surfacing treatments: roller compacted concrete

Road class	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Toll Road, Expressway or Motorway				✓[1]			✓			
2. National or State Highway				✓			✓			
3. Provincial or Prefectural Road										
4. Municipal Road					✓					
5. Junction access, bus bays										

1 Pilot study of a composite section with an asphalt surface.

Summary

- The most common surfacing adopted is the grooved surface on a wide range of road class, with a brushed surface adopted in some countries on heavily-trafficked roads. Aggregate exposed surfacings are used in Japan, and Korea is conducting a pilot study. There is some use of roller compacted pavement in Korea, Malaysia and the Philippines.

Other concrete pavement surfacing types (surface treatments)

In terms of other concrete pavement surfacing types:

- Composite pavements are used on toll roads, expressways or motorways in Indonesia and Japan.
- Longitudinal tyning is applied to toll roads, expressways or motorways in Korea.
- A thin asphalt overlay is applied to national highways in Indonesia.

3.5 Surface Distress

3.5.1 Asphalt pavements

Countries were asked to highlight the types of surface distress commonly encountered in their country. Details of the surface distress types, including definitions and photographs, are presented in Appendix A, whilst a summary of the responses in presented in Table 3-31, and photos of typical distress types are shown in Figure 3-18.

Table 3-31: Observed surface distress: asphalt pavements

Surface distress	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Abrasion or ravelling by studded tyre			✓		✓		✓		✓	
2. Rutting or plastic flow	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[1]
3. Partial rutting or plastic flow	✓	✓	✓	✓		✓	✓	✓	✓	✓
4. Cracking in wheelpath	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5. Reflection cracking	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6. Reflective cracking of asphalt overlay on concrete	✓	✓	✓	✓	✓		✓		✓	✓
7. Thermal cracking			✓	✓	✓		✓			
8. Ageing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9. Corrugations	✓	✓	✓	✓			✓	✓	✓	
10. Faulting at bridge joints	✓	✓	✓	✓	✓		✓	✓	✓	
11. Faulting in soft soil areas	✓	✓	✓	✓	✓		✓	✓	✓	✓
12. Aggregate stripping	✓	✓	✓	✓	✓		✓	✓	✓	
13. Fatigue cracking	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14. Bleeding	✓	✓	✓[2]	✓[3]					NF, Exp	✓
15. Bumps & sags	✓*	✓		✓						✓
16. Depressions/flooding in depressions	✓	✓	✓[3]	✓						✓
17. Transverse or longitudinal cracking	✓	✓	✓[3]	✓						✓
18. Shoving	✓	✓		✓						✓
19. Lane or shoulder drop-offs	✓	✓		✓						✓
20. Potholes	✓	✓		✓					NF, UR, Exp	✓

NF: National freeway.; Exp: Expressway; UR: Urban road.

* Assumed to mean 'corrugations'.

[1] > 60%. [2] bridges. [3] Earthquake.

Abrasion or ravelling by studded tyre

Rutting

Shoving

Plastic flow

Corrugations

Block cracking

Crocodile cracking

Transverse cracking

Longitudinal cracking

Edge break

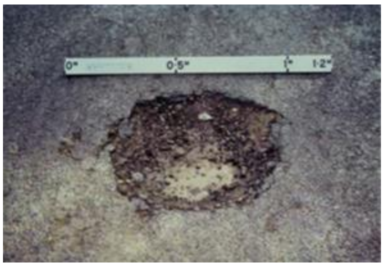
Edge drop-off

Delamination

Flushing or bleeding

Diagonal cracking

Stripping of sprayed seals



Potholing

Polishing of aggregate

Patching

Blistering *Faulting at bridge decks* *Bumps & sags (depression and heave)*

Figure 3-18: Typical distress types – flexible pavements (Sources: REAAA Indonesia, Korea, Japan: Austroads 2019b; NZTA 2001)

Summary

- The most common forms of distress in asphalt pavements (rutting, fatigue cracking) are observed in all countries, whilst reflection cracking is observed in most countries. Aggregate stripping and faulting in areas of soft soil are also common forms of distress.
- Ageing of the asphalt is observed in all countries but this may be a symptom explaining the forms of distress rather than a distress itself.
- Faulting at bridge joints is also a common form of distress.
- Stripping of sprayed/chip seal pavements is often observed in Australia and New Zealand.
- Most countries do not have vehicles which use studded tyres.
- The distress types can be not only related to heavy traffic but also to natural disasters such as heavy rain, earthquakes or changes in sub-surface conditions.

