NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

ANNUAL SUMMARY REPORT

P69: Selection and Use of Unbound Granular Pavements with Thin Asphalt Surfacing (2018/19)

ARRB Project No.: PRP18029

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SUMMARY

In 2017, TMR sponsored a multi-year project under the National Asset Centre of Excellence (NACoE) research program with the aim of improving the understanding and design methodology associated with unbound granular pavements with thin asphalt surfacings (TAS-UB). This report summarises the activities and findings from the Year 2 of the project which include utilising trends of TAS performance as derived from inventory and condition data from ARMIS, an attempt to use data provided by local government organisation and the results from field testing of material properties of performing TAS segments.

Findings from the analysis and investigation include:

- TAS-UB pavements have primarily been used for routes with ESA/day-at-year-of-opening of between 300 to 1000 with 5 to 10% HV traffic proportion.
- Reducing the number of ESA/day-at-year-of-opening bin by combining category A and B (combined total length of approximately 126 km) will not impact how the performance of TAS is classified.
- There is a well-defined trend that TAS on cement stabilised bases perform better than the unbound granular base at higher traffic capacity bins.
- Based on the percentage of segments performing beyond their design life, OGA followed by SMA are performing better than DGA.
- No obvious relationship between low stiffness and fatigue cracking can be observed from the data.
- The granular base curvature is generally higher for all traffic volumes than the cement stabilised materials and the proportion of curvatures lower than 150 decreases as traffic volume increases, which may indicate use of higher quality unbound granular materials.
- No notable differences in material properties were observed between the test sites for any of the ESA/day at opening values, ranging from approximately 420-900 ESAs. Notably, this only included one test site with HV proportions exceeding 10%.
- Site 3, where a sprayed sealed is sandwiched between two thin asphalt applications and a very good waterproofing surfacing might contribute to the unexpectedly good performance despite of a low CBR value.
- There appears to be no correlation between the strength of the underlying layers and the curvature results obtained from ARMIS. A very weak negative correlation was observed.
- Other factors considered to be contributing the performance of TAS are adequate drainage and waterproofing, typically found in urban residential setting of kerb-to-kerb surfacing.
- The small sample size of material properties of known performing sites limits any substantial relationship to be drawn
- The data from Logan City Council and the result of the back calculation of TSD deflection were not used in analysis.

The following scope is therefore recommended to be undertaken in Year 3:

- Further investigation should be made to explore potential use of the combination of ESA at the time of crack initiation and curvature/maximum deflection to establish a relationship.
- Explore the needs to acquire more data points needed to establish a relationship between base type and TAS pavement performance e.g. more testing to include both performing and non-performing sites.
- The above may include laboratory testing of unbound granular materials in the Accelerated Loading Facility (ALF) to provide a better understanding of TAS-UB performance in-situ.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 BACKGROUND

In 2017, TMR sponsored a multi-year project under the National Asset Centre of Excellence (NACoE) research program with the aim of improving the understanding and design methodology associated with unbound granular pavements with thin asphalt surfacings (TAS-UB). The first year of the project, was documented in *P69: Selection and Use of Unbound Granular Pavements with Thin Asphalt Surfacing (2017/2018)* (Noya & Coomer 2019).

1.2 YEAR 1 SUMMARY

Year 1 of the project provides a summary of the literature review on relevant studies and national and international design practices:

- In some countries (South Africa and parts of Europe), TAS is not designed for fatigue but only for rutting. Fatigue cracking is tolerable provided that a sufficient maintenance regime is in place. A study around the life cycle cost of TAS in Australia is required to check the viability of this option. This project can provide the initial step in that direction by identifying in-service TAS and include them in NACOE's long-term pavement performance (LTPP) project.
- For application in an urban area, Europe is more concerned about the safety and amenity than surface cracking. Thus, their research was focused more on optimising skid resistance and noise reduction properties in the asphalt mix.
- Only studies in WA provide a clear evidence of in-service performing section that outlast the estimated fatigue life. It validated the expectation that TAS on unbound pavement can work given a high subgrade strength of more than CBR 10.
- A good quality, stiff unbound pavement is important to ensure adequate support the TAS. Ensuring adequate compaction have been addressed by TMR. An anecdotal comment from a study in Iceland suggests that a better unbound performance can be achieved by splitting the layer into two different grading, with a coarser grading as a sub-base. More investigation is needed in this area before potentially including it as one of the test configurations when setting up an APT test bed in a later stage of the project.
- The boundary condition for using TAS is expressed in terms of stiffness in New Zealand. This should be explored to review the current TMR provision for designing TAS as part of Year 2 scope

It was recommended that Year 2 tasks expand the in-service performance evaluation and conduct geotechnical testing by coring to confirm the make-up material and the back-calculated unbound layer strength to further refine the draft guide to TAS-UB pavement suggested in Year 1 (Table 1.1).

Table 1.1: Draft guide to TAS-UB composition

ESA/day at opening	Base options	Surfacing options[1,2,3]
< 50	Type 2.1 Type 3.1	AC10M(C320) AC14M(C320) SMA10, SMA14 Crumb rubber gap graded4
50 to 100	Type 2.1* Type 3.1* *And, minimum compaction standard of 102.0%[5]	AC10M(C320) AC14M(C320) SMA10, SMA14 Crumb rubber gap graded4

100 to 300	Type 1 (HSG) Type 2.1* Type 3.1* Lightly bound base *And, minimum compaction standard of 102.0%[5]	AC10M(A15E), AC10H(A15E) AC14M(A15E), AC14H(A15E) SMA10, SMA14 Crumb rubber gap graded4
300 to 1000	Type 1 (HSG) Type 2.1* Type 3.1* Lightly bound base *And, minimum compaction standard of 102.0%[5]	AC10M(A15E), AC10H(A15E) AC14M(A15E), AC14H(A15E) SMA10, SMA14 Crumb rubber gap graded[4]
1000 to 3000[6]	Lightly bound base	AC14M(A15E), AC14H(A15E) SMA14 Crumb rubber gap graded4
>3000	Pavement type not typically suitable	

Notes

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

1.3 YEAR 2 APPROACH

The recommendations from Year 1 to be carried out in the second year was accomplished through the following approach:

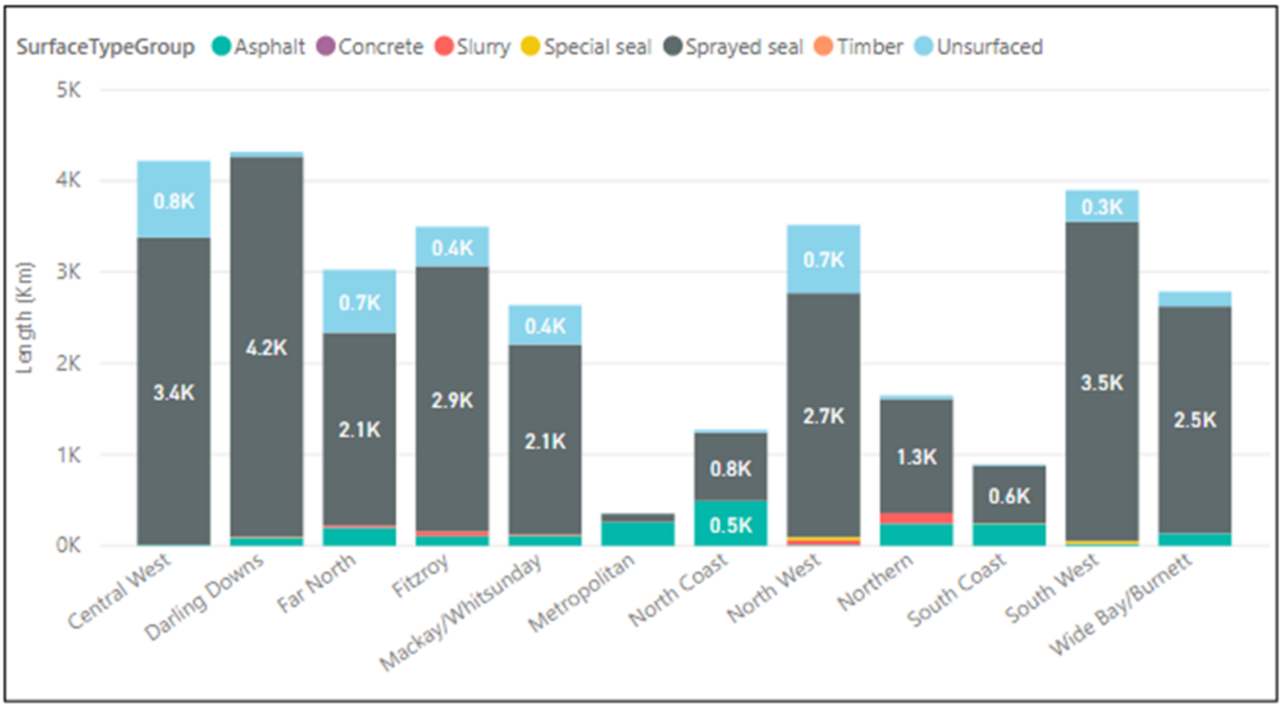
- Understand the in-service performance of all unbound granular pavements with thin asphalt surfacings within the TMR network for a range of geographical locations, pavement materials and traffic compositions drawing from inventory and condition data from ARMIS and Logan City Council – Section 2.
- Conduct field testing for the selected sites to accurately determine pavement layer and condition information to establish links between design parameters and pavement performance – Section 3.
- Document findings and recommendations based on the project outcomes – Section 4.

2 EVALUATING IN-SERVICE PERFORMANCE

2.1 NETWORK OVERVIEW

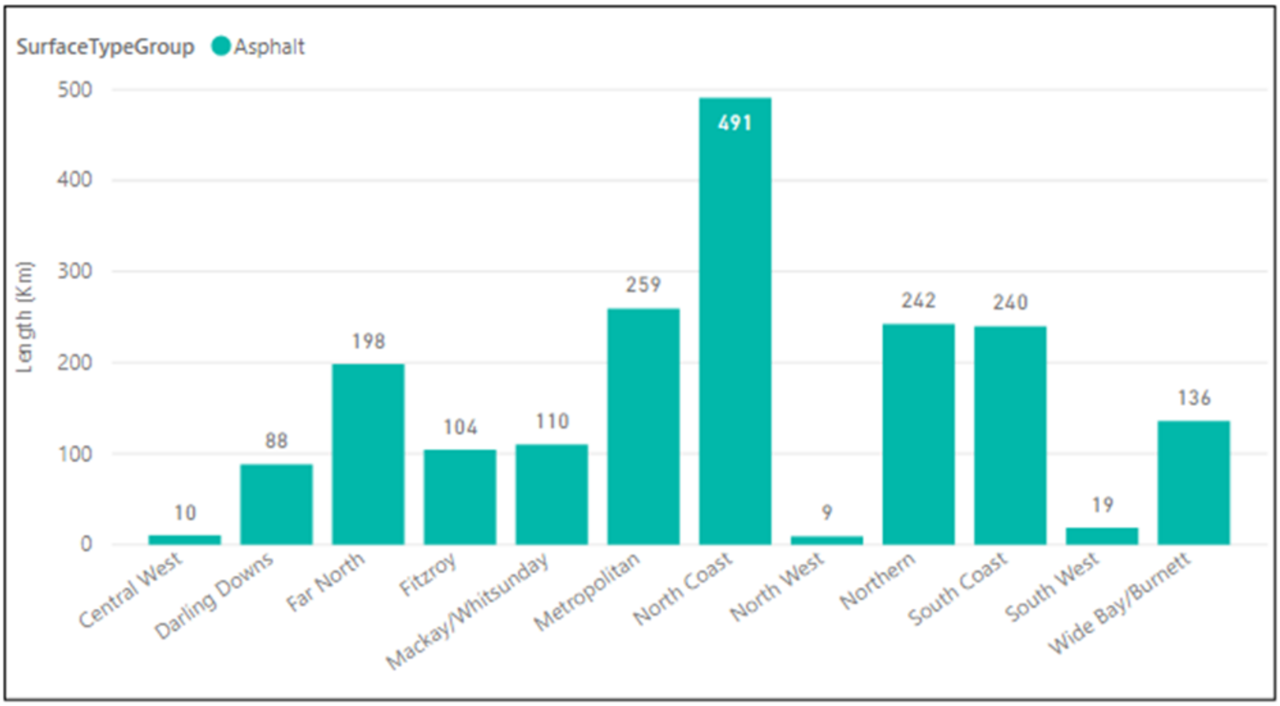
The state-controlled network of Queensland is made up of various pavement types managed by TMR covering approximately 35 000 km of total road, both sealed and unsealed roads. This is primarily sprayed seals surfacings (77%), asphalt surfacings (10%) and unsealed roads (13%). Figure 2.1 provides a detail proportion of surface type in each TMR district. Notably, the highest proportion of asphalt usage is in the urban centres of Queensland e.g. Metropolitan Brisbane, the North Coast (Sunshine Coast) and the South Coast (Gold Coast).

Figure 2.1 Surface type vs. district name by segment length



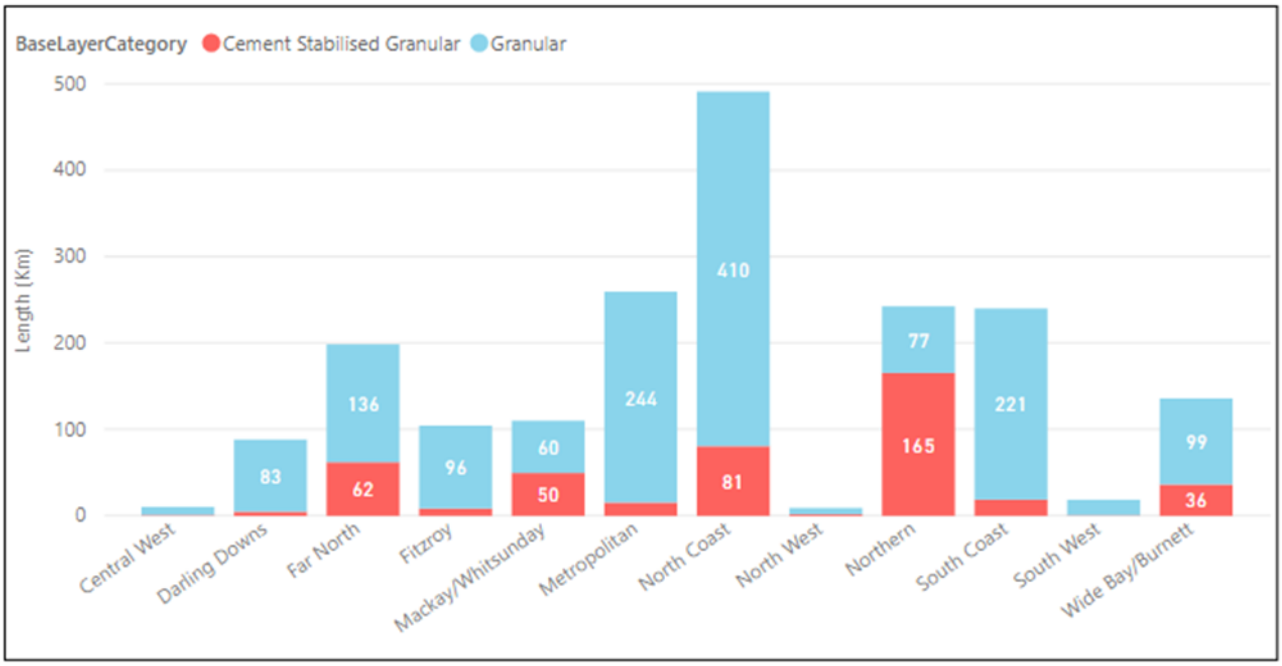
Furthermore, the thin asphalt surfacing (TAS) covers approximately 55% (1900 km) of total of the total asphalt surfaced network. The prevalence of TAS by district is displayed graphically in Figure 2.2 showing that North Coast district has the highest proportion of TAS of almost 500 Km in length followed by the Metropolitan Brisbane, Northern and South Coast of approximately 250 Km in each of the district.

