Pavement maintenance patch trials
December 2017

G Arnold (Road Science)
G Mudgway (Road Science)
O Dickin (Downer)

New Zealand Transport Agency research report 635
Contracted research organisation – Road Science

ISBN 978-1-98-851285-3 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Arnold, G, G Mudgway and O Dickin (2017) Pavement maintenance patch trials. *NZ Transport Agency research report 635.* 103pp.

Road Science was contracted by the NZ Transport Agency in 2014 to carry out this research.

Keywords: maintenance, patches, potholes

An important note for the reader

Acknowledgements

The researchers acknowledge the financial assistance by the NZ Transport Agency and the kind assistance from Downer staff for constructing the maintenance patch road trials and providing asset data. The steering group members and peer reviewers are also acknowledged as listed below:

Steering Group members:

John Donbavand – NZTA
Martin Gribble – NZTA
Ollie Dickins – Downer
Adam Leslie – Fulton Hogan
Roger Ashworth – NZTA

Peer reviewers:

Ross Peploe – Bartley Consultants Ltd
Bruce Steven - Beca

Abbreviations and acronyms

AADT	annual average daily traffic
AC	asphaltic concrete
CBR	California bearing ratio
ESA	equivalent standard axles
FWD	falling weight deflectometer
HCV	heavy commercial vehicle
IANZ	International Accreditation New Zealand
ITS	indirect tensile strength
MESA	million ESA
NDM	nuclear density meter
PI	Plasticity Index
PSD	particle size distribution
QA	quality assurance
RAMM	road assessment and maintenance management
RLT	repeated load triaxial (tests)
RP	route position
SH	state highway
TP	test pit
UCS	unconfined compressive strength

Contents

Executive summary

This research project was commissioned by the NZ Transport Agency to address the current lack of knowledge of treatment selection, design and life estimates of maintenance patches. Anecdotally on the state highway network, maintenance patches often fail within a year and new patches are often repairs of earlier patches. This patch on patch practice eventually gets recorded as high maintenance costs on the road section which then justifies the need for a pavement renewal.

Research was undertaken to develop a framework for predicting the life of patches to enable asset managers to choose the right treatment to give the life required with the lowest whole-of-life costs. Twelve maintenance patches were trialled on three different New Zealand state highways. These maintenance patches consisted of the three most common patch treatments: in-situ stabilisation (two cement contents 1.5% and 3%), full depth granular reconstruction, and mill and asphaltic concrete inlay. The patches were treated as full pavement renewals in terms of testing and investigation prior to their construction. This information allowed basic pavement characteristics, such as the impact of traffic; pavement depth (adequate, inadequate or very inadequate); aggregate quality (good, average or poor); and pavement deflection (high, medium or low), to be determined prior to patching. The patches were monitored for three years and during this period most failed. The monitoring allowed the creation of algorithms, based on the basic pavement characteristics, to predict the life of the patch treatments.

A framework tool was developed as part of the research and is recommended for asset managers, when considering the expected life of a maintenance patch, to determine if a standard patch is the best treatment compared with a more robust patch or if pavement renewal is justified before high maintenance costs are spent on this site. This research report details the results of the trials and presents (in a separate appendix D available at www.nzta.govt.nz/resources/research/reports/635) the associated tool in the form of a maintenance patch treatment design spreadsheet.

Abstract

There is anecdotal evidence that pavement maintenance patches fail within a few years and research was undertaken to develop a framework for predicting the life of patches to enable asset managers to choose the right treatment to give the life required with the lowest whole-of-life costs. A total of 12 maintenance patches were constructed consisting of cement stabilisation (two cement contents 1.5% and 3%); mill and asphaltic concrete inlay; and full depth granular reconstruction replicated on three different state highways. These maintenance patches were treated as full pavement renewals in terms of testing and investigation prior to their construction. This information allowed basic pavement characteristics, such as the impact of traffic; pavement depth (adequate, inadequate or very inadequate); aggregate quality (good, average or poor); and pavement deflection (high, medium or low), to be determined prior to patching. The patches were monitored for three years and during this period most failed. The monitoring allowed the creation of algorithms based on the basic pavement characteristics to predict the life of the patch treatments. A tool was developed to allow designers and asset managers to make informed choices on the type of patch treatment based on predicted life, and so prevent early failure of the patches.

1 Introduction

This research project was commissioned by the NZ Transport Agency in 2014 to address the current lack of knowledge of treatment selection, design and life estimates of maintenance patches. Anecdotally on the state highway network, maintenance patches often fail within a year and new patches are often repairs of earlier patches. This patch on patch practice eventually gets recorded as high maintenance costs on the road section which then justifies a pavement renewal. There is a need for asset managers to consider the expected life of the maintenance patch to determine if this is the best treatment compared with a more robust patch or if the predictions of maintenance patch life justify the pavement renewal before high maintenance costs are spent on this site. To develop a tool to predict maintenance patch life 12 maintenance patches were trialled on the state highway network between March and June 2015 on the East Waikato state highway network using three common patch treatments (in-situ stabilisation, full depth granular reconstruction, mill and asphaltic concrete (AC) inlay). This research report details the results of the trials and presents in a separate appendix D (available at www.nzta.govt.nz/resources/research/reports/635) the associated maintenance patch treatment design spreadsheet developed as a result of this research.