3.5.2 Concrete pavements

Countries were asked to highlight the types of surface distress commonly encountered in their country. Details of the surface distress types, including definitions and photographs, are presented in Appendix B, whilst a summary of the responses in presented in Table 3-32, and photos of typical distress types are shown in Figure 3-19.

Table 3-32: Observed distress types: concrete pavements

Surface distress	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. Abrasion or ravelling by studded tyre			✓				✓		✓	✓
2. Longitudinal cracking	✓	✓	✓	✓			✓	✓		✓
3. Transverse cracking	✓	✓	✓	✓	✓		✓	✓		✓
4. Punchout	✓	✓	✓	✓	✓		✓	✓	NF	
5. Faulting		✓	✓	✓					NF	
6. Joint loss/joint spalling	✓	✓	✓	✓	✓		✓	✓	✓	✓

Summary

- Transverse and longitudinal cracking is common in all countries.
- Loss of material through the joints and punchout is observed in most countries.
- Many countries do not have vehicle which use studded tyres.

Joint fault

Joint spalling

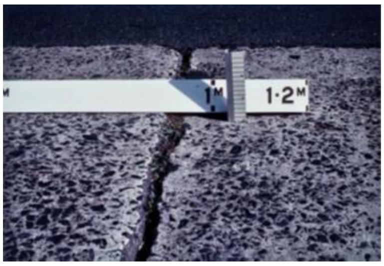
Punchout

Fatigue cracking

Scaling

Sealant distress

Exposed aggregate surface



Joint stepping/faulting

Slab rocking

Abrasion or ravelling by studded tyre

Longitudinal cracking

Transverse cracking

Freezing/thawing

Alkali aggregate reaction

Figure 3-19: Typical distress types – concrete pavements
(Sources: REAAA Indonesia, Japan, Korea; Austroads 2019b)

3.6 Rehabilitation Methods

3.6.1 Asphalt pavements

Countries were asked to nominate the typical time, in years, that national or State highways operate before they need rehabilitation, and the results are presented in Table 3-33.

Table 3-33: Typical time, in years, that national or State highways operate before they need rehabilitation

Life before repair (years)	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. 5 – 10					✓			Exp		NH
2. 10 – 15	✓	NH & Exp	NH & Exp	✓		✓	✓		NF & UR	
3. 15 – 20										
4. ≥ 20										

NH: National highway; Exp: Expressway; NF: National freeway; UR: Urban road.

They were then asked to nominate the methods used to rehabilitate asphalt pavements, and the results are shown in Table 3-34.

Table 3-34: Methods used to rehabilitate asphalt pavements

Rehabilitation method	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. AC overlay	✓	✓		✓	✓				NF & Exp	NH
2. Cut & AC overlay		✓	✓	✓	✓	✓	✓	✓	NF, UR & Exp	MW
3. Spread emulsion	✓									
4. In situ recycling	✓				✓					NH

NH: National highway; Exp: Expressway; UR: Urban road; MW: Motorway.

In situ recycling is used in some applications in Australia, Malaysia and Thailand. The extent to which in situ recycling is used highly depends on each country's experience and the paving infrastructure. For example, Japan uses in situ recycling but its use is very small compared with cut and asphalt overlay, because most of the pavements in Japan are asphalt plant and asphalt mixes are cheap compared to other pavement material surfacing types. Australia, on the other hand, has a large number of low-volume roads composed of natural materials which may need to be strengthened as traffic loads increase.

Summary

- The most common pavement life for asphalt pavements before rehabilitation is required is 10 to 15 years.
- The most common rehabilitation treatment is cut and asphalt overlay.
- In situ recycling is used in some applications in Australia, Malaysia and Thailand. The extent to which in situ recycling is used highly depends on each country's experience and the paving infrastructure.

3.6.2 Concrete pavements

Countries were asked to nominate the typical time, in years, that national or State highways operate before they need rehabilitation, and the results are presented in Table 3-35.

Table 3-35: Typical time, in years, that national or State highways operate before they need rehabilitation

Life before repair (years)	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. 10 – 20		NH								NH
2. 20 – 30	✓	Exp	Exp	✓	✓		✓	✓	NF	
3. 30 – 40	✓		NH							
4. ≥ 40										

NH: National highway; Exp: Expressway; NF: National freeway.