Figure 2.2 Thin asphalt surfacing by District



The supporting basecourse types of the TAS used in Queensland include granular, asphalt, cement stabilised granular, and bitumen stabilised granular. The extent of the network comprising a thin asphalt surfacing with unbound granular base (TAS-UB) or cement stabilised bound base (TAS-B) is shown in Figure 2.3. Majority of TAS-UB pavement was found in North Coast followed by Metropolitan then South Coast districts with the Northern district was found to be the district with the highest TAS-B pavement proportion.

Figure 2.3 Thin asphalt surfacing with unbound or bound base by District



2.2 TAS-UB PERFORMANCE – EVALUATION PARAMETERS

A database of condition of all the TAS segments within TMR network was established and analysed including the roughness, rutting, cracking and deflection data. The data was sourced from ARMIS, TMR's data repository system, for pavements comprised of asphalt surfacing with layer less than or equal to 70 mm in thickness.

The TAS in-situ pavement composition and condition data were used to identify performing and non-performing segments with respect to traffic loading. Traffic loading was expressed in the form of equivalent standard axle (ESA) loading per day at opening and was calculated using Equation 1.

$$ESA/day_{opening} = \frac{ESA/day}{(1 + 0.01 * HV)^{age_{seal}}} \quad (1)$$

where

$ESA/day_{opening}$	=	ESAs per day at surface opening
ESA/day	=	ESAs per day
HV	=	heavy vehicle (HV) annual growth rate (assumed) (%)
age_{seal}	=	seal age

The performance criteria adopted for the project is the combination of performance due to crack initiation and the traffic carrying expectation against the design life as follow:

- Non-performing – an observed crack initiation was used as a surrogate to fatigue life with those with more than 7% of crocodile cracking deemed as 'Non-performing' segments.
- Performing as intended – are segments with no cracking observed but is yet to exceed their intended design traffic carrying capacity, this is abbreviated as "Perf: ESA<Design" in the charts.
- Performing beyond the design target – are segments which have exceed the design traffic carrying target and are yet to show sign of fatigue, this is referred as "Perf: ESA>Design"

The traffic carrying performance was based upon the comparison of accumulated traffic demand at the time of analysis calculated with Equation 2, against the assumed design traffic life for each type of asphalt surfacing calculated using Equation 3, where the HV annual growth rate was assumed to be 3%.

Accumulated traffic at the time of fatigue (when crack initiated) was also calculated using Equation 4.

$$ESA_{to-date} = (365 * SealAge \quad * ESA/day_{opening}) * (1 + 0.01 * HV)^{age_{seal}} \quad (2)$$

where

$ESA_{to-date}$	=	Demand up to when crack first initiated in ESAs
$SealAge$	=	Seal age at the time of analysis

$$ESA_{design} = (365 * design\ life * ESA/day_{opening}) * (1 + 0.01 * HV)^{design\ life} \quad (3)$$

where

ESA_{design}	=	design ESAs of asphalt surfacing type
$design\ life$	=	assumed design life in years varies by asphalt surfacing type where OGA, DGA and SMA was assumed to be 8, 12 and 15 years, respectively. GGA and asphaltic concrete of unknown type was assumed to be 10 years.

$$ESA_{crk} = (365 * SealAge_{Crk} * ESA/day_{opening}) * (1 + 0.01 * HV)^{age_{seal}} \quad (4)$$

where

ESA_{crk} = Demand up to when crack first initiated in ESAs

$SealAge_{Crk}$ = Year when crack first appear – year of seal

It is important to note the following limitations on the data obtained through ARMIS that impacts the analysis including:

- Availability of cracking data – a time-series data was used from 2014 to 2018 to identify the first appearance of crack by looking for cracking extent of more than 7% in any year when there was no cracking observed in the previous year. Whilst the project team can comfortably identify the year when cracking first initiated between 2015 and 2018, there is no way to ascertain that cracking of more than 7% in 2014 was in fact first initiated in that year.

  In other words, the 'Non-performing' classification includes segments which have been performing to their intended design life but cracked sometimes before 2014.
- Base material properties are limited to unbound or various stabilisation options, the unbound granular type (Type 2, Type 3 etc.) was not specified.
- Surfacing mix types were not available, including nominal mix size or binder type.

Every 100 m of TAS segment is classified into analysis parameter bins in Table 2.1.

Table 2.1: Analysis parameter bins and project performance criteria

Parameter bins						
ESA/day at opening	**Seal age (years)**	**Base type**	**Surfacing type**	**Curvature data (2018)**	**Performance based on Cracking**	**Project Performance Criteria**
<50	0-5	Granular	DGA	<150	Performing (<7% cracking)	Non-performing seal.
50-100	5-10	Cement stabilised granular	SMA	150-180	Non-performing (>= 7% cracking)	Performing with ESAto-date < ESAdesign life (Perf: ESA<Design)
100-300	10-15		OGA	>180		Performing with ESAto-date > ESAdesign life (Perf: ESA>Design)
300-1000	>15		GGA			
1000-3000			Asphalt (unknown type)			
>3000						

2.3 PERFORMANCE ANALYSIS RESULT

From the total length of the entire TAS network of approximately 1900 km, 1450 km is of unbound granular base and 450 km cement stabilised base materials. The performance of this subnetwork was analysed by utilising Microsoft Power BI to visualise various performance trends.

The aim is to identify any relevant trends that may guide the selection of TAS-UB pavements. Being the key parameter in design, as a starting point, the traffic carrying bin (ESA/day-at-year-of-opening) follows those proposed in the initial matrix for designing TAS-UB in Table 1.1. The visualisation of observing performance based on the above analysis parameters is design to answer the following exploratory questions to refine the initial design:

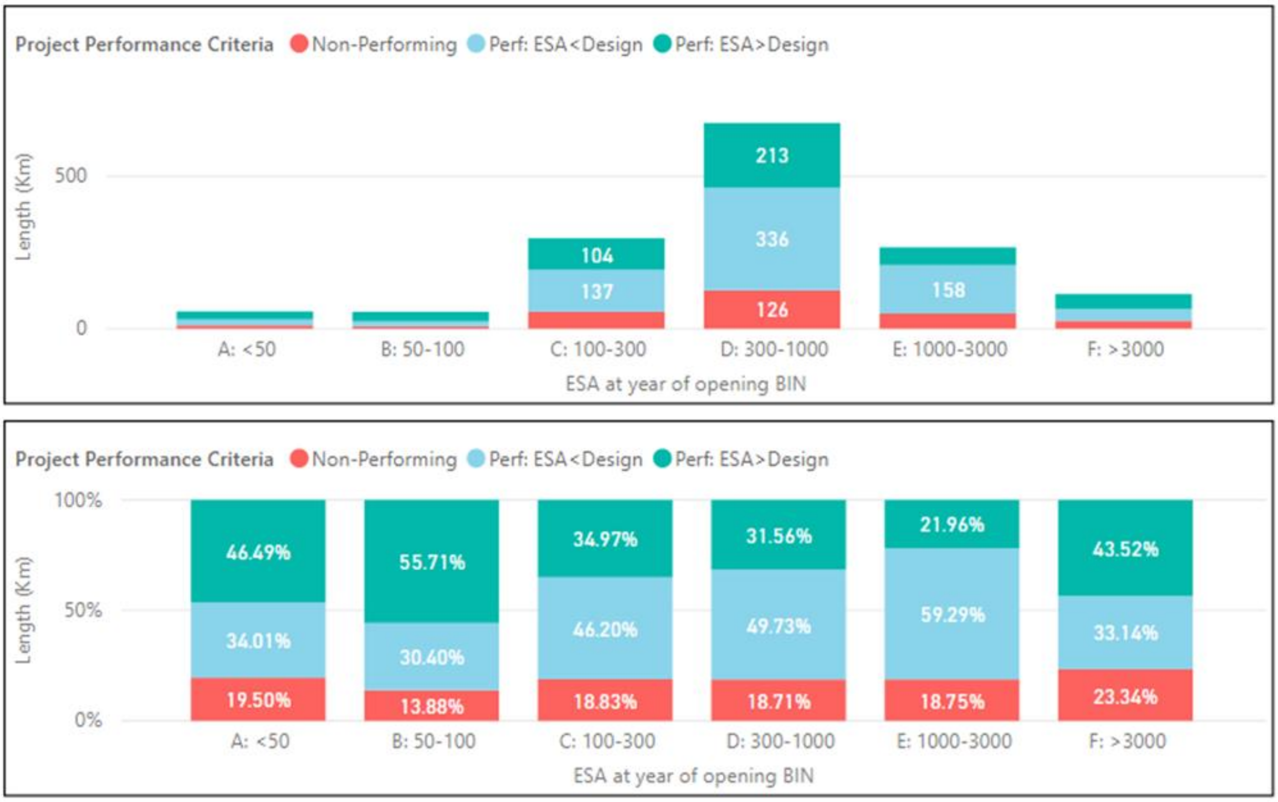
- Is the number and the range of the traffic carrying bins represent the needs based on TAS distribution around the network?

- Is the lower (<50) and upper ends (>3000) of the traffic carrying bin correct?
- Based on performance criteria, can the following be determined:
  - When lightly bound base is preferred
  - Varying quality of unbound base have any impact on performance
  - Performance of various asphalt surfacing options
- Can deflection data be utilised as part of the matrix?

2.3.1 PERFORMANCE BY TRAFFIC CARRYING CAPACITY

Figure 2.4 presents the distribution of the traffic carrying bins with the performance of the pavements by segment length.

Figure 2.4 ESA/day opening vs. performance by segment length and percentage



There are six bins initially proposed with majority of the TAS falls within three categories that ranges between 100 to 3000 ESA/day-at-year-of-opening. The percentage of non-performing segments are consistently low across all traffic carrying category at around 19% overall.

A large percentage of the performing TAS is still within the intended design traffic expectation (Perf: ESA<Design), 48% overall. A moderate percentage of segments which performing beyond their design life (Perf: ESA>Design) is also observed at around 33% overall.

Comments:

- Reducing the number of ESA/day-at-year-of-opening bin by combining category A and B (combined total length of approximately 126 km) will not impact how the performance of TAS is classified.
- There is still a significant length of over 156 km of road with ESA/day-at-year-of-opening of greater than 3000 and therefore recommend leaving this bin as is.

2.3.2 UNBOUND VS (LIGHTLY) BOUND

It appears that the classification of stabilised base in ARMIS includes the distinction between cement stabilised and modified layer. However, the accuracy on how this information is recorded is questionable. For this project, the base is decidedly classified as granular or cement stabilised base only. The performance of TAS classified by base type is provided in Figure 2.5.

Figure 2.5 Base type vs performance by segment length proportions

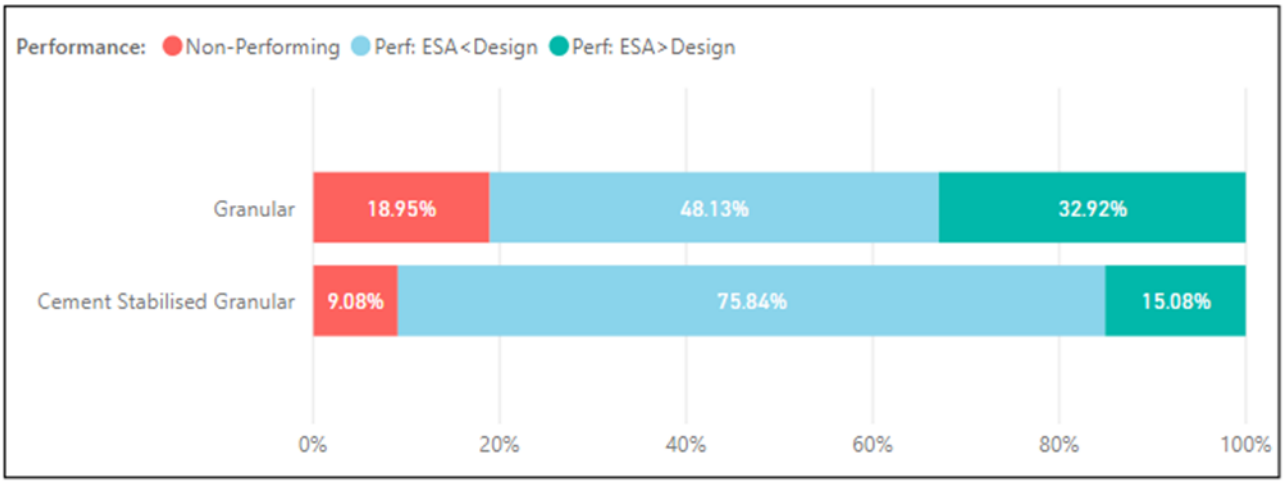
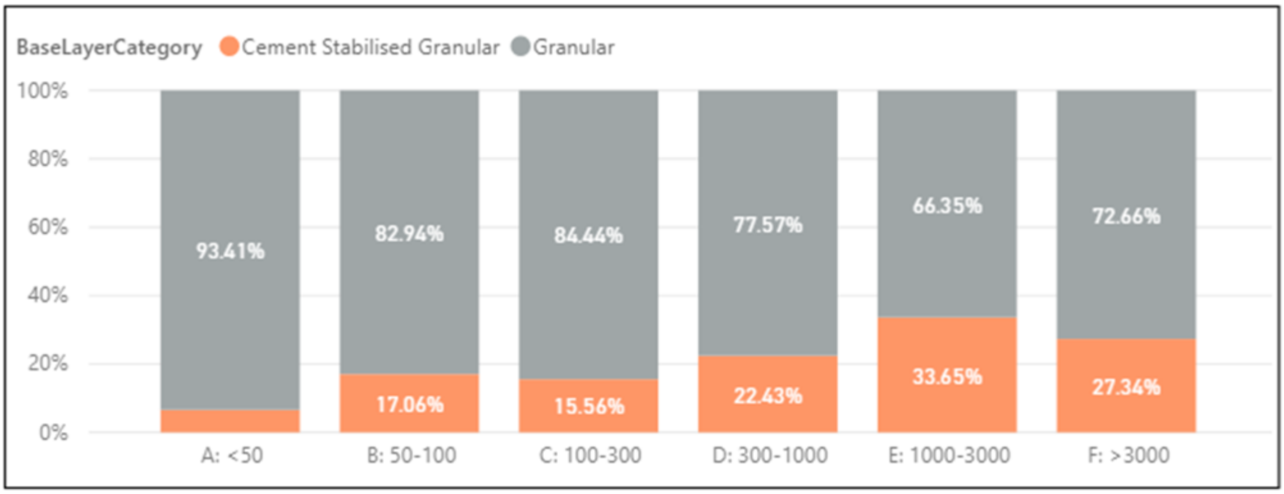


Figure 2.6 provides a distribution TAS base type by the traffic capacity category. The use of cement stabilised base is more prevalent as the traffic demand increases. A significant use is observed from 300 ESA/day-at-year-of-opening onwards with additional jump of 11% more use of cement stabilised base at 1000 ESA/day-at-year-of-opening.