2 Maintenance patch trials

2.1 Introduction

Twelve maintenance patches, consisting of four maintenance patch treatments repeated on three state highways, were constructed between March and June 2015, with the first inspections carried out in October 2015. There are risks with constructing patches in winter in terms of first-coat seal failures although construction was programmed in periods of fine weather (no rain) and the patches did not show evidence of first-coat seal failures despite this being a common problem on other networks. Nevertheless patching is unavoidable in winter as this is generally the time when pavements fail and reactive maintenance is needed. The four patch treatments were:

1 1.5% cement in-situ stabilisation to a depth of 150 mm

2 3% cement in-situ stabilisation to a depth of 150 mm

3 Full depth granular reconstruction to a depth of 500 mm

4 Mill and AC inlay 80 mm of mix 10.

The patch treatments were constructed on three state highway locations as detailed in table 2.1 alongside traffic loading.

Table 2.1 Maintenance patch trial locations and traffic levels

	SH24 – RS0 **Constrained by kerb and channel** **Flat straight road 2% to 3% crossfall**	**SH26 – RS80** **Low lying land with drainage ditches** **Flat straight road 2 to 3% crossfall**	**SH27 – RS46** **Flat site with road level raised on fill over low lying land** **Flat straight road 2% to 3% crossfall**
Traffic – AADT %HCV 3-month inspection ESA 16-month inspection ESA 10-year traffic total 25-year traffic total	9,029 13% 88,000 480,000 4 million ESA (MESA) 13 MESA	4,014 9% 27,000 148,000 1.3 MESA 4 MESA	5,870 21% 93,000 500,000 4.3 MESA 13.7 MESA
3% cement stabilisation – RP	1,405 – 1,465 (increasing side) (2 m by 60 m) Built 23 March 2015	13,612 – 13,642 (decreasing side) (2 m by 30 m) Built March 2015	17,825 – 17,839 (decreasing side) (2 m by 14 m) Built March 2015
1.5% cement stabilisation – RP	1,465 – 1,485 (increasing side) (2 m by 20 m) Built March 2015	13,304 – 13,364 (decreasing side) (2 m by 60 m) Built March 2015	17,430 – 17,466 (decreasing side) (2 m by 36 m) Built March 2015
Full depth granular reconstruction – RP	1975– 1994 (increasing side) Built May 2015	13,394 – 13,434 (decreasing side) Built March 2015	17,965 – 17,980 (increasing side) Built March 2015
Mill and AC inlay – RP	2,102 – 2,122 (increasing side) Built June 2015	13,582 – 13,592 (decreasing side) Built June 2015	17,455 – 17,471 (decreasing side) Built June 2015

2.2 Construction methodology

Typical standard construction practices for small maintenance patches were used as detailed below:

2.2.1 1.5% and 3% cement in-situ stabilisation patches

In- situ stabilisation steps	Detail
1. Prepare site – traffic control and protect drains from possible cement runoff 	Sumps and drains are covered to prevent cement runoff into the waterways. Traffic control needed following an approved traffic management plan.
2. Spread cement (to the required rate either 1.5% or 3%) 	A cement spreader truck is used to spread the correct amount of cement to achieve the required dose of either 1.5% or 3% cement by dry mass of aggregate.
3. Tractor hoe to stabilise to a depth of 150 mm 	A tractor towed hoe is used to stabilise the pavement and mix in the cement spread on the surface.

In- situ stabilisation steps	Detail
4. Spread stabilised aggregate 	The hoed material needs to be spread towards the edges.
5. Apply water 	Water is applied on the loose stabilised aggregate.
6. Trim shape and compact 	A grader is used to trim any excess after rolling.
7. Final water and roll to prepare surface 	Final rolling with a water cart to achieve a smooth surface.

In- situ stabilisation steps	Detail
8. Surfacing with first coat of chipseal (spray bar method) • Stabilised patch left unsealed for 1 day allowing traffic to drive over patch but with traffic control to slow traffic down. • Seal crew will then sweep patch to form a stone mosaic. • First-seal coat with 1.3 l/m2 residual bitumen and grade 3 chip. • Second-seal coat with 0.9 l/m2 residual bitumen and grade 5 chip.	Standard chipseal practice employed as per the NZ Transport Agency's (2005) chipsealing manual.

2.2.2 Dig-out granular reconstruction

Dig- out granular reconstruction steps	Detail
1. Excavate and remove the existing pavement 	An excavator and a truck are used to remove the existing pavement materials.
2. Log existing pavement depth to store in RAMM 	After excavation the depth of the existing pavement is logged to store in RAMM to help with future patch designs.
3. Use a Scala penetrometer to determine subgrade strength and required digout depth 	A Scala penetrometer is used to determine the required pavement depth needed based on the pavement thickness design chart in Austroads (2012, figure 8.4). (See example spreadsheet tool for this in figure 2.1.)