They were then asked to nominate the methods used to rehabilitate concrete pavements, and the results are shown in Table 3-36.

Table 3-36: Methods used to rehabilitate concrete pavements

Rehabilitation method	AU	ID	JP	KR	MY	NZ	PH	SG	TW	TH
1. AC overlay		✓	✓	✓	✓				NF	✓
2. Cut & AC overlay	✓			✓						
3. Cut & concrete overlay	✓	✓						✓		
4. Surface treatment/texturing, etc.	✓		✓	✓	✓		✓			

NF: National freeway.

Summary

- The most common pavement life for concrete pavements before rehabilitation is required is 20 to 30 years.
- Various rehabilitation treatments are used, with the most common being the application of an asphalt overlay. The use of surface treatments/texturing is also common.

4 SUMMARY

The main findings of the survey questionnaire are as follows.

Applications

- Both asphalt and concrete pavements are used in most countries, with asphalt being by far the most dominant type. There are no concrete pavements in New Zealand.
- Only the Philippines has a higher ratio of concrete pavements (60-70%) than asphalt pavements.
- Concrete pavements are favoured on expressways in Korea.
- Taiwan uses a detailed road classification according to national freeways, urban roads and expressways.
- The major application of concrete pavements is heavily-trafficked pavements, including tollways, expressways and national highways.
- The only country that uses concrete pavements exclusively in tunnels is Malaysia.
- Concrete pavements are used both inside and outside tunnels in most countries.
- Concrete pavements are used for junction access and applications such as busways in Singapore and Taiwan.
- Australia and New Zealand are unique, with sprayed bituminous surfacings representing 90% of sealed road applications.
- Over 60% of Australia's roads are unsealed.

Pavement structural design guides

- Australia uses the Austroads series of guides for the structural design and rehabilitation of pavements. The various states and territories issue supplements to take account of local conditions.
- New Zealand practice is also based on Austroads. However, they have also published a supplement to take account of local conditions in that country.
- Japan imported the Structural Number policy from the AASHO Road Test (CBR 3) and modified it so it would be usable for a wide range of CBR values to match the operating conditions in that country.
- Practice in Korea, the Philippines and Taiwan is also based on AASHTO, although Korea has developed its own guidelines based on mechanistic-empirical pavement design guide (MEPDG) concepts. However, AASHTO is also referenced when finalising the design.
- Practice in Malaysia and Singapore is based on UK practice though Malaysia (JKR) has developed its own guidelines. TRL have issues several supplements since Road Note 29 was published.
- Practice in Thailand is based on the US Asphalt Institute (1970) guidelines.

Typical pavement structure for highway pavements

- Thicker pavement structures such as the four-layer-system tend to be used on toll roads or national highways. However, they may be widely use at the local level in Indonesia and Singapore. The thinner structures tend to be used in provincial or municipal roads.
- Malaysia is working towards adopting the three-layer system into municipal roads.
- Concrete pavements with steel mesh and with asphalt intermediate layers are only used on National highways in Japan.
- Concrete pavements without asphalt intermediate layers but with steel mesh are mostly used on toll roads, and national or provincial highways. Indonesia adopts a lean mix concrete interface to provide a levelling layer with the concrete slab above it. A drainage base layer is used, which may be suitable for use in countries with high annual rainfall. Continuously reinforced concrete is also used for longer durability.
- Korea uses a lean concrete base for both jointed pavements and continuously reinforced concrete pavements. A plastic sheet is applied over the lean concrete base of jointed pavements.
- Concrete pavements without steel mesh are used in Indonesia on all road classes, including municipal roads. Other countries mostly use steel mesh on toll roads or National highways.

- Concrete pavements without steel mesh and without intermediate layers are only used in the Philippines.
- Malaysia is working towards increasing the usage of concrete pavement into its National highway or State highway system.