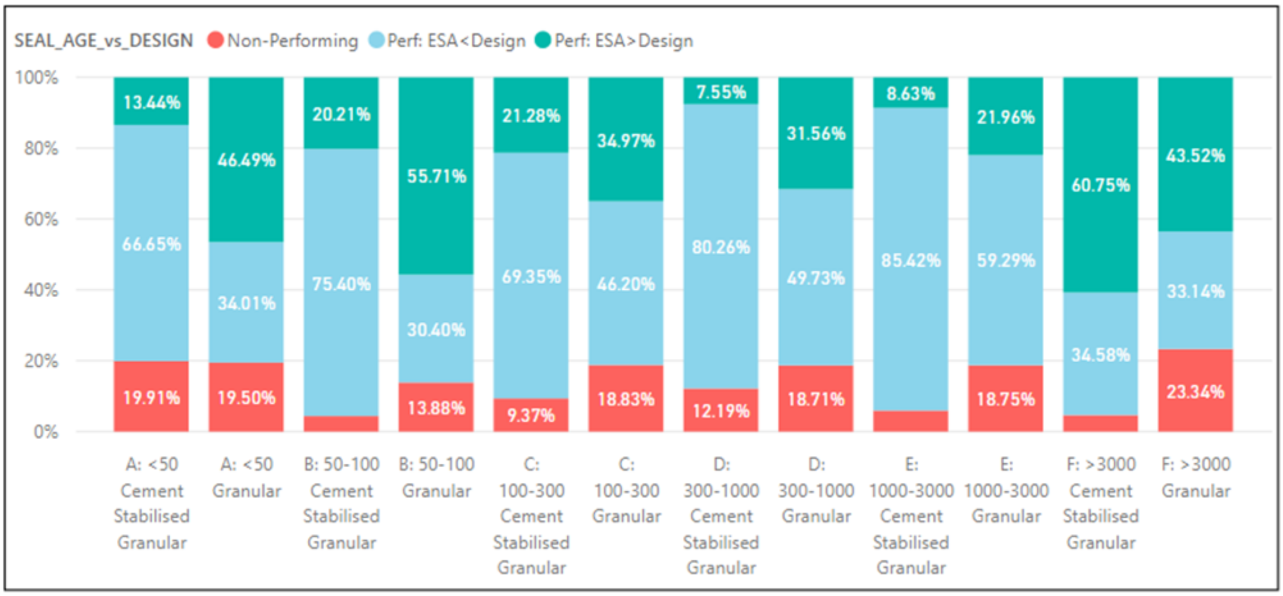
Figure 2.6 Base type used by ESA/day-at-opening-year group



It should be noted that the use of granular base at high end of traffic carrying category is still relatively high at around 70% of TAS.

As the traffic carrying demand increases the performance of pavement with the cement stabilised base improves as indicated by decreasing percentage of the non-performing section. The performance of granular base is consistent throughout all the traffic carrying bins at around 18% shown in Figure 2.7.

Figure 2.7 Base type in each ESA bin vs performance by segment length proportions



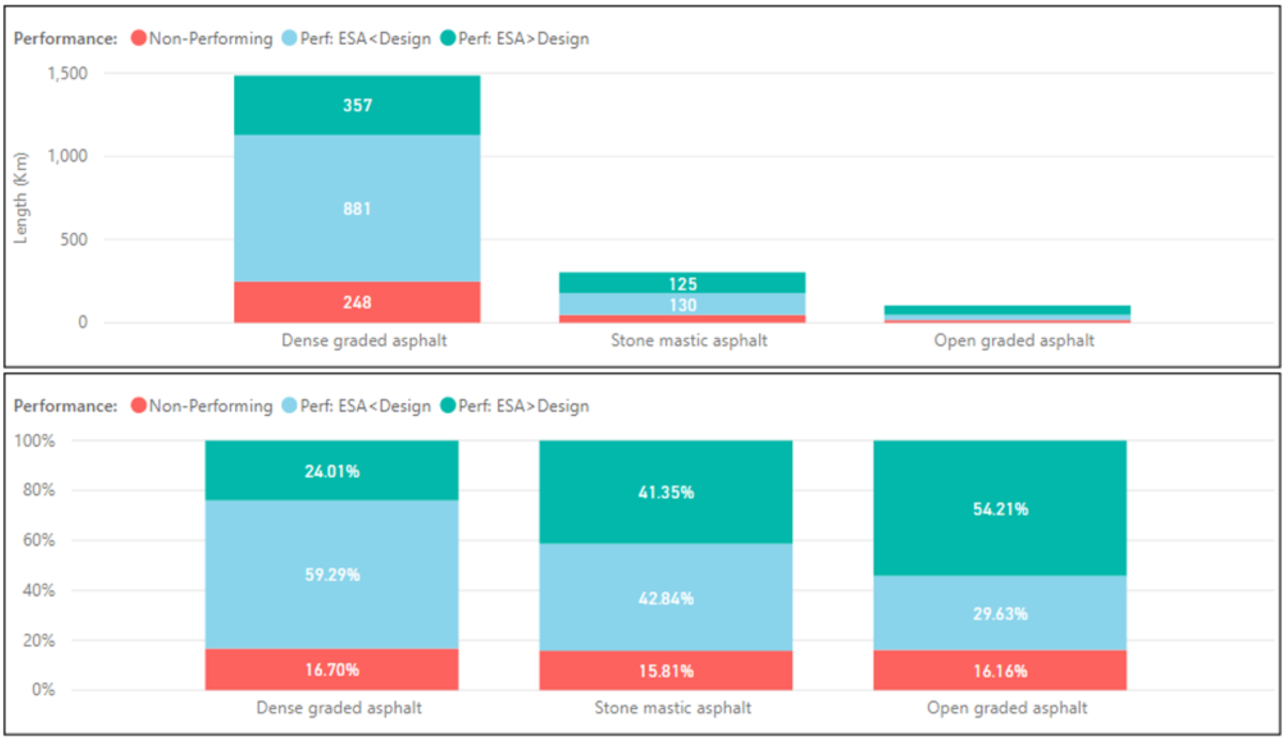
Comments:

- The data visualisation shows indication of effectiveness of having a stiffer base in cement stabilised material. A much lower percentage of non-performing segments of no more than 12% is observed at 300 – 1000 ESA/day and is significantly reduced to less than 6% above 1000 ESA/day.
- Not having the information such as the type of granular material or whether the cement stabilised material is bound or lightly bound limits the team from making a more conclusive findings based on data.
- At the highest end of traffic carrying category, category F, there is a high percentage of cement stabilised section performing beyond their intended design life.

2.3.3 SURFACING TYPE

The asphalt surfacing types are categorised into five types, DGA, SMA, OGA, GGA and asphaltic concrete of unknown type. Figure 2.9 presents the performance of the most predominant types of DGA, SMA and OGA.

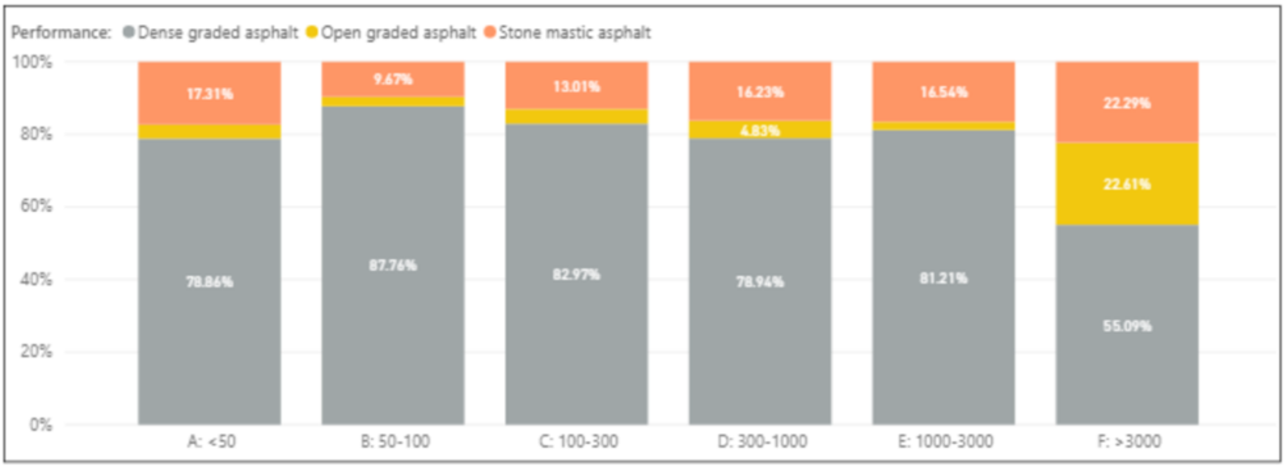
Figure 2.8 Surfacing type vs. performance by segment length



The percentage of non-performing segments is similarly across the three asphalt surfacing types at no more than 17%. The percentage of segments performing beyond their expected design target however is much greater for OGA followed by SMA then DGA.

The usage of SMA increases slightly as the traffic demand increases whilst a significant usage of OGA of more than 20% is observed at the highest traffic carrying bin, category F.

Figure 2.9 Surfacing type vs ESA bin



Comments:

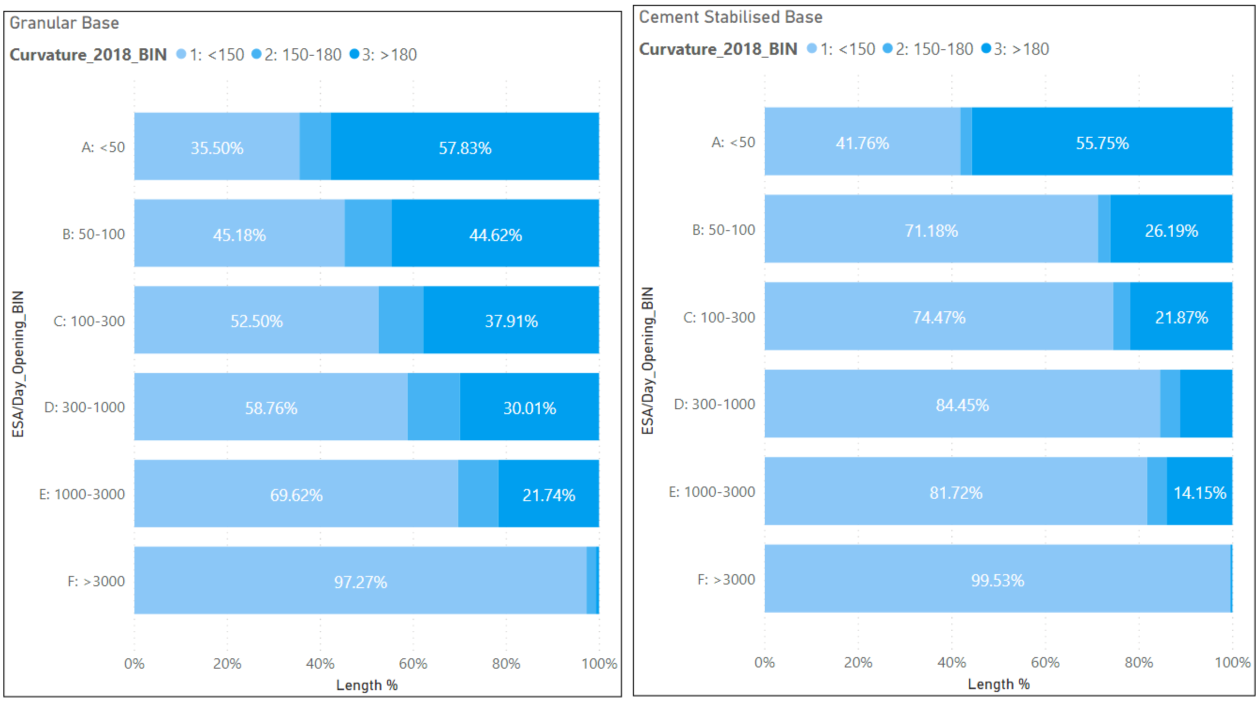
- No conclusive observation can be made based on the non-performing segments as all three asphalt surfacing types show similar percentage.
- Based on the percentage of segments performing beyond their design life, OGA followed by SMA are performing better than DGA.

2.3.4 CURVATURE

Deflection data can provide significant information about the state of the pavement strength, where high values of curvature may indicate low stiffness in the pavement basecourse. Figure 2.10 depicts the

ESA/day-at-opening against the curvature performance by segment length for both granular and cement stabilised bases. The charts confirm the expectation of a more stiffer cement stabilised base compared to granular base by observing the change in percentage of segments with curvature greater than 180 µm in each traffic carrying bins. It shows that granular base curvature is generally higher than the cement stabilised materials. For both base types, the pavement is stiffer with an increase of traffic carrying demand. This reflects both the performance as well as the result of the usage of higher quality materials at higher traffic level.

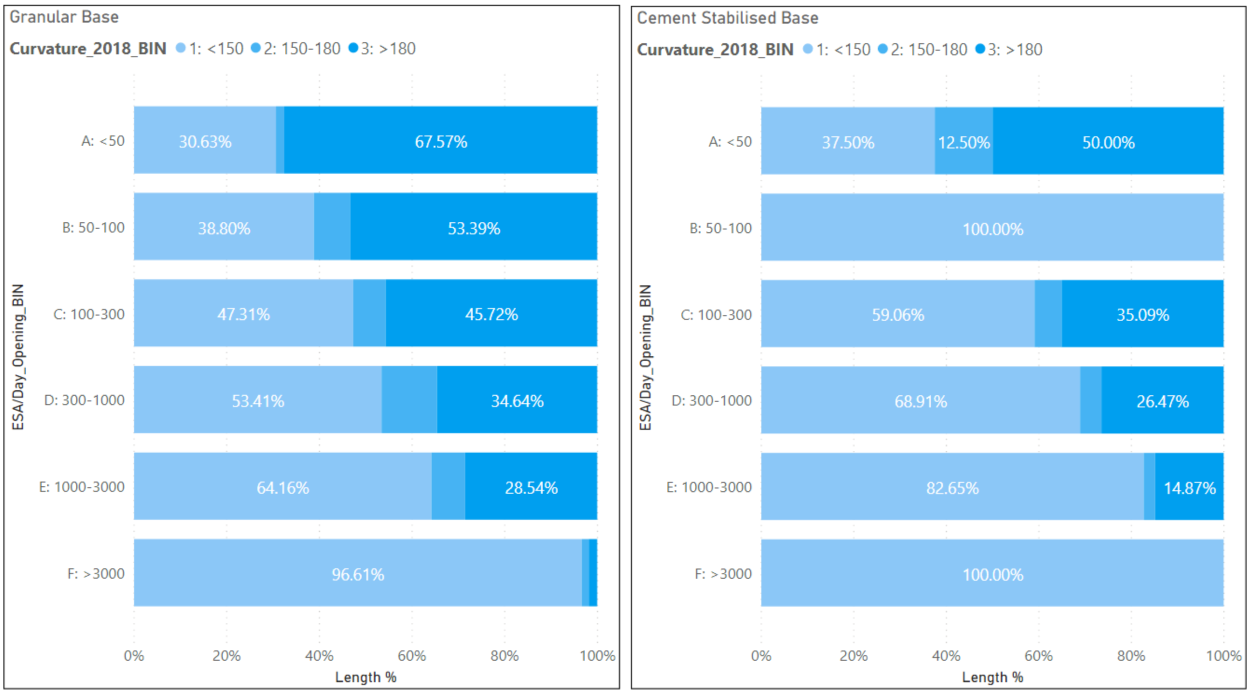
Figure 2.10 Curvature distribution (granular, left and cement stabilised, right)



It is important to note that curvature greater than 180 µm does not necessarily correlate to the definition of a non-performing segments adopted for this project as performance is based on percentage cracking rather than base stiffness. This is demonstrated by comparing the non-performing segment lengths of granular and cement stabilised bases and observing the percentage of stiffer base of less than 150 µm as shown in Figure 2.12.