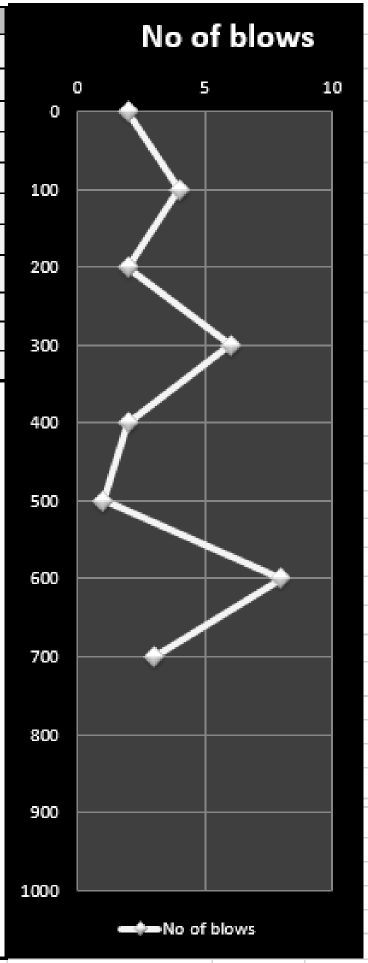
Dig- out granular reconstruction steps	Detail
4. Place GAP65 subbase aggregate to 170 mm below finish level 	
5. Compact subbase aggregate 	6 to 10 passes are required to compact subbase aggregate.
6. Place first 70 mm layer of M4 AP40 basecourse aggregate (water added at quarry to get to optimum moisture content) 	The final layer is an aggregate compliant with specification *TNZ M/4:2006* aggregate that is at optimum moisture content of around 6%.
7. Compact first layer of M4 basecourse 	

Dig- out granular reconstruction steps	Detail
8. Place and compact second and final layer of M4 basecourse  	
9. Surfacing with first coat chipseal (spray bar method) • Patch left unsealed for 1 day allowing traffic to drive over patch but with traffic control to slow traffic down. • Seal crew will then sweep patch to form a stone mosaic. • First-seal coat with 1.3 l/m2 residual bitumen and grade 3 chip. • Second-seal coat with 0.9 l/m2 residual bitumen and grade 5 chip.	

Figure 2.1 Example spreadsheet tool to determine granular digout depth (Source: Downer intra- web)

AADT (No of vehicles per day)	400
Number of lanes	2
Heavy commercial vehicles %	10%
Design Period (years)	25
Year of trafic counts	2017
Traffic Growth Rate	2.0%
Proposed construction year	2017
NES =	3.58E+05

No of blows	Penetration (mm)	mm / blows	CBR %
	0		
2	100	50	3
4	200	25	8
2	300	50	3
6	400	17	14
2	500	50	3
1	600	100	1
8	700	13	21
3	800	33	6
	900		
	1000		



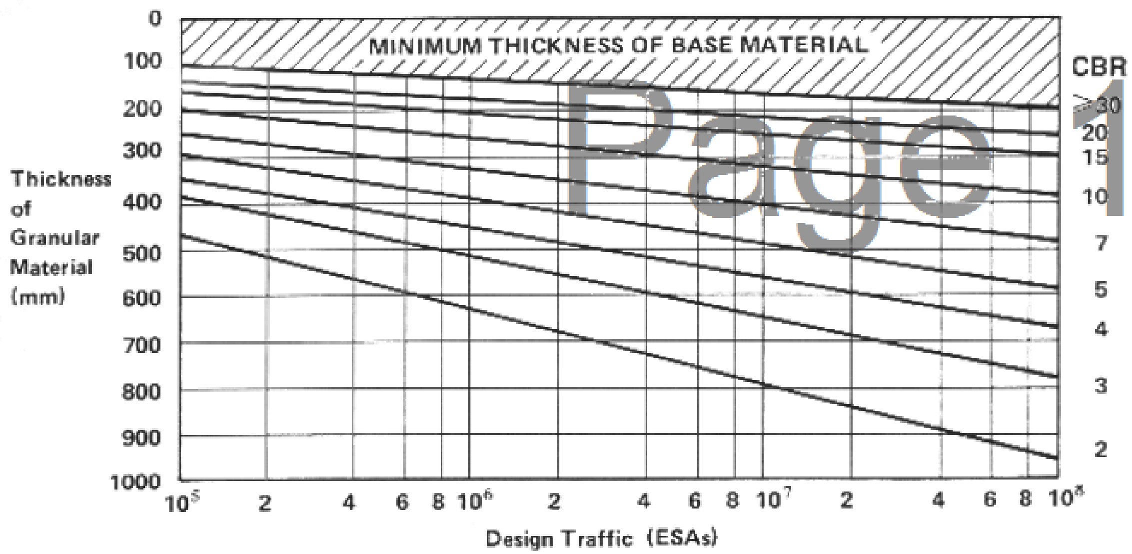


FIG 8.4

$t = [219 - 211(\log CBR) + 58(\log CBR)^2]\log(DESA/120)$

$\text{LogCBR} = 2.2 - 0.77(\log DCP)^{1.5}$

CBR (%)	7
Depth of grannular material (mm	275

2.2.3 Mill and AC inlay

Mill and asphalt steps

1. Mill out to 70 mm

A mill is used to remove the existing surfacing(s) down to a depth of 70 mm for AC inlay.

2. Apply an emulsion tack coat of bitumen along edges and some in the milled area

A bitumen emulsion is sprayed along the edge of the milled patch.

3. Place asphalt

Asphalt is tipped onto the milled area

4. Spread asphalt

Spread asphalt using a bob-cat with a spreader.

5. Compact asphalt

Four to six passes to compact asphalt layer.

3 Maintenance patch trials – investigation prior to construction

Prior to construction of the maintenance patch trials, test pits (TPs) and laboratory testing were undertaken similar to the investigation and testing conducted for pavement renewals on the state highway network. For each of the three state highway sites (SH24, SH26, SH27) four patches (1.5% and 3% cement stabilisation, mill and AC inlay and full depth granular reconstruction) were constructed in close proximity and thus one test pit on the state highway in the middle of the four patch locations was deemed representative of the characteristics found at each individual patch location located near the TP. The falling weight deflectometer (FWD) tests were conducted at 1 m intervals and results summarised for each of the 12 patch locations. This involved TPs, Scala penetrometer tests and laboratory tests on the in-situ aggregates. The aim was to treat the maintenance patches as small pavement renewals to determine if their performance/life could have been predicted using already established pavement design methodologies.