Pavement structural thickness design

- The design period generally adopted for the design of asphalt pavements is between 10 and 20 years. A range of traffic options are used, including AADT, the estimated number of heavy vehicles and equivalent standard axle loads (ESAL).
- Australia adopts a design period of 30 years and uses the number of load repetitions of each axle load on each axle group type, together with a load-damage exponent, for calculating traffic.
- Passenger vehicles are not considered in any of the guidelines for estimating design traffic.
- The most commonly method used to determine subgrade strength is the CBR method, though back-calculation of resilient modulus based on deflection testing is used in Australia and Korea. Various methods are used in Taiwan depending on the class or road being considered.
- Various thickness design methods are used for the design of asphalt pavements, with the use of design curves based on design traffic and subgrade strength (empirical methods) most common. Australia uses project reliability factors based on road class. Reliability factors are also used in Korea, New Zealand and Taiwan.
- The design period for concrete pavements varies from 20 or 30 years and can be higher than that adopted for asphalt pavements. Most countries use AADT or the estimated number of heavy vehicles or ESAL when calculating future traffic. Both Australia and Indonesia adopt a design period of 40 years and use HVAG and damage exponents in traffic estimation.
- Various design methods are used for the determination of the design thickness of rigid pavements, with the use of design curves based on design traffic and subgrade strength (empirical methods) commonly used. Reliability factors are used in Korea and Taiwan. The method used in Australia is based on the USA Portland Cement Association (PCA). There is also the ability to design to a selected project reliability level.

Road surfacings – asphalt/sprayed seal pavements

- Dense-graded asphalt is used in all countries and is by far the most common asphalt surfacing type used.
- The use of porous asphalt is becoming more widespread in several countries, with usage the highest in Japan, Korea, New Zealand and Singapore. Porous asphalt is used in Taiwan in higher-speed applications and where the control of traffic noise is an issue.
- Stone mastic asphalt is used in all countries and its use is increasing, particularly in heavily-trafficked applications.
- Gap-graded asphalt is used in six countries, mainly in heavily-trafficked applications, though they are also used in lightly-trafficked applications in Australia.
- Gap-graded asphalt is used in Japan in higher skid resistance applications, though not widely.
- The use of semi-flexible asphalt pavements is limited to heavily-trafficked applications in Japan and the Philippines.
- Taiwan cited the use of recycled asphalt pavement (RAP), a treatment probably used in other countries but not identified in the survey.
- Double bituminous surfacing treatments are used in some applications in Indonesia, Malaysia and the Philippines.
- Sprayed/chip seal pavements are used in multiple applications in Australia and New Zealand. They are the most common surfacing type used in those countries.
- Geotextile reinforced seals are used as a surfacing in remote parts of Australia.

Road surfacings – concrete pavements

- The most common concrete pavement surfacing is the grooved surface on a wide range of road class, with a brushed surface adopted in some countries on heavily-trafficked roads. Aggregate exposed surfacings are used in Japan and Korea is conducting a pilot study. There is some use of roller compacted pavement in Korea, Malaysia and the Philippines.
- Other concrete pavement surfacing types include:
  - composite pavements, which are used on toll roads, expressways or motorways in Indonesia and Japan
  - longitudinal tyning, which is applied to toll roads, expressways or motorways – including pavements in long-span tunnels – in Korea
  - a thin asphalt overlay, which is applied to national highways in Indonesia.

Pavement distress – asphalt pavements

- The most common forms of distress in asphalt pavements (rutting, fatigue cracking) are observed in all countries, whilst reflection cracking is observed in most countries. Aggregate stripping and faulting in areas of soft soil are also common forms of distress.
- Ageing of the asphalt is observed in all countries but this may be a symptom explaining the forms of distress rather than a distress itself.
- Stripping of sprayed/chip seal pavements is often observed in Australia and New Zealand.
- Faulting at bridge joints is also a common form of distress.
- Most countries do not have vehicles which use studded tyres.
- The distress types can be not only related to heavy traffic but also to natural disasters such as heavy rain, earthquakes or changes in sub-surface conditions.

Pavement distress – concrete pavements

- Transverse and longitudinal cracking is common in all countries.
- Loss of material through the joints and punchout is observed in most countries.
- Many countries do not have vehicle which use studded tyres.

Pavement rehabilitation

- The most common pavement life for asphalt pavements before rehabilitation is required is 10 to 15 years.
- The most common rehabilitation treatment is cut and asphalt overlay.
- In situ recycling is used in some applications in Australia, Malaysia and Thailand. The extent to which in situ recycling is used highly depends on each country’s experience and the paving infrastructure.
- The most common pavement life for concrete pavements before rehabilitation is required is 20 to 30 years.
- Various rehabilitation treatments for concrete pavements are used, with the most common being the application of an asphalt overlay.