A high percentage (of more than 50%) of segments with stiffer base, curvature of less than 150 µm, is observed from ESA/day-at-opening of 100 or more regardless of the base type. If there is a discernible trend between curvature and cracking performance, this proportion is expected to be much lower.

Figure 2.11: Non-performing segments of curvature distribution by base type (granular, left and cement stabilised, right)



Comments:

- Cement stabilised base does provide a stiffer pavement, however, high percentage of pavement with granular base are also showing similar level of base stiffness. This is likely due to higher quality of granular material specified for higher order road.
- Using the numbers as they are, there is no obvious relationship between low stiffness and fatigue cracking. However, further investigation should be made to explore potential use of the combination of ESA at the time of crack initiation and curvature/maximum deflection to establish a relationship.

2.4 LOGAN CITY COUNCIL DATA

2.4.1 DATABASE RELEVANCY

Data obtained from the test pits on TMR-controlled roads was supplemented by geotechnical investigation and network inventory and condition data supplied by the Logan City Council. However, as local government-controlled roads are typically required to withstand lower design traffic loadings than state-controlled roads, this data was filtered to exclude base materials that do not conform to the requirements for Type 2 or Type 3 materials in accordance with MRTS05 Unbound Pavements (TMR 2018). The requirements for Type 2 materials are summarised in Table 2.2. The highest and lowest values of each property were used as filters, noting that these upper and lower limits are also applicable to Type 3 materials.

Table 2.2: TMR Type 2 property requirements

Property	Subtype				
	2.1	2.2	2.3	2.4	2.5
Liquid limit, max (%)	25	25	28	35	40
Plasticity index, max (%)	6	6	8	12	14
Linear shrinkage, max (%)	3.5	3.5	4.5	6.5	7.5
CBR soaked, min (MPa)	80	60	45	35	15

Source: TMR (2018).

2.4.2 EVALUATION PARAMETERS

The Logan City Council (LoCC) data was obtained in November 2018 and was used to evaluate the in-service performance of thin asphalt pavements. Once the Type 2 and Type 3 compliant materials were identified the database was further refined to pavements with asphalt surfacing layers less than 70 mm thick. These pavements were analysed using the parameter bins summarised in Table 2.3.

Table 2.3: Analysis parameter bins

Parameter bins					
ESA/day at opening	**Surface age (years)**	**Base type**	**Surfacing type**	**Condition data (2016-2018)**	**Project Performance Criteria**
<50.	0-5.	Granular	Asphalt (unknown type	Roughness.	Performing (<7% cracking).
50-100.	5-10.			Rutting.	Non-performing (>7% cracking).
100-300.	10-15.			Crocodile cracking.	
300-1000.	>15.			All cracking.	
1000-3000.					
>3000					

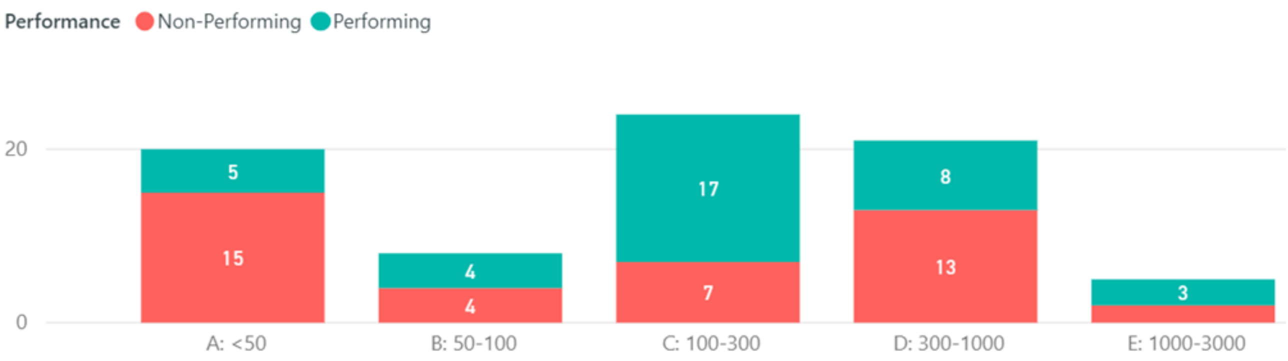
It is important to note that there were several limitations on the data obtained from LoCC which did not allow the same analysis as undertaken in Section 2.2, including:

- Segment lengths were not available.
- HV traffic proportions were not available.
- Pavement condition data was often incomplete or did not go back as far as the surfacing age. It was not always possible to determine what year the extent of cracking exhibited in the surface would cause the pavement to be deemed non-performing or whether the asphalt surfacing had failed before or after reaching the design ESA.
- Base material properties were not available.
- Surfacing mix types were not available, including nominal mix size or binder type.

2.4.3 PERFORMANCE OBSERVATION

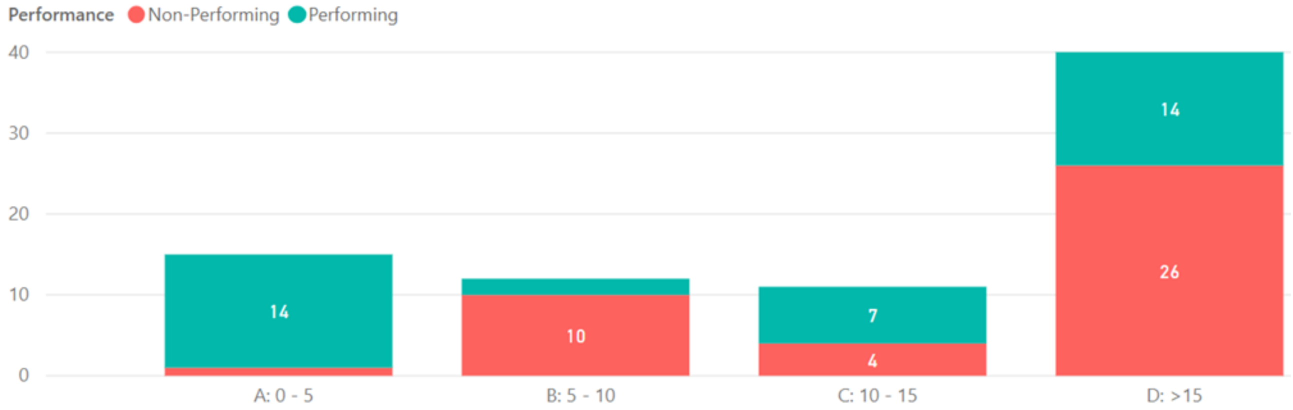
The Logan City Council (LoCC) database contains 60 segments of TAS-UB that complied to the Type 2 and Type 3 TMR material requirements. Figure 2.12 presents a comparison of the performance of these segments grouped by the ESA/day at opening.

Figure 2.12 ESA/day opening vs. performance by number of segments



A comparison of the surface age and performance by the number of segment is presented in Figure 2.13, showing that the seals aged 5-10 years and older than 15 years have the highest proportion of non-performing pavements.

Figure 2.13 Seal age vs. performance by number of segments



Comments:

- Due to limited information received, the project team decided to not use the trend or indication of trend from this dataset.

3 PAVEMENT INVESTIGATIONS

3.1 OVERVIEW

One of the limitations of the ARMIS data obtained from TMR is that the material properties of the granular basecourse for each of the segments was not available and is a key parameter that impacts the performance of TAS-UB pavements. In an effort to characterise the material properties of unbound granular basecourse materials at sites that have been performing for more than 10 years, a pavement investigation was undertaken at the following locations:

1. Oxley Dr, mid-block between Brisbane Rd to Harbour Town Dr, northbound carriageway (Chainage 13-13.8 km).
2. Redland Bay Rd, mid-block between Windemere Rd and Vienna Rd intersection, southbound carriageway (Chainage 3-3.81 km).
3. Redland Bay Rd, mid-block between Princess St and Bay St, southbound carriageway (Chainage 1-2.7 km).
4. Bribie Island Rd, mid-block between Beames Rd and Aylward Rd, northbound carriageway (Chainage 8.5-10 km).
5. Bribie Island Rd, mid-block between Regina Av and Ruby Av, northbound carriageway (Chainage 12.6-13.6 km).
6. South Pine Rd, mid-block between Leitchs Rd and Scouts Crossing Rd intersection, westbound carriageway (Chainage 5.9-6.5 km).

The characteristic of each site against the analysis parameters outlined in Table 2.1 is provided in Table 3.1 where a number of ESA/day-at-year-of-opening bins within the range of 300-1000 were targeted.

Table 3.1: Test site analysis parameters from ARMIS

Site No (Road ID)	Parameter						
	ESA/day at opening bin (ESA of site)	%HV traffic	Surface age bin (Age of site)	Base type	Surfacing type	Curvature bin (Curvature of site)	Project Performance Criteria
Site 1 (114)	300-1000 (420)	<5%	10-15 (12)	Granular	DGA	<150 (118)	Performing (seal ESA < design ESA)
Site 2 (1102)	300-1000 (700)	10-20%	10-15 (14)	Granular	SMA	<150 (97)	Performing (seal ESA < design ESA)
Site 3 (109)	100-300 (250)	<5%	10-15 (15)	Granular	SMA	<150 (149)	Performing (seal ESA < design ESA)
Site 4 (126)	300-1000 (600)	5-10%	>15 (20)	Granular	SMA	>180 (295)	Performing (seal ESA > design ESA)
Site 5 (125)	300-1000 (600)	<5%	>15 (18)	Granular	SMA	<150 (130)	Performing (seal ESA > design ESA)
Site 6 (403)	300-1000 (900)	5-10%	>15 (18)	Granular	DGA	<150 (5)	Performing (seal ESA > design ESA)

The pavement investigation at the selected test sites were then subject to the following TMR test methods for material property characterisation:

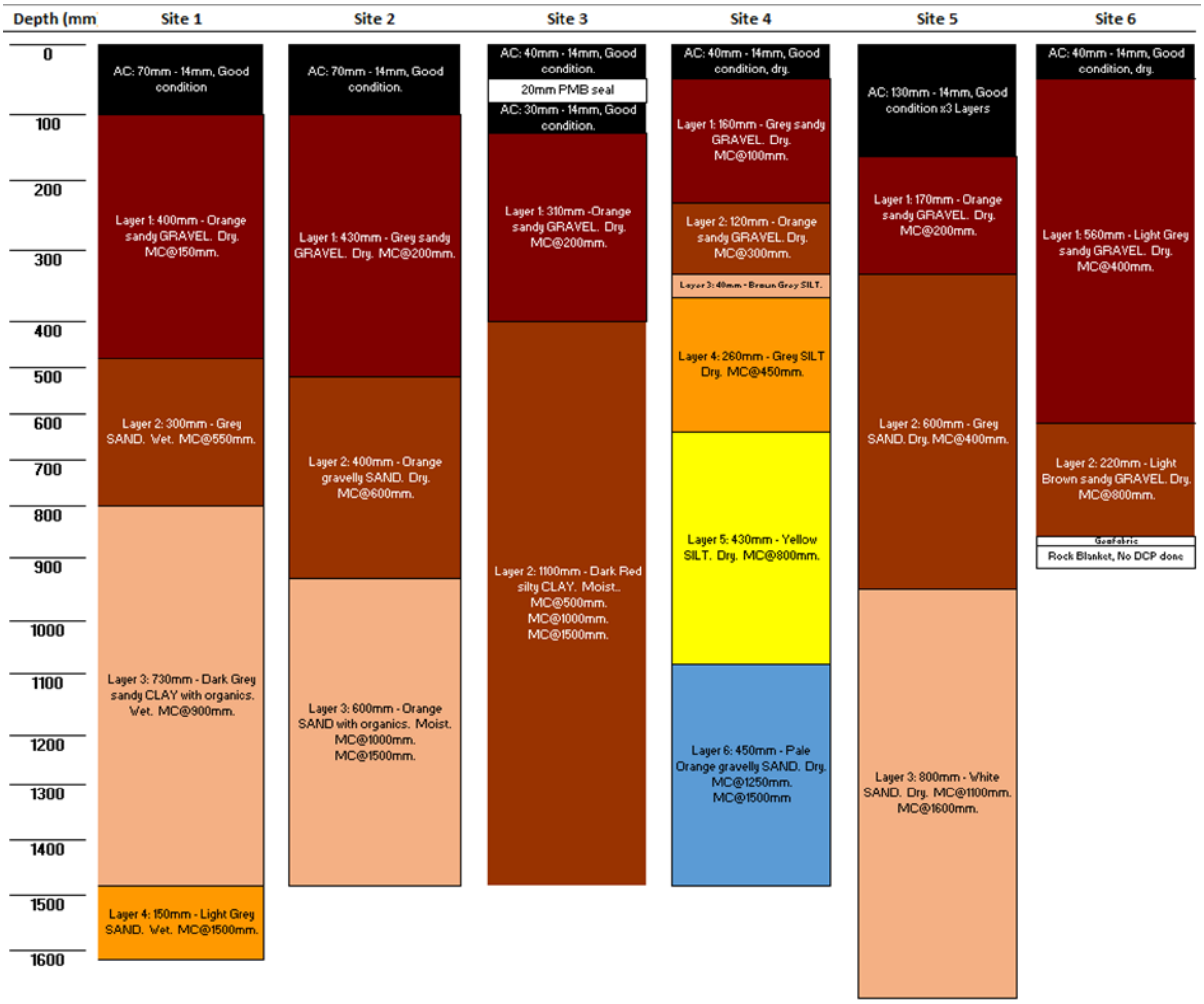
- Q102A: Moisture content (field in situ layer moistures and dynamic cone penetrometer (DCP) moisture correlation for in situ CBR values).
- Q114B: DCP 1.5 m in depth from subgrade level.
- Q103A, Q104A, Q105, Q106: Materials properties classification.
- Q142A: Moisture-density relation for maximum dry density (MDD) and optimum moisture content (OMC).
- Q113C: CBR single point, 4-day swell tests
- Q303B: Asphalt coring.
- Q308A: Bitumen content and grading by solvent method.

3.2 TEST RESULTS

3.2.1 ASPHALT AND GRANULAR LAYERS THICKNESS

The detailed results for the pavement investigation tests for each site are presented in Appendix A for both the granular materials and the asphalt cores. Summary of layer thicknesses for each site is provided in Figure 3.1.