Full details of this investigation are given in appendix A while summaries are given in tables 3.1 and 3.2.

3.1 Test pit results and associated laboratory tests

Table 3.1 Summary of maintenance patch investigations prior to construction (existing site conditions) – site 1 SH24 and site 2 SH26

Location	Test pits (and Scala CBRs) sufficient pavement depth (Austroads 2012, figure 8.4)	RLT (rut resistance of basecourse	RLT (rut resistance of subbase	PSD (basecourse)	PI (BC)	Four day soaked CBR	Cement reactivity (strength)
Site 1 – SH24 –RS0 *AADT 9,029 – HCVs 13%* *(0.4 MESA per year)*	Subgrade CBR 6 to 13 Pavement depth sufficient except TP1 needs 200 mm overlay	Dry RLT average – 8 MESA Wet RLT poor <0.01 MESA	Dry RLT average – 5 MESA	Just outside fine side of M4 AP40	12	2% (if use this soaked CBR then insufficient depth)	Highly reactive 1.5%C (UCS 3 MPa) 3%C (UCS 6 MPa)
	Pavement depth OK except TP1	Just below average quality BC and SB, moisture sensitive with plastic fines.				Insufficient pavement depth using soaked CBR	Bound behaviour very brittle.
	FWD deflections (10th %ile): D0 – 1.8 mm; curvature (D0-D200) – 0.55 mm; subgrade CBR 3 – predicted life 1 year.						
Site 2–-SH26 – RS80 AADT *4014 – HCVs 9%*	Subgrade CBR 6 to 13 Depth insufficient by 100mm in second test pit other three test pit depths OK	Dry RLT below average – 5 MESA Wet RLT very poor <0.001 MESA	Dry RLT average – 8 MESA	Within the limits of M4 AP40	20	7% and 12%	Average reactivity 1.5%C (UCS 2 MPa) 3%C (UCS 3 MPa)

Location	Test pits (and Scala CBRs) sufficient pavement depth (Austroads 2012, figure 8.4)	RLT (rut resistance of basecourse	RLT (rut resistance of subbase	PSD (basecourse)	PI (BC)	Four day soaked CBR	Cement reactivity (strength)
(0.13 MESA per year)	Pavement depth OK except second TP.	Below average basecourse that is very sensitive to weakness by water as shown in RLT and the high plasticity with a PI of 20. The subbase is better quality than the basecourse.				It appears 4-day soaking does not weaken the subgrade compared with Scala in-situ CBRs.	1.5%C still above Austroads limit of 1.5 MPa UCS.
	FWD deflections (10th %ile): D0 – 1.9 mm; curvature (D0-D200) – 0.55 mm; subgrade CBR 2 – predicted life 1 year.						

Note: CBR = California bearing rate; RLT = repeated load triaxial; SB = Subbase; PSD = particle size distribution; BC = basecourse; PI = Plasticity Index; AADT = annual average daily traffic; HCV = heavy commercial vehicle; UCS = unconfined compressive strength; TP = test pit.

Table 3.2 Summary of maintenance patch investigations prior to construction (existing site conditions) – site 3 SH27

Location	Test pits (and Scala CBRs) sufficient pavement depth (Austroads 2012, figure 8.4)	RLT (rut resistance of BC)	RLT (rut resistance of SB)	PSD (in- situ BC)	PI (BC)	Four day soaked CBR	Cement reactivity (strength)
Site 3 – SH27 – RS46 *AADT 5870 – HCVs 21%* *(0.4 MESA per year)*	Subgrade CBR 6 to 30 (at 700 mm depth CBR =2) Depth insufficient by 100 mm in first test pit other three test pit depths OK	Dry RLT poor – 2 MESA Wet RLT poor <0.01 million ESA	Dry RLT average – 7 MESA	Finer than the limits of M4 AP40	23	8% and 4%	Average reactivity 1.5%C (UCS 2 MPa) 3%C (UCS 4 MPa)
	Pavement depth OK except first TP.	In-situ basecourse poor quality, with excess clay and excess fines making it very moisture sensitive.				Soaked CBR similar to Scala in-situ CBRs and does not affect overlay depth requirements	Average strength 1.5%C close to 1.5 MPa limit set at a lower density and thus unbound granular behaviour expected.
FWD deflections (10th %ile): D0 – 1.22 mm; curvature (D0–D200) – 0.29 mm; subgrade CBR 2 – predicted life 1 year.							

Note: CBR = California bearing rate; RLT = repeated load triaxial; SB = subbase; PSD = particle size distribution; BC = basecourse; PI = Plasticity Index; AADT = annual average daily traffic; HCV = heavy commercial vehicle; UCS = unconfined compressive strength; TP = test pit.

3.2 Performance and maintenance history (RAMM)

High-speed rut depth measurements in RAMM prior to and after patch construction were analysed using Juno viewer as shown in figures 3.1 to 3.6. There was very little high-speed rutting recorded except on these sites. Sites chosen for maintenance patches were based on visual condition by the network inspector who recorded rutting, shoving, cracking and flushing. The network inspector also chose patch sites that would prevent reactive pothole repairs during winter and heavy rain.