5 CONCLUSIONS AND RECOMMENDATIONS

One of the goals of the REAAA Pavement Technical Committee (PTC) is to reflect issues of major concern in REAAA member countries and also to be in line with the PIARC Strategic Plan. One of the strategic initiatives is to investigate the challenges and incentives used in different countries to encourage the use of methods and materials that minimize the use of natural resources, reduce energy consumption and emissions, and improve health impacts during the lifetime of pavements (recycling, low temperature mixes/warm mix asphalt, new binders/aggregates).

In line with this goal, the PTC decided to develop a compendium on the current procedures used by each member country for the structural design and rehabilitation of their highway pavements. It was agreed that the best way to derive the information sought was to develop a questionnaire on the current procedures being used for the design and rehabilitation of pavements in each member country. The contents of the survey covered a wide range of issues, ranging from general issues to structural design to road surface distress to repair methods.

This report presents details of the questionnaire, the responses and an analysis of the results in terms of consistency, or variations, in current practice.

It was confirmed that that there is some consensus in terms of practice, with similar procedures being used to manage pavements. These similarities are very important, because this assures all members that they can benefit from the application of promising design or repair methodologies in the future without the need for unnecessary trials and associated expenditure. By sharing knowledge and experience, implementation of a new technology can be steadily achieved.

Among the most important emerging topics is how to conduct repair design and put it into practice in the field. For example, the use of double bituminous surface treatments or the use of sealing methods is of high interest to REAAA members. The potential use of recycled materials is also of growing interest.

5.1 Recommendations

One possible avenue for future work could be to prepare a set of design criteria, with members asked to use their guidelines to develop a range of pavement scenarios which meet these criteria. The resulting pavement designs could then be compared.

Appendix L of Austroads (2019a) presents examples of the use of the mechanistic-empirical design procedure for the design of flexible pavements. Excerpts from this Appendix follow.

Appendix L Examples of Use of the Mechanistic-Empirical Procedure for Flexible Pavements

This appendix gives examples of the use of mechanistic-empirical procedures for the design of the following three flexible pavement types:

- sprayed seal surfaced unbound granular pavement
- full depth asphalt pavement
- asphalt pavement containing a cemented material subbase.

The following design parameters are used:

- subgrade design CBR = 5%
- design traffic for 30 year design life = 10^7 HVAG.

The traffic load distribution (TLD) is in accordance with the example distribution (see Appendix G). Using a Weighted Mean Annual Pavement Temperature of 28 °C and design traffic speed of 60 km/h, the following asphalt design moduli were calculated:

- asphalt modulus size 14 mm mix = 2200 MPa
- asphalt modulus size 20 mm mix = 2500 MPa
- desired project reliability = 97.5%.

L.2 Full Depth Asphalt Pavement

Following the steps Table 8.1, Table 8.2 and Table 8.3:

Step 1

Try pavement composition shown in Table L 3.

Table L 3: Candidate pavement: full depth asphalt pavement

Material type	Thickness (mm)
Size 14 mm asphalt, E = 2200 MPa	50
Size 20 mm asphalt, E = 2500 MPa	200
Subgrade, design CBR = 5%	Semi-infinite

L.3 Asphalt Pavement Containing Cemented Material Subbase

Following the steps in Table 8.1, Table 8.2 and Table 8.3:

Step 1

Try pavement composition shown in Table L 16.

Table L 16: Candidate pavement: pavement with cemented material subbase

Material type	Thickness (mm)
Size 14 mm asphalt, E = 2200 MPa	50
Size 20 mm asphalt, E = 2500 MPa	125
Cemented material, E = 3000 MPa	200
Granular material	200
Subgrade, design CBR = 5%	Semi-infinite

The design flexural strength of the cemented material is 1.2 MPa. Both modulus and flexural strength of the cemented material were determined from laboratory tests.

As the thickness of asphalt over the cemented material is greater than or equal to 175 mm, the post-cracking phase of cemented material life may be considered (Section 8.2.6).

REFERENCES

American Association of State Highway and Transportation Officials 1993, *AASHTO guide for design of pavement structures*, AASHTO: Washington https://habib00ugm.files.wordpress.com/2010/05/aashto1993.pdf

American Association of State Highway and Transportation Officials 2015, *Mechanistic-empirical pavement design guide – a manual of practice*, AASHTO, Washington, USA.