Figure 3.1 Sites test pit thickness summary



Site 1 and 2 have 70 mm of asphalt surfacing, which falls under the category of TAS for this project but may not be a single layer asphalt when placed, another definition when designing for TAS. This also applies to Site 3, which has two asphalt layers separated by a sprayed seal layer.

Site 5 is not a TAS as shown in the core sample photos in Figure 3.2 and only Site 4 (shown in Figure 3.3) and 6 have a single layer of asphalt surfacing.

Figure 3.2 Asphalt core sample photos of Site 5 – Bribie Island Road 2

Figure 3.3 Asphalt core sample photos of Site 4 – Bribie Island Road 1

None of the base layers was found to have cement content confirming all the basecourses are unbound granular material.

3.2.2 UNBOUND GRANULAR MATERIAL PROPERTY

The TMR Type 2 property requirements are summarised in Table 3.2 and the properties of the layer immediately below the asphalt layer are presented in Table 3.3.

Table 3.2: TMR Type 2 property requirements

Property	Subtype				
	2.1	2.2	2.3	2.4	2.5
Liquid limit, max (%)	25	25	28	35	40

Property	Subtype				
	2.1	2.2	2.3	2.4	2.5
Plasticity index, max (%)	6	6	8	12	14
Linear shrinkage, max (%)	3.5	3.5	4.5	6.5	7.5
CBR soaked, min (MPa)	80	60	45	35	15
Fines ratio	0.30-0.55	0.30-0.65	0.30-0.65	–	–

Source: TMR (2018).

Table 3.3: Material properties summary of sites

Property	Layer 1 properties					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Liquid limit (%)	19.0	19.6	25.4	23.6	19.0	21.8
Plasticity index (%)	6.4	4.4	12.0	5.4	3.0	4.8
Linear shrinkage (%)	2.6	3.2	6.6	3.0	–	2.6
Fines ratio	0.58	0.44	0.67	0.55	0.28	0.58
CBR soaked	130	70	11	55	70	80
Compliant with TMR unbound property requirements	Type 2.1	Type 2.2	NC	Type 2.3	Type 2.2*	Type 2.2
Compliant with TMR grading requirements	C*	C	NC-C	C	NC-C	C
Compliant with TMR asphalt PSD requirements	14 mm DGA	14 mm SMA	14 mm DGA	14 mm SMA	14 mm DGA	14 mm DGA

**Note: marginally non-compliant based on relatively small sample size.*
NC-C = non-compliant with C-grading.

The Particle Size Distribution (PSD) of Layer 1 of all sites, apart from Site 5, complied to the TMR C-grading in accordance with MRTS05 Unbound Pavements (TMR 2018). Furthermore, the soaked CBR results indicate that Site 1 and Site 6 may be classified as Type 2.1 materials, and Site 2 and Site 5 as Type 2.2 materials. Site 3 does not comply with minimum CBR requirements nor maximum plasticity index for Type 2 materials.

The soaked CBR results from each of the layers below the asphalt are presented in Table 3.4. It shows that below Layer 1, the CBR is generally low, indicating that although the in-situ subgrade has relatively low strength the pavement continues to perform.

It is interesting to note that the base layer (Layer 1) at Site 3 is showing a low CBR of 11 but has been performing all this year with no sign of extensive patching, see Figure 3.4. Further investigation into this specific site for contributing factor might be warranted.

Table 3.4: Soaked CBR by site/layer test results summary

Layer	Soaked CBR value					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1	130	70	11	55	70	80

Layer	Soaked CBR value					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
2	20	15	10	30	30	15
3	17	8	–	13	20	–
4	25	–	–	30	–	–
5	–	–	–	18	–	–
6	–	–	–	15	–	–

It is important to note that due to the age of the investigated sites, PSD non-conformances and low soaked CBR values may have been caused by material breakdown in-service. As such, these results may not reflect the material quality or properties when initially constructed.

3.2.3 ASPHALT SURFACING MATERIAL PROPERTY

The asphalt PSD of each site indicated that Site 1, Site 3, Site 5 and Site 6 are 14 mm DGA whereas Site 2 and Site 4 are 14 mm SMA surfacing in accordance with MRTS30 Asphalt Pavements (TMR 2017). Notably, the data sourced from ARMIS indicated that Site 2 and Site 5 were surfaced by SMA.

3.3 BACK-CALCULATION OF MODULUS

To back-calculate the layer moduli from deflections, a linear elastic analysis program, EFROMD3 was utilised with the most recent Traffic Speed Deflectometer (TSD) deflection measurements. Back-calculation of modulus was undertaken using the layer thicknesses determined from the test pits in addition to other construction considerations such as material type, subgrade thickness, embankment data and subsurface conditions. However, the thin asphalt pavements exhibited highly nonlinear subgrade behaviour. This caused back-calculation analyses to yield results with superficially high subgrade stiffness modulus and extremely low stiffness modulus at the road base layer. As outlined by Chai et al. (2016), this is described as an inverted pavement, resulting in errors and incorrect modelling of the pavement responses. Chai et al (2016) also states that current deflection-based models over predict the subgrade CBR and models were found not to be suitable for sprayed seal and thin asphalt pavements that exhibit highly non-linear subgrade behaviour.

The current deflection-based models were developed using the FWD deflections. The research in correlating TSD and FWD results have shown that only the first 300 mm of the deflection bowl correlates relatively good, with weak to no correlation established from middle to the tail end of the bowl.

Based on the reasons outlined above, the back-calculation modulus analyses were not included in this report.

3.4 OTHER FACTORS INFLUENCING PERFORMANCE

Having an adequate drainage is a key component in ensuring the design life of any pavement is achieved. All sites were observed to have good drainage, with those located in urban residential or urban industrial areas provided with kerb and channel as shown in Figure 3.4.

Stiffness of the supporting unbound base is determined by compaction adequacy as well as the material quality. There is no data on level of compaction at construction stage for any of these sites. To ensure a maximum base stiffness, a minimum compaction standard of 102 % of the unbound layer is recommended.

Figure 3.4: Street level view of Site 3 – Redland Bay Road 2

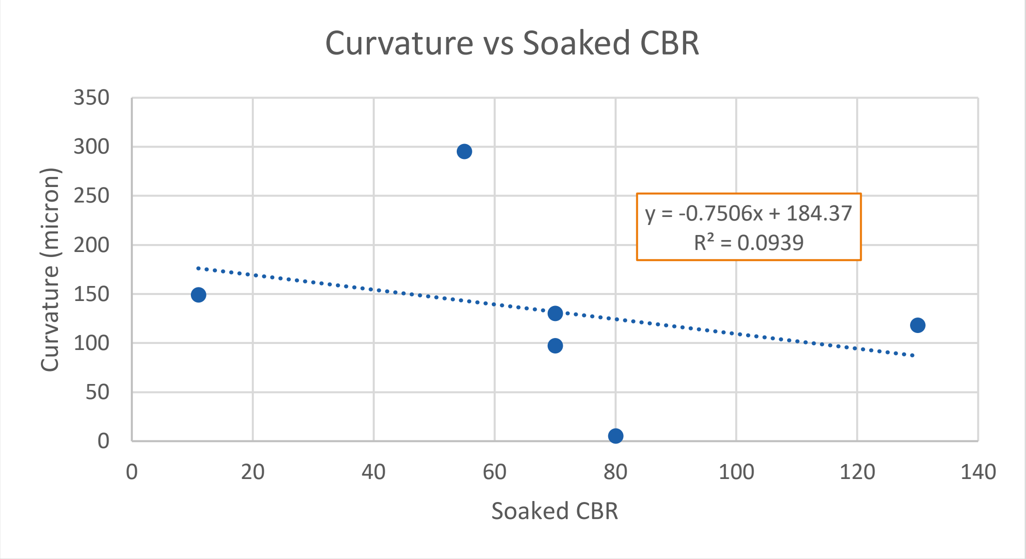
3.5 DISCUSSION

The results of the pavement investigations indicate that the material properties of the unbound granular basecourse of sites that have been performing for more than 10 years generally conform to the TMR Type 2 property requirements and C grading in accordance with MRTS05.

Findings from the test pits include:

- Site 5 is not a TAS and should therefore be excluded from further reference for analysis or consideration.
- Site 1, 2 and 3 have a calculated $ESA_{to\text{-}date}$ that is less than $ESA_{design\ life}$, no greater than 15 years old with varying proportions of HV traffic, and curvature.
- Site 3 is still performing despite a low basecourse CBR value. At this stage, low percentage of heavy vehicle and good waterproofing from having been sealed from kerb-to-kerb might be the advantage. Having a sprayed seal layer sandwiched between two thin asphalt applications might also contribute to the unexpectedly good performance.
- Site 4, 5 and 6 have a calculated $ESA_{to\text{-}date}$ that is more than $ESA_{design\ life}$. These sites ranged from 600-900 ESAs/day at opening with basecourses comprised of materials complying to Type 2.2 and Type 2.3 requirements. However, it is notable that the HV proportions did not exceed 10%.
- There appears to be no correlation between the strength of the underlying layers and the curvature results obtained from ARMIS. A very weak negative correlation was observed when soaked CBR and curvature was plotted shown in Figure 3.5. This might improve with a larger sample size.

Figure 3.5: Curvature vs CBR plot



- No notable differences in material properties were observed between the test sites for any of the ESA/day-at-year-of-opening ranging from approximately 420-900 ESAs. This indicates that Type 2.1, Type 2.2 and Type 2.3 materials may be used for ESA/day-at-year-of-opening bins of 300-1000. This may include the use of 14 mm SMA or DGA surfacings.
- The small sample size of material properties of known performing sites limits any substantial relationship to be drawn. Further testing from more sites, both performing and non-performing sites may be required to ascertain the relationship between the evaluation parameters and material properties.

The project team is considering the potential benefit that the performance of TAS-UB pavements might have from being under traffic for long periods of time, which would increase the compaction and thus, strength of the underlying granular layers. At this point however, it is not easy to distinguish between brownfield and greenfield sites from ARMIS data. When this issue can be resolved, comparing performance of brownfield and greenfield sites of TAS-UB should be explored.

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The second year of this project aimed at further developing design guidance on the selection and use of TAS-UB pavements by evaluating TMR condition data, conducting field testing for selected sites and assessing relevant pavement investigations from the LoCC. Findings from the analysis and investigation include:

- TAS-UB pavements have primarily been used for routes with ESA/day-at-year-of-opening of between 300 to 1000 with 5 to 10% HV traffic proportion.
- Reducing the number of ESA/day-at-year-of-opening bin by combining category A and B (combined total length of approximately 126 km) will not impact how the performance of TAS is classified.
- There is a well-defined trend that TAS on cement stabilised bases perform better than the unbound granular base at higher traffic capacity bins.
- Based on the percentage of segments performing beyond their design life, OGA followed by SMA are performing better than DGA.
- No obvious relationship between low stiffness and fatigue cracking can be observed from the data.
- The granular base curvature is generally higher for all traffic volumes than the cement stabilised materials and the proportion of curvatures lower than 150 decreases as traffic volume increases, which may indicate use of higher quality unbound granular materials.
- No notable differences in material properties were observed between the test sites for any of the ESA/day at opening values, ranging from approximately 420-900 ESAs. Notably, this only included one test site with HV proportions exceeding 10%.
- Site 3, where a sprayed sealed is sandwiched between two thin asphalt applications and a very good waterproofing surfacing might contribute to the unexpectedly good performance despite of a low CBR value.
- There appears to be no correlation between the strength of the underlying layers and the curvature results obtained from ARMIS. A very weak negative correlation was observed.
- Other factors considered to be contributing the performance of TAS are adequate drainage and waterproofing, typically found in urban residential setting of kerb-to-kerb surfacing.
- The small sample size of material properties of known performing sites limits any substantial relationship to be drawn
- The data from Logan City Council and the result of the back calculation of TSD deflection were not used in analysis.

Therefore, based on the Year 2 findings it is recommended that:

- Further investigation should be made to explore potential use of the combination of ESA at the time of crack initiation and curvature/maximum deflection to establish a relationship.
- Explore the needs to acquire more data points needed to establish a relationship between base type and TAS pavement performance e.g. more testing to include both performing and non-performing sites.
- The above may include laboratory testing of unbound granular materials in the Accelerated Loading Facility (ALF) to provide a better understanding of TAS-UB performance in-situ.

REFERENCES

Chai, G, Manoharan, S, Golding, A, Kelly, G & Chowdhury, SH 2016, 'Evaluation of the traffic speed deflectometer data using simplified deflection model', *Transport Research Procedia*, vol. 14, Elsevier, Amsterdam, Netherlands, pp. 3031-9.

Noya, L & Coomer, J 2019, *P69: Selection and Use of Unbound Granular Pavements with Thin Asphalt Surfacing (2017/2018),* NACOE Annual Report P69, National Asset Centre of Excellence (NACOE), Brisbane, Qld.

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APPENDIX A PAVEMENT INVESTIGATION RESULTS

A.1 SITE 1 – RD 114 OXLEY DR / HARBOUR TOWN DR

Table **Error! No text of specified style in document.** 1: Site 1 classification report

Test method	Material property	Site 1-1	Site 1-2	Site 1-3	Site 1-4
	Layer	Layer 1	Layer 2	Layer 3	Layer 4
	Depth (mm)	70-470	470-770	770-1500	1500-1650+
Particle size distribution (Q103A) (% passing)	53.0	100.0	–	–	–
	37.5	98.0	–	–	–
	26.5	93.2	–	–	–
	19.0	86.6	–	–	–
	9.5	68.6	100.0	100.0	–
	4.75	50.7	99.8	99.3	–
	2.36	35.7	99.6	98.8	100.0
	0.425	14.6	98.8	97.9	98.9
	0.075	8.5	84.8	10.4	7.8
	Dust ratio	0.58	0.86	0.11	0.08
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	19.0	23.6	23.2	23.0
	Plastic index (%)	6.4	0.4	0.6	1.6
	WPI	92.5	44.3	57.0	148.8
	Linear shrinkage (%)	2.6	–	–	–
	Weighted linear shrinkage	36.8	0.0	0.0	0.0
	Material classification	GP - GC orange gravel with sand and clay	ML grey silt with sand	SM dark grey sand with silt	SP pale grey sand with silt
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	6.5	14.5	9.5	13.5
	MDD (t/m³)	2.19	1.69	1.75	1.71
	Target lab moisture ratio (%)	100.0	100.0	100.0	100.0
	Target lab density ratio (%)	100.0	97.0	95.0	95.0
	Comp. MC (%)	6.0	15.3	9.9	13.7
	Lab moisture ratio (%)	93	106	102	103
	Comp. dry density (t/m³)	2.20	1.63	1.65	1.62
	LDR (%)	100.5	96.5	94.5	94.5
	Swell (%)	0.0	-0.1	0.8	0.0
	After pen. top MC (%)	6.1	16.7	15.2	17.7

Test method	Material property	Site 1-1	Site 1-2	Site 1-3	Site 1-4
	Layer	Layer 1	Layer 2	Layer 3	Layer 4
	Depth (mm)	70-470	470-770	770-1500	1500-1650+
	After pen. remainder MC (%)	6.2	17.5	16.8	18.7
	CBR 2.5	90.0	14.0	12.0	25.0
	CBR 5.0	130.0	20.0	17.0	17.0
	CBR	130.0	20.0	17.0	25.0