Figure 3.1 SH27-RS46 RP 17430-17466 1.5% cement stabilisation patch

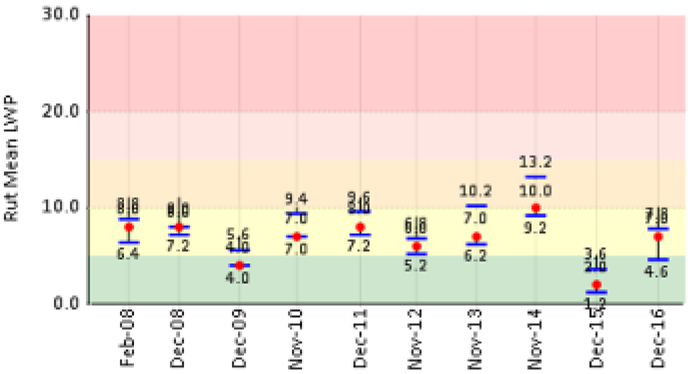


Figure 3.2 SH27-RS46 RP 17965-17980 1.5% full depth granular digout patch location

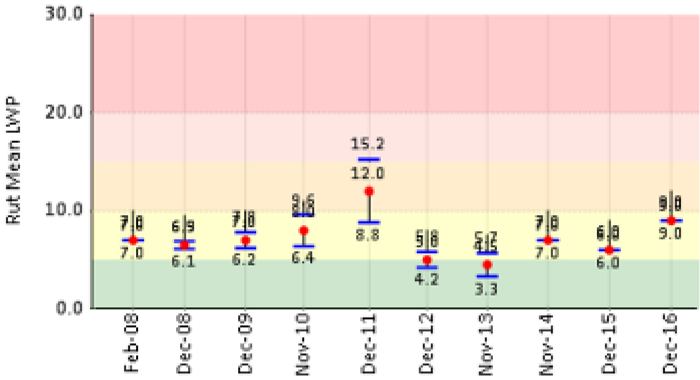


Figure 3.3 SH27-RS46 RP 17455-17471 1.5% mill and AC inlay patch location

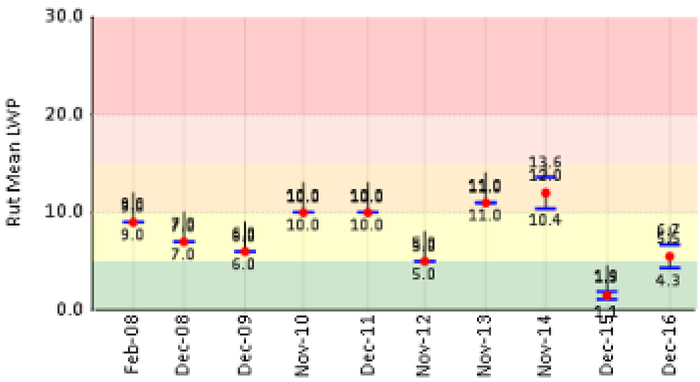


Figure 3.4 SH26-RS80 RP 13394-13434 full depth granular reconstruction patch location

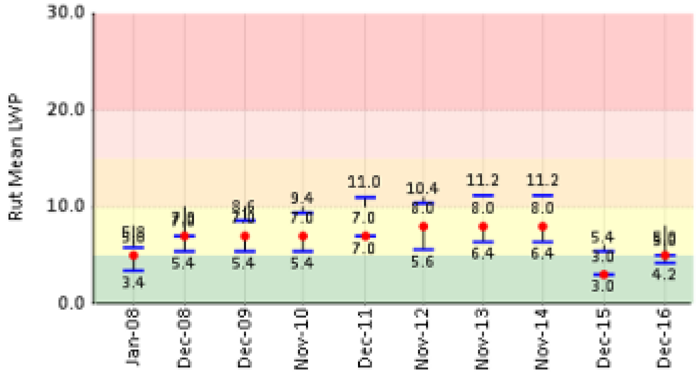


Figure 3.5 SH26-RS80 RP 13612-13642 3% cement stabilisation patch location

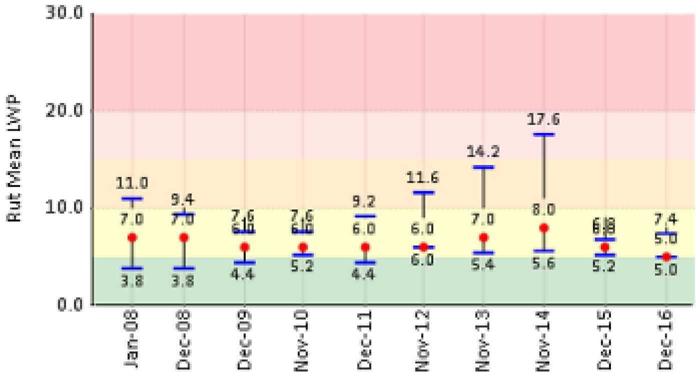
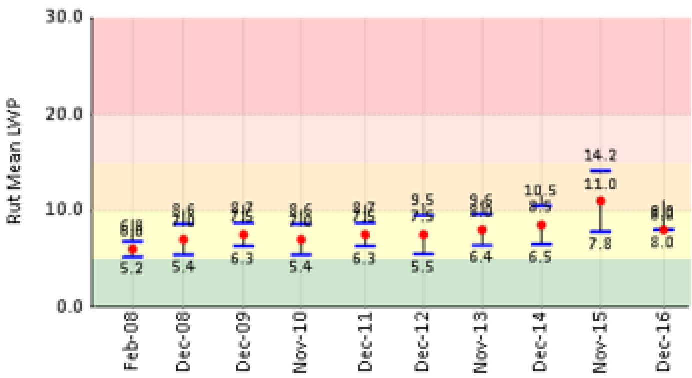


Figure 3.6 SH26-RS24 RP 2102-2122 mill and AC inlay patch location



Tables 3.3 to 3.5 on the following pages summarise the condition of the patches, with observations by the network inspector on the condition and on the high-speed data.