Asphalt Institute 1970, *Thickness design – full depth asphalt pavement structures for highways and streets*, Manual series no. 1 (MS-1), 8th edition, August.

Austroads 2009, *Guide to pavement technology part 6: unsealed pavements*, AGPT06-09, Austroads, Sydney, NSW.

Austroads 2018, *Guide to pavement technology part 3: pavement surfacings*, AGPT03-09, Austroads, Sydney, NSW.

Austroads 2019a, *Guide to pavement technology, part 2: pavement structural design*, AGPT02-17, Austroads, Sydney, NSW.

Austroads 2019b, *Guide to pavement technology part 5: pavement evaluation and treatment design*, AGPT05-19, Austroads, Sydney, NSW.

Federal Highway Administration 2014, *Distress identification manual for the long-term pavement performance program*, 5th edition, FHWA-HRT-13-092, May.

New Zealand Transport Agency 2001, 'Bridge inspection and maintenance manual', SP/M/016, NZTA, Wellington, NZ.

New Zealand Transport Agency 2017, *New Zealand guide to pavement structural design, version 1.1* https://www.nzta.govt.nz/resources/new-zealand-guide-to-pavement-structural-design/

Packard, RG 1984, 'Thickness design for concrete highway and street pavements', Portland Cement Association, Skokie, IL, USA.

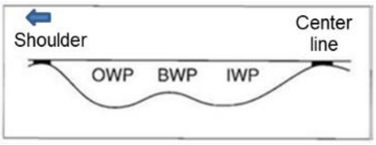
Public Works Department Malaysia 2017, *Manual on pavement design*, ATJ 5/85.

Transport Research Laboratory 1970, *A guide to the structural design of pavements for new roads*, 3rd edition, road note 29, Department of the Environment, UK.

APPENDIX A SURFACE DISTRESS: ASPHALT PAVEMENTS

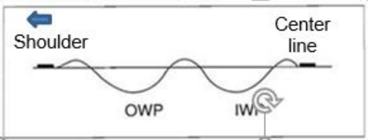
Source: NEXCO documents based on FHWA (2014)

Abrasion or ravelling by studded tyre



AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
			○		○		○		○	

Rutting or plastic flow

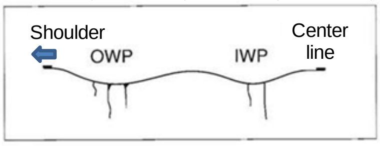


AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○	○	○	○	○	>60%

Partial rutting or plastic flow

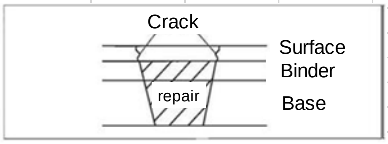
AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○			○	○	○	○	○

Cracking in wheelpath



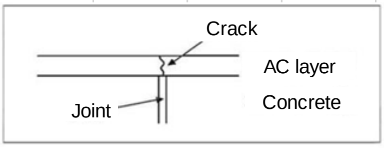
AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○		○	○	○	○	○	○

Reflective cracking



AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○		○	○	○	○	○	○

Reflective cracking on asphalt overlay of concrete



AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○		○		○	○

Thermal cracking

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
			○	○	○		○			

Ageing

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○	○	○	○	○	○

Corrugations

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
		○	○				○	○	○	

Faulting at bridge joint

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
		○	○	○	○		○	○	○	

Faulting at soft soil areas

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○		○		○	○	○	○

Aggregate stripping

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○		○		○	○	○	

Fatigue cracking

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○	○	○	○	○	○

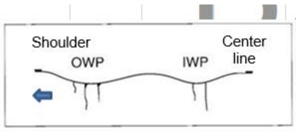
APPENDIX B SURFACE DISTRESS: CONCRETE PAVEMENTS

Source: NEXCO documents based on FHWA (2014)

Abrasion or ravelling by studded tyre

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
			○				○		○	○

Longitudinal cracking



AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○			○	○		○

Transverse cracking

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○		○	○		○

Punchout

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
		○	○	○	○		○	○	○	

Joint loss/joint spalling

AU	BN	ID	JP	KR	MY	NZ	PH	SG	TW	TH
○		○	○	○	○		○	○	○	○

Faulting