Table **Error! No text of specified style in document.** 2: Site 1 DCP

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	2.4	1-1	150
500-585	85	35	8.8	1-2	550
585-590	5	>60	–	–	–
–	–	–	8.9	1-3	900
–	–	–	14.4	1-4	1500

Figure **Error! No text of specified style in document.** 1: Site 1 PSD

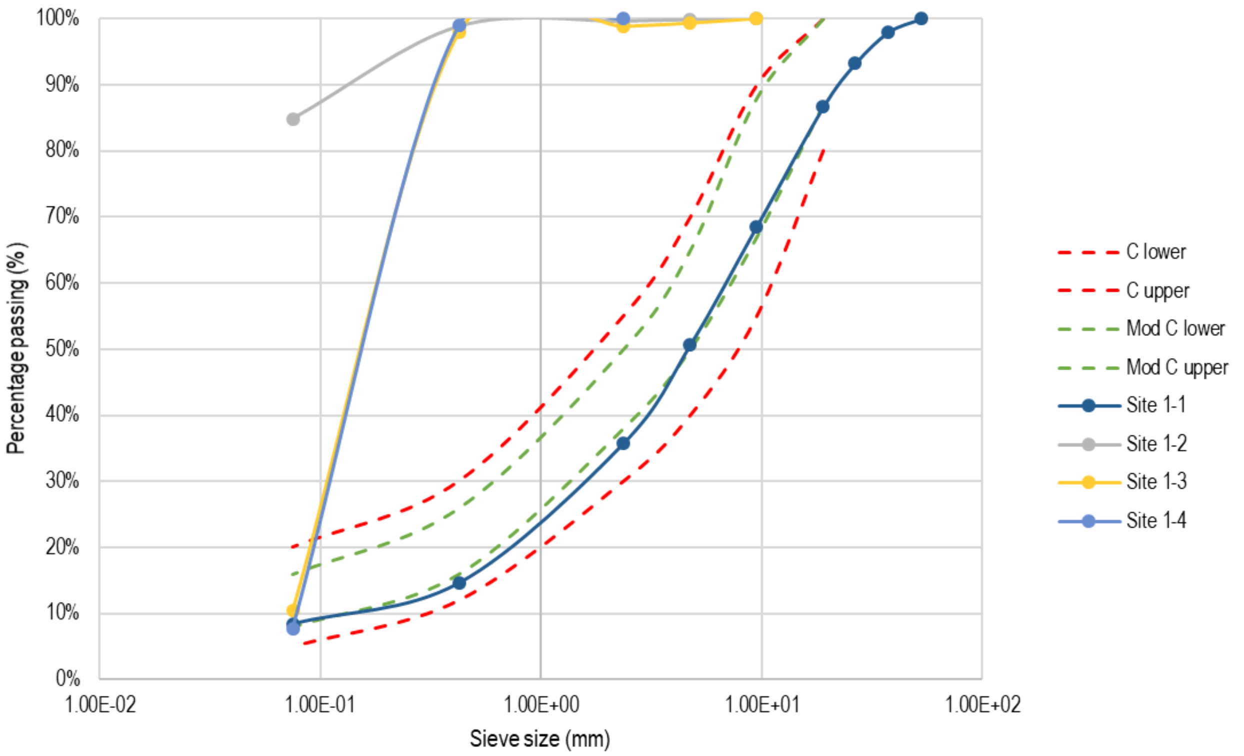
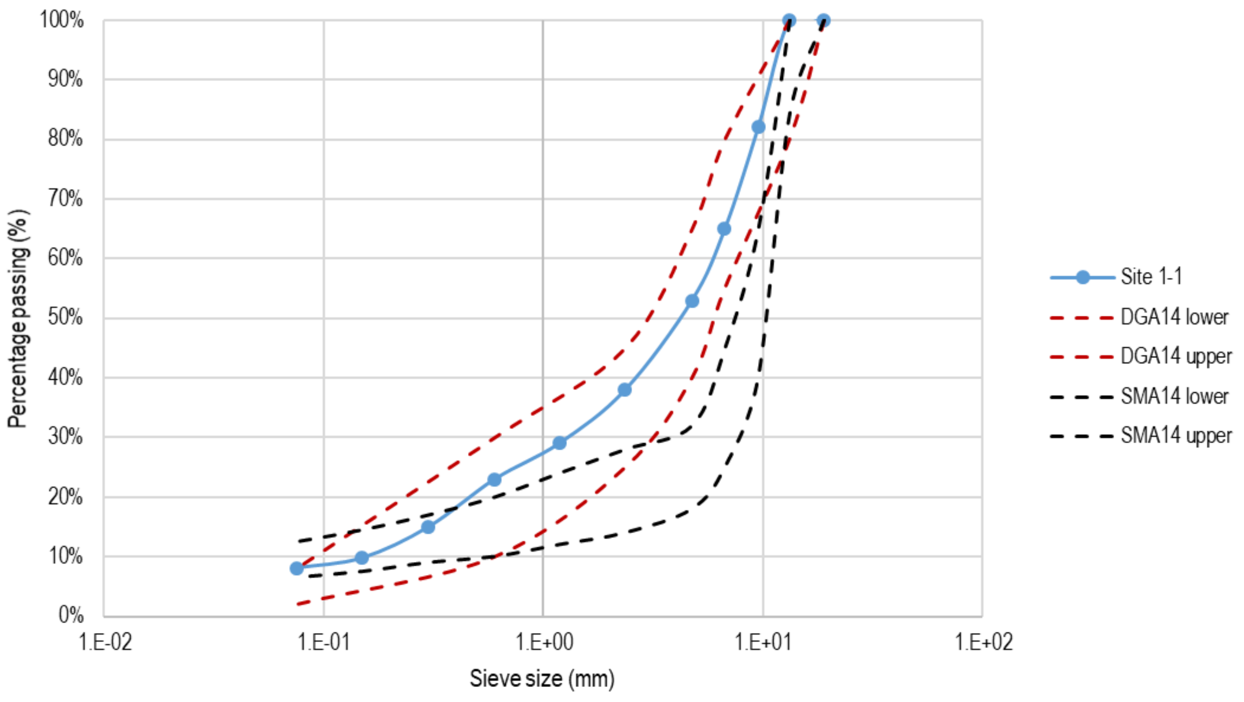


Table **Error! No text of specified style in document.** 3: Site 1 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	4.50
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	100
	9.5	82
	6.7	65
	4.75	53
	2.36	38
	1.18	29
	0.600	23
	0.300	15
	0.150	9.8
	0.075	8.1

Figure **Error! No text of specified style in document.** 2: Site 1 asphalt PSD



A.2 SITE 2 – RD 1102 CAPALABA-VICTORIA POINT RD

Table **Error! No text of specified style in document.** 4: Site 2 classification report

Test method	Material property	Site 2-1	Site 2-2	Site 2-3
	Layer	Layer 1	Layer 2	Layer 3
	Depth (mm)	70-500	500-900	900-1500
Particle size distribution (Q103A) (% passing)	53.0	–	–	–
	37.5	100.0	–	–
	26.5	99.8	–	–
	19.0	98.1	100.0	100.0
	9.5	85.3	98.7	99.9
	4.75	61.1	92.2	99.1
	2.36	45.4	91.6	98.8
	0.425	23.3	60.7	69.5
	0.075	10.3	19.8	30.2
	Dust ratio	0.44	0.33	0.43
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	19.6	19.0	34.0
	Plastic index (%)	4.4	2.0	18.4
	WPI	103.7	121.7	1280.7
	Linear shrinkage (%)	3.2	1.0	8.2
	Weighted linear shrinkage	73.4	56.2	566.1
	Material classification	GM grey sandy gravel with silt	SM orange silty sand with gravel	SC orange clayey sand
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	9.0	9.0	13.0
	MDD (t/m³)	2.19	1.98	1.93
	Target lab moisture ratio (%)	100.0	100.0	100.0
	Target lab density ratio (%)	100.0	97.0	95.0
	Comp. MC (%)	9.6	9.4	12.9
	Lab moisture ratio (%)	107	105	99
	Comp. dry density (t/m³)	2.17	1.91	1.84
	LDR (%)	99.5	96.5	95.0
	Swell (%)	0.7	-0.4	0.2
	After pen. top MC (%)	8.1	10.5	14.2
	After pen. remainder MC (%)	8.1	11.3	13.9
	CBR 2.5	45.0	15.0	8.0
	CBR 5.0	70.0	11.0	7.0
	CBR	70.0	15.0	8.0

Table **Error! No text of specified style in document.** 5: Site 2 DCP

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	3.5	2-1	200
550-665	115	50	8.9	2-2	600
665-690	25	>60	–	–	–
–	–	–	13.1	2-3	1000
–	–	–	17.4	2-4	1500

Figure **Error! No text of specified style in document.** 3: Site 2 PSD

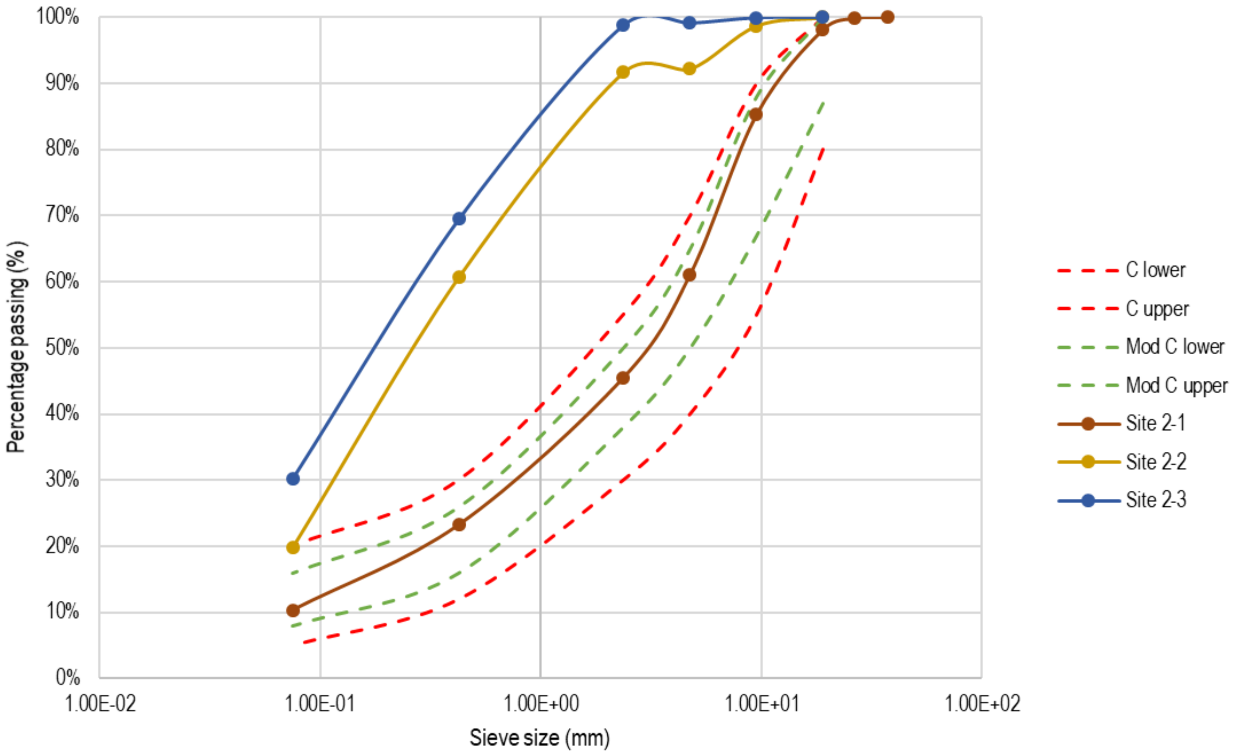
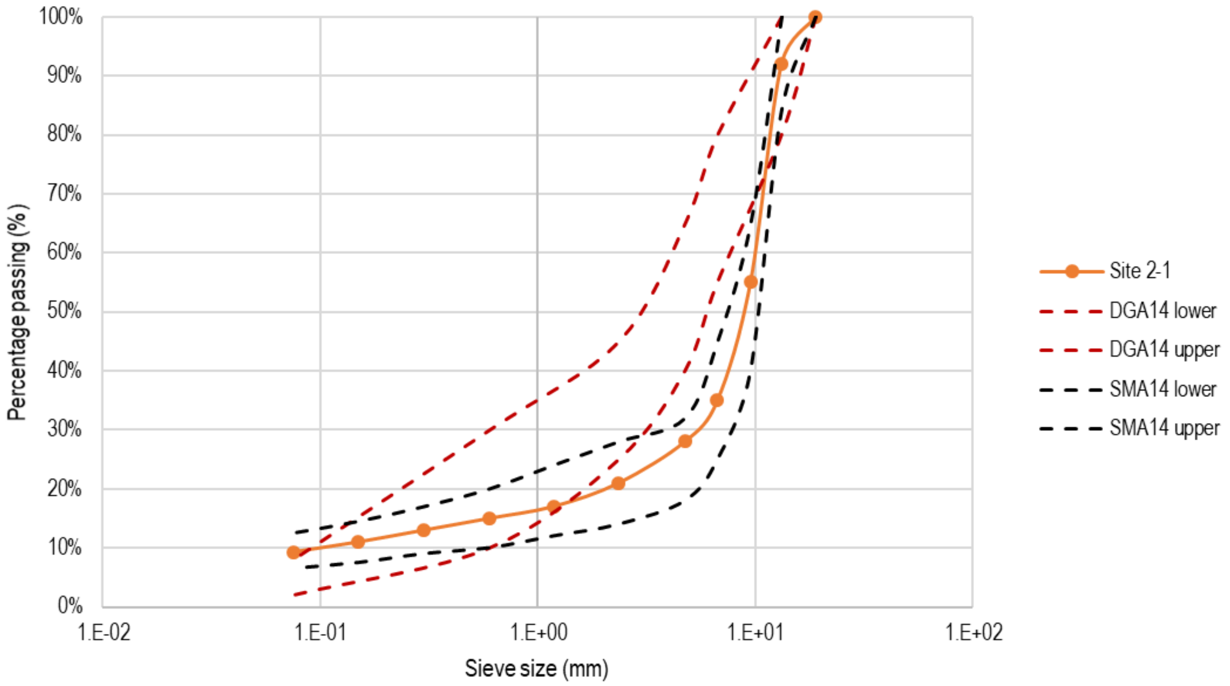


Table **Error! No text of specified style in document.** 6: Site 2 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	6.00
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	92
	9.5	55
	6.7	35
	4.75	28
	2.36	21
	1.18	17
	0.600	15
	0.300	13
	0.150	11
	0.075	9.3

Figure **Error! No text of specified style in document.** 4: Site 2 asphalt PSD



A.3 SITE 3 – RD 1102 BLOOMFIELD ST, CLEVELAND-REDLAND BAY RD

Table **Error! No text of specified style in document.** 7: Site 3 classification report