Table 3.3 Maintenance patch rut and roughness levels (90th percentile) from high- speed data along with visual condition prior to patching for SH24 sites

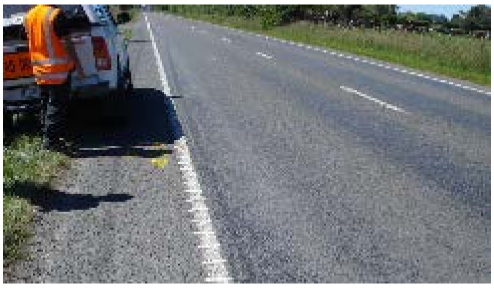
	SH24 - RS0	
3% cement stabilisation	RP = 1405 – 1465 inc Rut = 5 mm Roughness (NAASRA counts per km) = 151 Deformation, shoving, minor rutting with high speed data showing only 5 mm ruts and flushing	
1.5% cement stabilisation	RP = 1465 – 1485 inc Rut = 5 mm Roughness (NAASRA counts per km) = 58 Deformation, shoving, minor rutting and flushing	
Full depth granular reconstruction	RP = 1975 – 1994 inc Rut = 10 mm Roughness (NAASRA counts per km) = 101 Shear failure of the old AC mill and fill has cracked	
Mill and AC inlay	RP = 2102–2122 inc Rut = 14 mm Roughness (NAASRA counts per km) = 170 Shear failure	

Note: RP = route position; NAASRA = National Association of Australian State Road Authorities

Table 3.4 Maintenance patch rut and roughness levels (90th percentile) from high- speed data along with visual condition prior to patching for SH26 sites

	SH26 – RS80	
3% cement stabilisation	RP = 13612 – 13642 dec Rut = 18 mm Roughness (NAASRA counts per km) = 131 Shear failure and cracking	
1.5% cement stabilisation	RP 13304 – 13364 dec Rut = 11 mm Roughness (NAASRA counts per km) = 124 Shear failure	
Full depth granular reconstruction	RP 13394 – 13434 dec Rut = 11 mm Roughness (NAASRA counts per km) = 125 Flushing and shoving	
Mill and AC inlay	RP 13582 – 13592 dec Rut = 6 mm Roughness (NAASRA counts per km) = 162 Deformation in bridge approach	

Table 3.5 Maintenance patch rut and roughness levels (90th percentile) from high- speed data along with visual condition prior to patching for SH27 sites

	SH27 – RS46	
3% cement stabilisation	RP 17825 – 17839 dec Rut = 6 mm Roughness (NAASRA counts per km) = 148 Shear failure with cracking, pumping and shoving	
1.5% cement stabilisation	RP 17430 – 17466 dec Rut = 13 mm Roughness (NAASRA counts per km) = 39 Deformation, shoving, rutting and flushing	
Full depth granular reconstruction	RP 17965 – 17980 inc Rut = 7mm Roughness (NAASRA counts per km) = 90 Deformation, block cracking and potholes repaired before	
Mill and AC inlay	RP 17455 – 17471 dec Rut = 14 mm Roughness (NAASRA counts per km) = 40 Deformation, block cracking and potholes repaired before	

4 Falling weight deflectometer testing

All maintenance patches were tested prior to construction using the FWD with the aim of characterising the sites to assist in predicting the lives of the various maintenance treatments. As the maintenance patches were small in length, the FWD testing was conducted in 1m increments. The traffic speed deflectometer that reports deflections every 2 m along state highways (although results are averaged for 10 m increments) could be used instead of the FWD, as it is not practical or cost effective to do FWD surveys to assist in treatment selection and design for maintenance patches. Full results of the FWD survey are in appendix B with results summarised in section 4.1.

4.1 FWD summary

Previous research has shown the best parameter from the FWD surveys for predicting performance is the 10th percentile value. Thus the 10th percentile peak deflection, curvature and life prediction from mechanistic analysis of the pavement cross-section determined from back analysis of the FWD measurements given in an unpublished report by Geosolve (New Zealand) are summarised against the performance of the patches in tables 4.1 and 4.2. It can be seen that all the in-situ stabilised patches have short lives and the FWD predicted lives of the pavements prior to stabilising is one year. Although inconclusive and an estimate it appears that with peak deflections below 1mm and curvature below 0.25 mm the chances of obtaining a higher life is more likely especially for the mill and AC inlay.