Test method	Material property	Site 3-1	Site 3-2
	Layer	Layer 1	Layer 2
	Depth (mm)	60-400	400-1500+
Particle size distribution (Q103A) (% passing)	53.0	–	–
	37.5	100.0	–
	26.5	99.5	–
	19.0	90.9	–
	9.5	80.5	100.0
	4.75	63.5	99.5
	2.36	48.3	98.4
	0.425	28.2	95.2
	0.075	18.8	85.3
	Dust ratio	0.67	0.90
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	25.4	53.0
	Plastic index (%)	12.0	30.4
	WPI	339.9	2900.8
	Linear shrinkage (%)	6.6	13.8
	Weighted linear shrinkage	184.8	1309.3
	Material classification	GC orange sandy clayey gravel	CH dark red clay
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	8.0	25.5
	MDD (t/m³)	2.13	1.54
	Target lab moisture ratio (%)	100.0	100.0
	Target lab density ratio (%)	100.0	97.0
	Comp. MC (%)	8.0	25.6
	Lab moisture ratio (%)	98	101
	Comp. dry density (t/m³)	2.14	1.50
	LDR (%)	100.0	97.0
	Swell (%)	-1.1	-0.7
	After pen. top MC (%)	8.4	27.6
	After pen. remainder MC (%)	8.1	27.3
	CBR 2.5	5.0	10.0
	CBR 5.0	11.0	8.0
	CBR	11.0	10.0

Table **Error! No text of specified style in document.** 8: Site 3 DCP

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	4.4	3-1	200
450-660	210	18	24.1	3-2	500
660-1520	860	30	25.7	3-3	1000
–	–	–	25.9	3-4	1500
–	–	–	–	–	–

Figure **Error! No text of specified style in document.** 5: Site 3 PSD

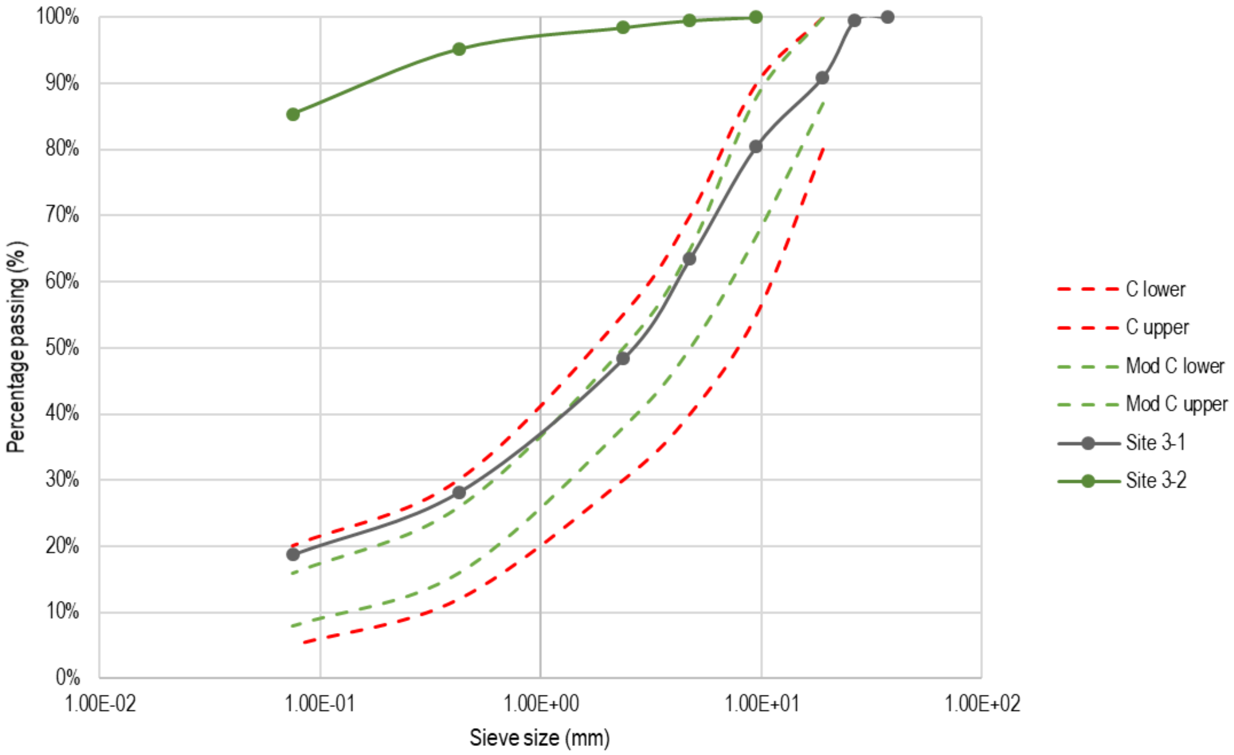
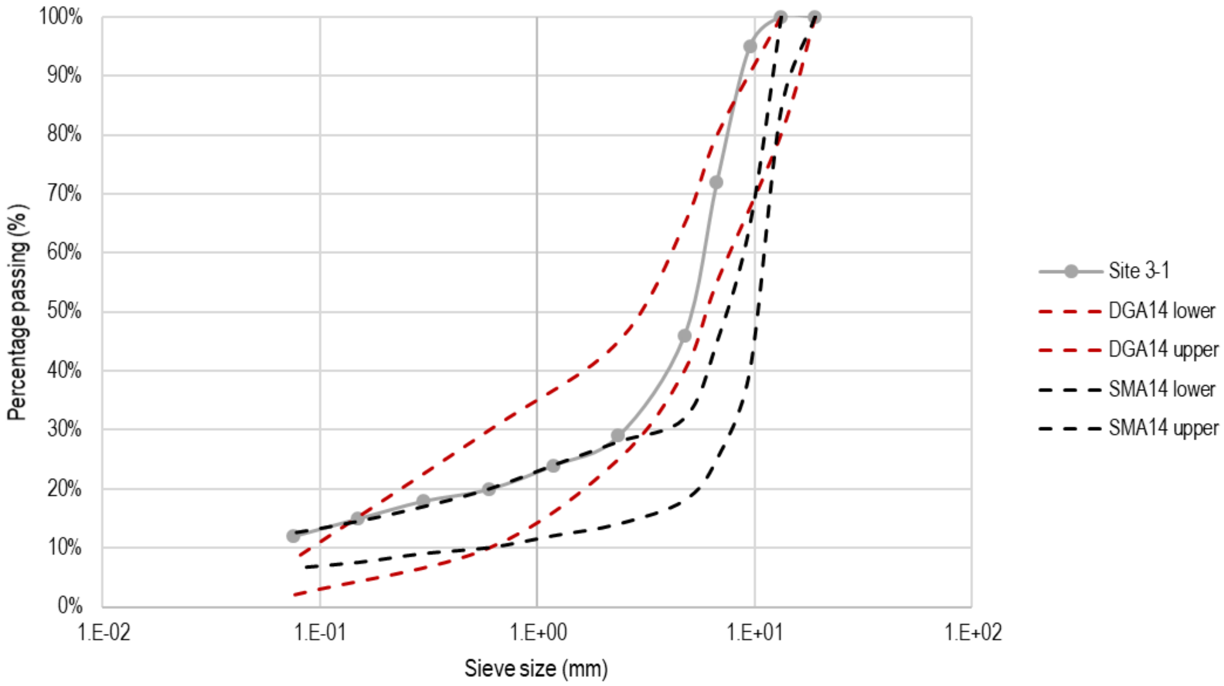


Table **Error! No text of specified style in document.** 9: Site 3 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	5.60
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	100
	9.5	95
	6.7	72
	4.75	46
	2.36	29
	1.18	24
	0.600	20
	0.300	18
	0.150	15
	0.075	12

Figure **Error! No text of specified style in document.** 6: Site 3 asphalt PSD



A.4 SITE 4 – RD 126 BRIBIE ISLAND RD

Table **Error! No text of specified style in document.** 10: Site 4 classification report

Test method	Material property	Site 4-1	Site 4-2	Site 4-3	Site 4-4	Site 4-5	Site 4-6
	Layer	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
	Depth (mm)	40-200	200-320	320-360	360-620	620-1050	1050-1500
Particle size distribution (Q103A) (% passing)	53.0	–	100.0	–	–	–	–
	37.5	–	99.8	100.0	–	–	–
	26.5	–	94.7	99.9	–	–	–
	19.0	100.0	82.9	99.2	–	100.0	100.0
	9.5	72.6	57.2	93.7	100.0	99.8	92.1
	4.75	53.0	40.6	83.6	99.4	99.0	62.8
	2.36	40.7	30.7	80.6	98.8	98.3	56.8
	0.425	21.1	18.4	67.8	88.8	89.7	49.3
	0.075	11.6	7.2	15.9	19.0	25.4	20.7
	Dust ratio	0.55	0.39	0.23	0.21	0.28	0.42
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	23.6	20.0	17.6	18.2	17.8	28.2
	Plastic index (%)	5.4	2.2	0.2	0.6	3.6	15.2
	WPI	114.0	38.9	8.3	48.5	314.9	750.9
	Linear shrinkage (%)	3.0	3.0	0.2	–	2.0	6.4
	Weighted linear shrinkage	61.3	54.8	11.3	0.0	175.9	315.7
	Material classification	GM grey sandy gravel with clayey silt	GP-GM orange sandy gravel with silt	SM brown grey silty sand with gravel	SM grey silty sand	SM yellow silty sand	GC orange sandy clayey gravel
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	7.0	7.5	9.0	10.5	10.0	10.5
	MDD (t/m³)	2.37	2.25	2.00	1.89	1.96	2.11
	Target lab moisture ratio (%)	100.0	100.0	100.0	100.0	100.0	100.0
	Target lab density ratio (%)	100.0	100.0	97.0	97.0	95.0	95.0
	Comp. MC (%)	7.0	7.5	8.7	10.9	9.4	10.5
	Lab moisture ratio (%)	99	98	97	106	94	101
	Comp. dry density (t/m³)	2.38	2.25	1.94	1.82	1.87	2.00
	LDR (%)	100.0	100.0	97.0	96.5	95.5	95.0
	Swell (%)	-0.3	-0.6	0.8	-0.1	-0.6	0.0
	After pen. top MC (%)	7.8	7.8	9.7	11.9	11.0	12.3

Test method	Material property	Site 4-1	Site 4-2	Site 4-3	Site 4-4	Site 4-5	Site 4-6
	After pen. remainder MC (%)	6.8	7.1	10.9	12.6	11.4	11.4
	CBR 2.5	35.0	11.0	10.0	25.0	18.0	14.0
	CBR 5.0	55.0	30.0	13.0	30.0	16.0	15.0
	CBR	55.0	30.0	13.0	30.0	18.0	15.0

Table **Error! No text of specified style in document.** 11: Site 4 DCP

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	5.0	4-1	100
–	–	–	3.9	4-2	300
–	–	–	4.9	4-3	350
410-426	16	>60	–	–	–
–	–	–	4.6	4-4	450
–	–	–	5.4	4-5	800
–	–	–	7.7	4-6	1250
–	–	–	12.6	4-7	1500

Figure **Error! No text of specified style in document.** 7: Site 4 PSD

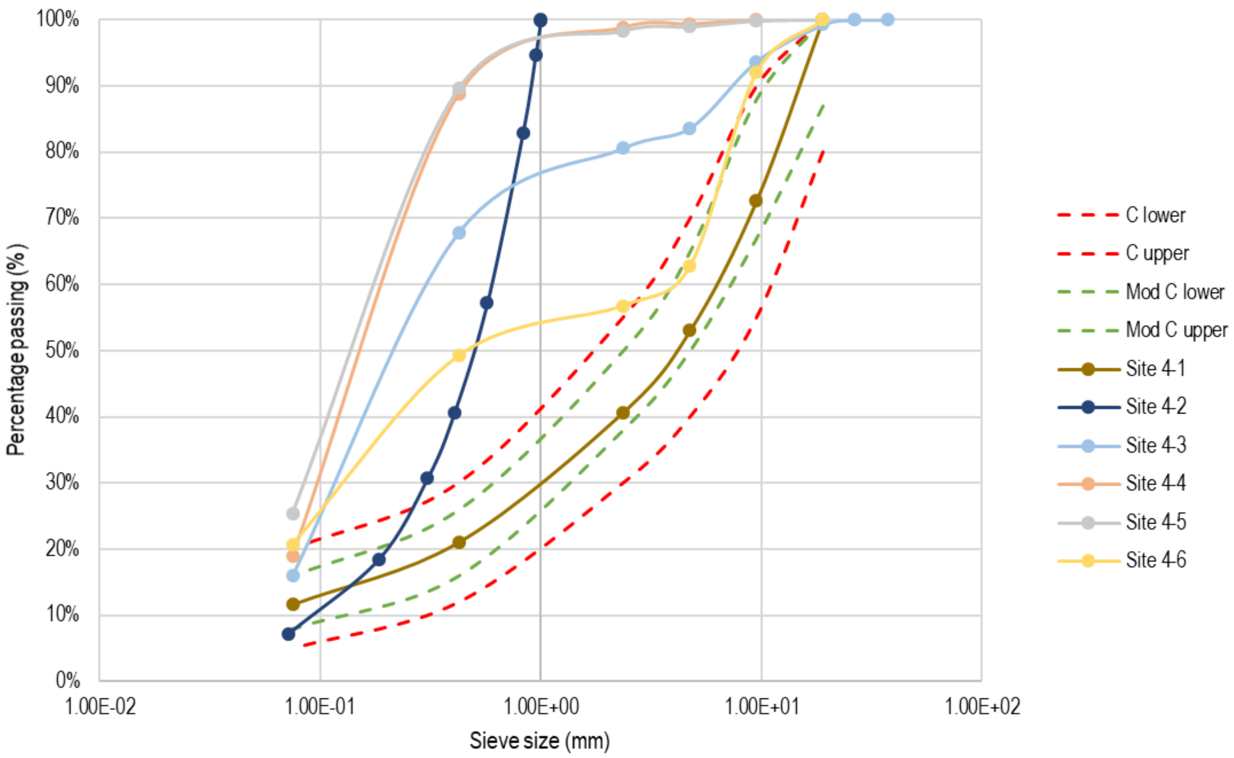
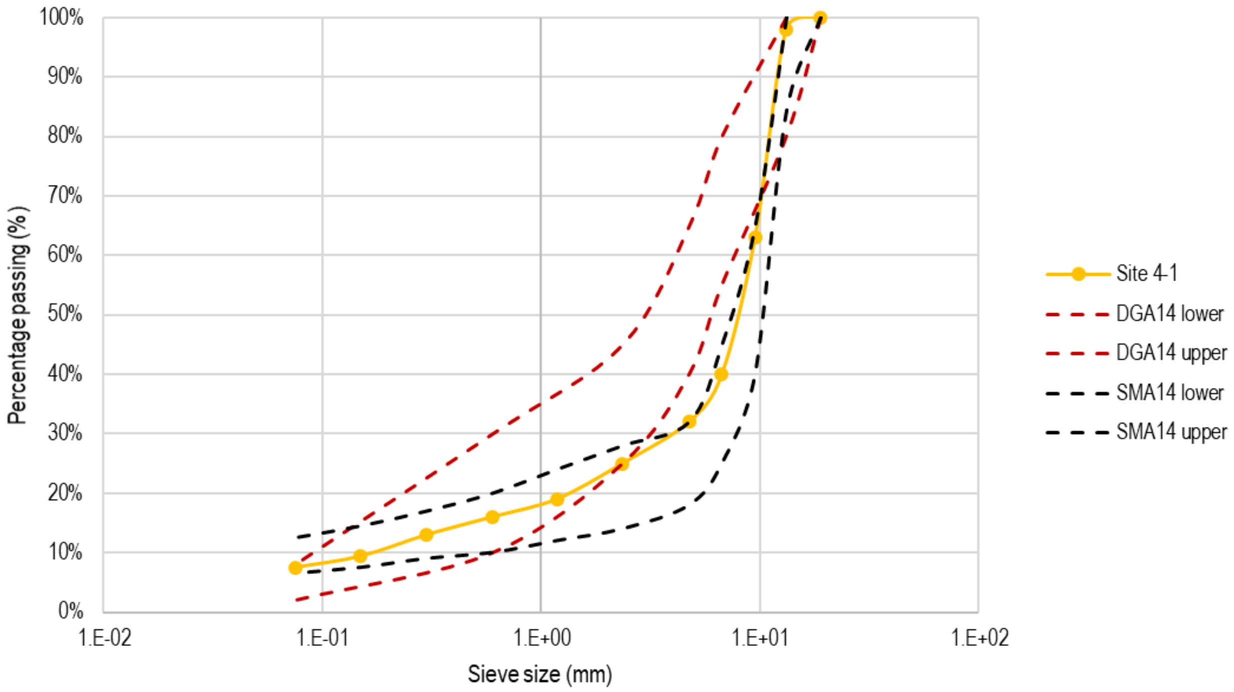