Table 4.1 Summary of maintenance patch FWD results compared with performance for in- situ stabilised patches

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	10th percentile FWD results prior to construction (Geosolve predictions)	Discussion on prediction of performance from FWD
3% cement in-situ stabilisation to a depth of 150 mm	SH24–RS0–1405–1465 (increasing side)	88,000 ESA – 3 months	D0 = 1.81 mm D0–D200 = 0.552 Predicted life = 1 year Subgrade CBR = 3	Good prediction of short life given high deflection of nearly 2 mm.
	SH26–RS80–13612–13642 (decreasing side)	Site not failed after 16 months with 148,000 ESA. (Cracking started so estimate life of 2.5 years or 300,000 ESA).	D0 = 1.93 mm D0–D200 = 0.582 Predicted life = 1 year Subgrade CBR = 2	An OK prediction. Actual life was expected to be shorter given deflection of nearly 2 mm, although 2.5 years life was shorter than a required 10 years for patches.
	SH27–RS46–17825–17839 (decreasing side)	Site not failed after 16 months with 500,000 ESA. (Cracking started in inside wheel path only so estimate life of 2.5 years for this inside wheel path or 1 MESA.)	D0 = 1.10 mm D0–D200 = 0.216 Predicted life = 1 year Subgrade CBR = 2	It could be seen the deflection and curvature (D0-D200) were low. From experience and according to Austroads (2012) a long life of at least 10 years would be predicted for the stabilised patch; however, actual

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	10th percentile FWD results prior to construction (Geosolve predictions)	Discussion on prediction of performance from FWD
				performance of the patch only lasted 2.5 years, although Geosolve predicted a 1-year life based on subgrade strain using the results of the FWD analysis.
1.5% cement in-situ stabilisation to a depth of 150 mm	SH24–RS0–1465–1485 (increasing side)	88,000 ESA – 3 months	D0 = 2.1 mm D0-D200 = 0.630 Predicted life = 1 year Subgrade CBR = 3	Good prediction of short life given high deflection of nearly 2 m.
	SH26–RS80–13304–13364 (decreasing side)	Not failed after 16 months or after 148,000 ESA, life estimated at 10 years or 1.5 MESA.	D0 = 1.98 mm D0-D200 = 0.562 Predicted life = 1 year Subgrade CBR = 2	A poor prediction as the actual life was expected to be shorter given deflection of nearly 2 mm.
	SH27 –RS46 – 17430-17466 (decreasing side)	100,000 ESA – 3 months	D0 = 1.46 mm D0-D200 = 0.382 Predicted life = 1 year Subgrade CBR = 2	An OK prediction although the actual life was expected to be higher as deflections were less than SH26 site.

Table 4.2 Summary of maintenance patch FWD results compared with performance for granular and asphalt patches

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	10th percentile FWD results prior to construction	Discussion on prediction of performance from FWD
Full depth granular reconstruction (digout and replace)	SH24–RS0–1975–1994 (increasing side)	Site not failed after 16 months with 479,000 ESA. (Life 25 years? Or 10 MESA?)	D0 = 0.94 mm D0–D200 = 0.242 Predicted life = 40 years Subgrade CBR = 5	FWD before construction is not relevant as this treatment digs out to a greater depth and puts new pavement back. Deflections before construction are therefore of little relevance, except to determine digout depth
	SH26 –RS80–13394–13434 (decreasing side)	Site not failed after 16 months with 148,000 ESA. (Life 25 years? Or 10 MESA?)	D0 = 1.83 mm D0–D200 = 0.485 Predicted life = 1 year Subgrade CBR = 2	

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	10th percentile FWD results prior to construction	Discussion on prediction of performance from FWD
	SH27–RS46–17965–17980 (increasing side)	500,000 ESA – 16 months	D0 = 1.23 mm D0–D200 = 0.330 Predicted life = 1 year Subgrade CBR = 2	
Mill and AC inlay	SH24–RS0–2093–2112	Only minor damage on edges at 479,000 ESA – 16 months. Life estimated 3 years or 1.5 MESA (perhaps higher).	D0 = 1.66 mm D0–D200 = 0.465 Predicted life = 1 year Subgrade CBR = 2	SH24 site when compared with SH26 and SH27 the FWD deflections are good predictor as a shorter life is obtained for the SH24 site with the highest deflection and curvature. It appears a criteria for long life for thin asphalt is D0<1 mm and D0–D200<0.2 mm. This is supported by the results.
	SH26–RS80–13582–13592 (decreasing side)	Not failed after 150,000 ESA – 16 months	D0 = 0.66 mm D0-D200 = 0.174 Predicted life = 142 years Subgrade CBR = 9	
	SH27–46–17455–17471 (decreasing side)	Not failed after 500,000 ESA – 16 months	D0 = 1.09 mm D0–D200 = 0.218 Predicted life = 1 year Subgrade CBR = 3	

5 Maintenance patch trials – monitoring

Three different state highways representing three different traffic volumes were chosen to trial four different standard maintenance patch treatments:

1. 3% cement in-situ stabilisation to a depth of 150 mm
2. 1.5% cement in-situ stabilisation to a depth of 150 mm
3. Full depth granular reconstruction (dig-out 500 mm and replace with 300 mm of GAP65 subbase and 200 mm of M4 AP40 basecourse)
4. Mill and AC inlay.

Twelve maintenance patches were constructed before the end of June 2015 and were monitored over 16 months with the results shown below. Two inspections were conducted, the first being three months after construction on 14 October 2015 and the second inspection on 24 November 2016, after a total of 16 months trafficking. Full details of the monitoring are given in appendix C with results of the monitoring summarised in section 5.1.

5.1 Trial summary

Table 5.1 summarises the monitoring of the trial sections.