Table **Error! No text of specified style in document.** 12: Site 4 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	5.00
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	98
	9.5	63
	6.7	40
	4.75	32
	2.36	25
	1.18	19
	0.600	16
	0.300	13
	0.150	9.4
	0.075	7.5

Figure Error! No text of specified style in document. **8: Site 4 asphalt PSD**



A.5 SITE 5 – RD 126 BRIBIE ISLAND RD

Table **Error! No text of specified style in document.** 13: Site 5 classification report

Test method	Material property	Site 5-1	Site 5-2	Site 5-3
	Layer	Layer 1	Layer 2	Layer 3
	Depth (mm)	130-300	300-900	900-1700
Particle size distribution (Q103A) (% passing)	53.0	–	–	–
	37.5	100.0	–	–
	26.5	99.1	–	–
	19.0	95.7	100.0	–
	9.5	87.4	99.8	–
	4.75	75.8	99.7	100.0
	2.36	67.7	99.6	99.9
	0.425	46.4	86.8	88.2
	0.075	12.8	1.9	1.4
	Dust ratio	0.28	0.02	0.02
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	19.0	23.8	24.0
	Plastic index (%)	3.0	0.2	0.4
	WPI	135.4	18.6	43.2
	Linear shrinkage (%)	–	–	–
	Weighted linear shrinkage	0.0	0.0	0.0
	Material classification	SM orange, gravelly silty sand	SP grey sand	SP white sand
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	8.5	16.0	16.0
	MDD (t/m³)	2.04	1.64	1.64
	Target lab moisture ratio (%)	100.0	100.0	100.0
	Target lab density ratio (%)	100.0	97.0	95.0
	Comp. MC (%)	9.2	15.4	15.3
	Lab moisture ratio (%)	107	97	96
	Comp. dry density (t/m³)	2.03	1.60	1.56
	LDR (%)	99.0	97.5	95.5
	Swell (%)	-0.1	-0.2	-0.2
	After pen. top MC (%)	13.7	16.8	17.8
	After pen. remainder MC (%)	9.3	17.2	19.3
	CBR 2.5	70.0	25.0	20.0
	CBR 5.0	60.0	30.0	20.0
	CBR	70.0	30.0	20.0

Table **Error! No text of specified style in document.** 14: Site 5 DCP

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	5.6	5-1	200
380-430	50	20	3.8	5-2	400
430-510	80	>60	–	–	–
–	–	–	1.8	5-3	1100

Layer depth (mm)	Thickness (mm)	CBR	Moisture content (%)	Sample no.	Depth (mm)
–	–	–	4.1	5-4	1600

Figure **Error! No text of specified style in document.** 9: Site 5 PSD

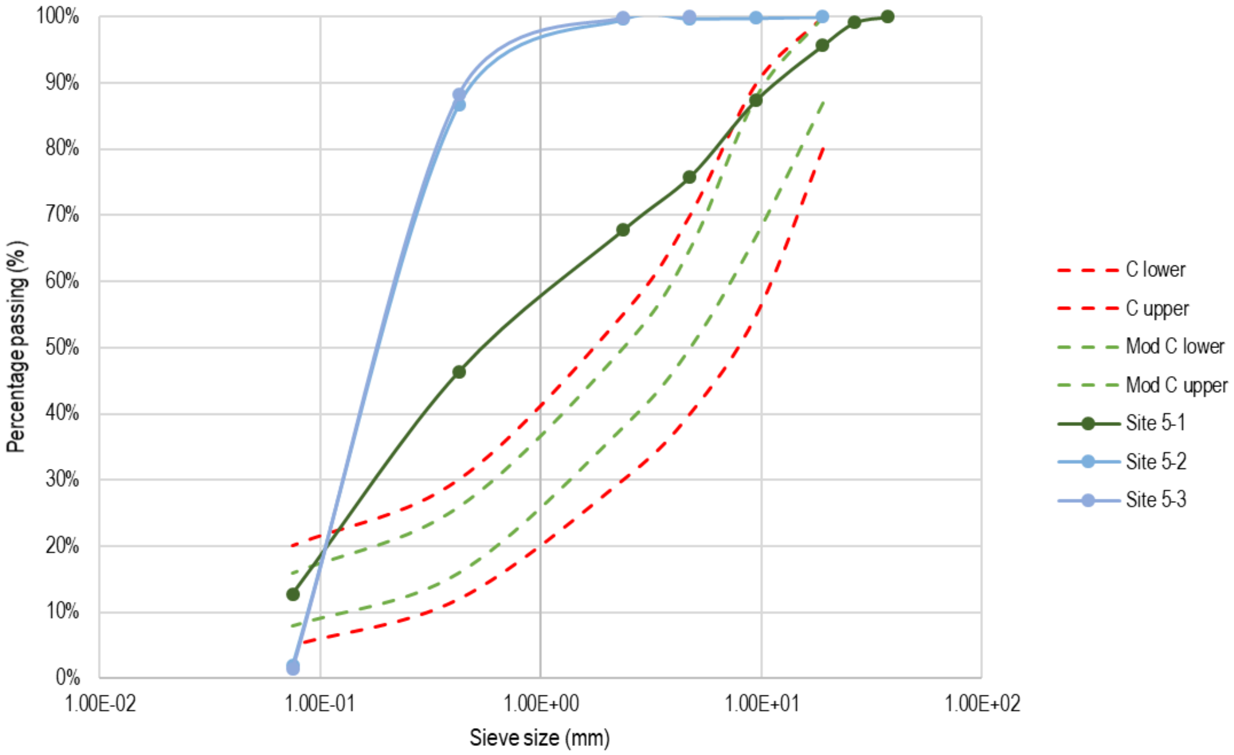
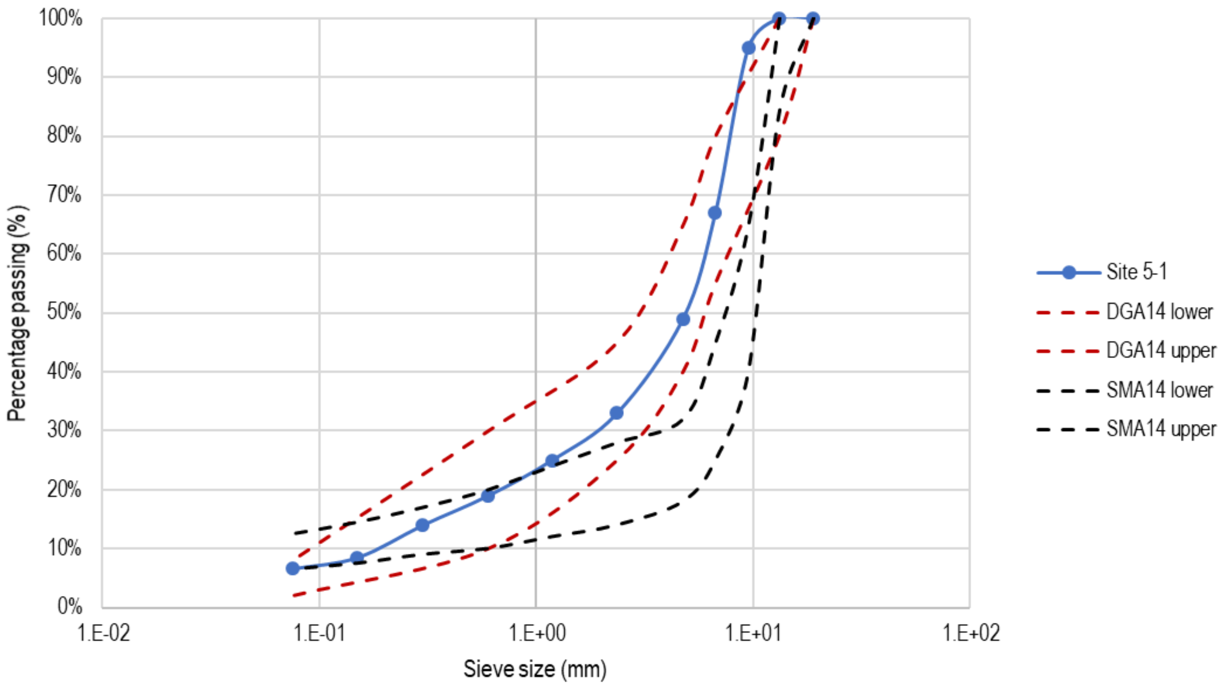


Table **Error! No text of specified style in document.** 15: Site 5 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	5.85
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	100
	9.5	95
	6.7	67
	4.75	49
	2.36	33
	1.18	25
	0.600	19
	0.300	14
	0.150	8.5
	0.075	6.6

Figure **Error! No text of specified style in document.** 10: Site 5 asphalt PSD



A.6 SITE 6 – RD 403 SOUTH PINE RD

Table **Error! No text of specified style in document.** 16: Site 6 classification report

Test method	Material property	Site 6-1	Site 6-2
	Layer	Layer 1	Layer 2
	Depth (mm)	70-470	470-770
Particle size distribution (Q103A) (% passing)	75.0	–	100.0
	53.0	–	96.1
	37.5	–	89.7
	26.5	–	81.3
	19.0	100.0	73.9
	9.5	71.9	48.7
	4.75	49.3	34.7
	2.36	36.4	26.1
	0.425	17.3	16.1
	0.075	10.0	10.8
	Dust ratio	0.58	0.67
Material testing properties (Q104A, Q105 & Q106)	Liquid limit (%)	21.8	27.2
	Plastic index (%)	4.8	11.8
	WPI	84.8	190.3
	Linear shrinkage (%)	2.6	5.0
	Weighted linear shrinkage	44.5	82.1
	Material classification	GP – GM gravel with sand and silt	GC brown gravel with sand and silt
Material compaction properties (Q142A, Q145A & Q113C)	OMC (%)	7.0	6.5
	MDD (t/m³)	2.41	2.36
	Target lab moisture ratio (%)	100.0	100.0
	Target lab density ratio (%)	100.0	97.0
	Comp. MC (%)	6.7	7.4
	Lab moisture ratio (%)	95	110
	Comp. dry density (t/m³)	2.42	2.27
	LDR (%)	100.5	96.0
	Swell (%)	-1.2	-0.1
	After pen. top MC (%)	6.5	7.5
	After pen. remainder MC (%)	6.6	7.5
	CBR 2.5	50.0	10.0
	CBR 5.0	80.0	15.0
	CBR	80.0	15.0

Figure **Error! No text of specified style in document.** 11: Site 6 PSD

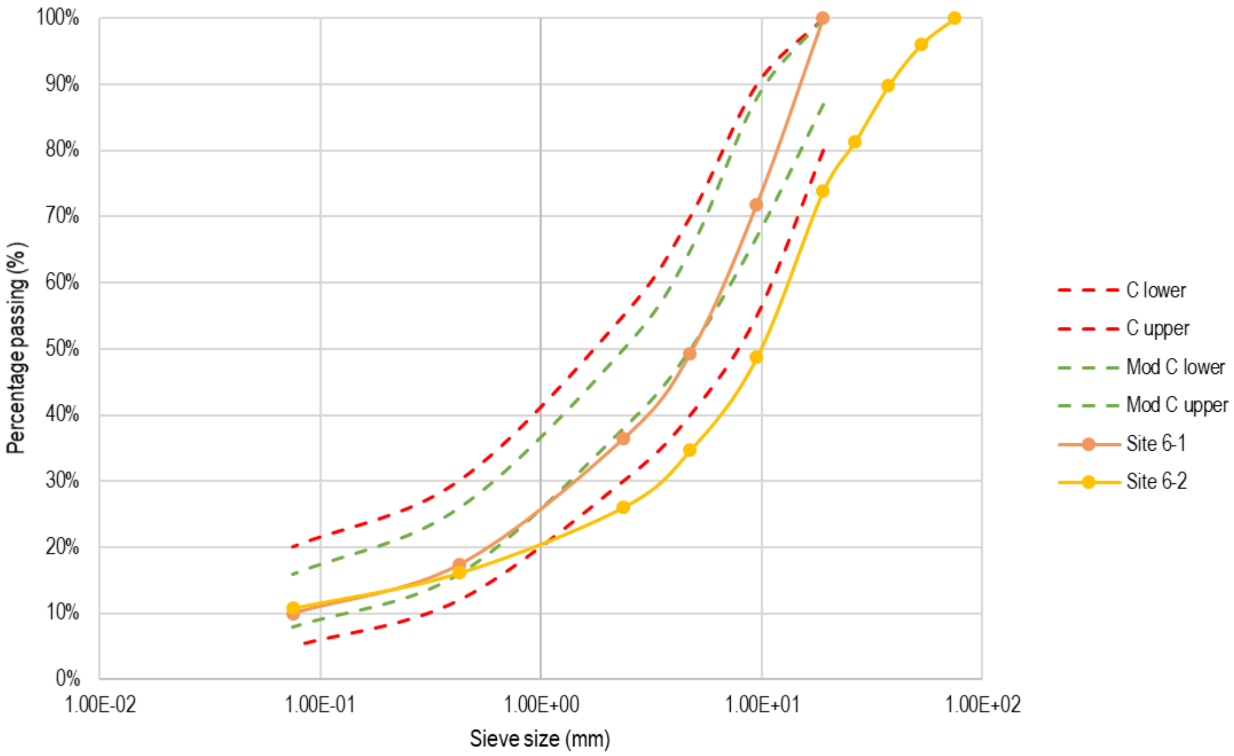


Table **Error! No text of specified style in document.** 17: Site 6 asphalt test results

Test method	Material property	Result
Bitumen content (Q308A) (%)	Bitumen content	4.90
Particle size distribution (Q308A) (% passing)	19.0	100
	13.2	99
	9.5	74
	6.7	58
	4.75	48
	2.36	36
	1.18	28
	0.600	22
	0.300	15
	0.150	9.4
	0.075	7.4

Figure **Error! No text of specified style in document.** 12: Site 6 asphalt PSD