Table 5.1 Summary of maintenance patch performance

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	Performance
3% cement in-situ stabilisation to a depth of 150 mm	SH24–RS0–1405–1465 (increasing side)	88,000 ESA – 3 months	Site started cracking within 3 months and at 16 months complete failure rutting and cracking.
	SH26–RS80–13612–13642 (decreasing side)	Site not failed after 16 months with 148,000 ESA. (Cracking started so estimate life of 2.5 years or 300,000 ESA).	At 16 months small area with minor alligator cracking and rutting <10 mm.
	SH27–RS46–17825–17839 (decreasing side)	Site not failed after 16 months with 500,000 ESA. (Cracking started in inside wheel path only so estimate life of 2.5 years for this inside wheel path or 1 MESA.)	At 16 months small area with minor alligator cracking and rutting <10 mm.
1.5% cement in-situ stabilisation to a depth of 150 mm	SH24–RS0–1465–1485 (increasing side)	88,000 ESA – 3 months	At 3 months, the site had extensive alligator cracking and rutting. At 16 months cracks were coming through thin asphalt repair.
	SH26–RS80–13304–13364 (decreasing side)	Not failed after 16 months or after 148,000 ESA, life estimated at 10 years or 1.5 MESA.	At 16 months, there was no pavement distress and rutting was less than 5 mm.
	SH27–RS46–17430–17466 (decreasing side)	100,000 ESA – 3 months	At 3 months, extensive alligator cracking and by 16 months complete failure repaired by asphalt patches which were also failing – rutting was 15 mm.

Maintenance patch type	Trial location	Traffic in ESA (when failure occurred)	Performance
Full depth granular reconstruction (dig-out and replace)	SH24–RS0–1975–1994 (increasing side)	Site not failed after 16 months with 479,000 ESA. (Life 25 years? Or 10 MESA?)	At 16 months pavement not failed although rutting around 8 mm.
	SH26–RS80–13394–13434 (decreasing side)	Site not failed after 16 months with 148,000 ESA. (Life 25 years? Or 10 MESA?)	At 16 months pavement had not failed although rutting was 15 mm in beginning of half of patch and in second half of patch only 3 mm. *(Note visual inspection with straight edge needed to confirm this).*
	SH27–RS46–17965–17980 (increasing side)	500,000 ESA – 16 months	At 3 months cracking had started and by 16 months all wheel paths had cracked and rutted from 15 to 23 mm. (Note cracking as top 150 mm was cement stabilised). The sub-contractor considered it was too risky not to stabilise on this site.
Mill and AC inlay	SH24–RS0–2093–2112	Only minor damage on edges at 479,000 ESA – 16 months. Life estimated 3 years or 1.5 MESA (perhaps higher).	At 16 months some cracking and edge failure with rutting <5 mm.
	SH26–RS80–13582–13592 (decreasing side)	Not failed after 150,000 ESA – 16 months	At 16 months the site had not failed but the Hawkeye survey showed high rutting up to 18 mm which needed confirmation.
	SH27–46–17455–17471 (decreasing side)	Not failed after 500,000 ESA – 16 months	At 16 months the site had not failed but rutting was as high as 13 mm on either end of patch from the Hawkeye survey. This needed confirmation with a straight edge.

5.2 Maintenance patch trial trends

The complete set of results for the maintenance patches is summarised in table 5.2 to give common themes and learnings from the 12 maintenance trial patches. For each maintenance patch treatment there were only three trials, which were insufficient to determine whether the variables resulted in short or long lives. Nevertheless, the results were reviewed and assessed to determine the relationship of the observed performance of the patches in terms of predicted life being either: short (<3 years), medium (5 to 10 years) or long (>10 years) along with basic site characteristics, such as:

- traffic – high, medium or low
- pavement depth – very inadequate (>200mm short); inadequate (100mm short) or adequate as based on Austroads (2012, figure 8.4), compared with actual pavement depth and subgrade CBR found from test pits
- in-situ basecourse strength/quality dry – good, medium, poor

- in-situ basecourse strength/quality wet – good, medium, poor
- cemented strength – high/brittle, medium strength, low strength/unbound
- pavement deflection – high, medium or low
- pavement curvature – high, medium or low.

Table 5.3 colour codes the contribution of each site's characteristics to the success or otherwise of the patch. Green is a good result and indicates a positive contribution to the life of the patch; red is not good and will likely reduce the performance of the patch; blue indicates an average result. For this analysis, high cementitious strength is rated 'red' as it results in brittle behaviour where cracking is more likely.

Overall the full depth granular reconstruction patches performed the best followed by mill and AC inlay, although the latter sections that performed well had low pavement deflection. All the cement stabilisation sections, both 1.5% and 3% cement, had short lives of less than three years except one section with 1.5% cement on SH26. It is likely the good performance of this section on SH26 was due to very low traffic volumes, which were one third those of the SH24 and SH27 sites.

Table 5.2 Maintenance patch trial summary – long

Life of Patch	Short <3yrs	Short <3yrs	Short <3yrs	Short <3yrs	Medium 10yrs	Short <3yrs	Long 25yrs	Long 25yrs	Short <3yrs	Short <3yrs	Medium 10yrs	Medium 10yrs
Trial Location	SH24 –RS0 – 1405 – 1465 (increasing side)	SH26 –RS80 – 13612 – 13642 (decreasing side)	SH27 –RS46 – 17825 – 17839 (decreasing side)	SH24 –RS0 – 1465 – 1485 (increasing side)	SH26 –RS80 – 13304 - 13364 (decreasing side)	SH27 –RS46 – 17430-17466 (decreasing side)	SH24 –RS0 – 1975 – 1994 (increasing side)	SH26 –RS80 – 13394 – 13434 (decreasing side)	SH27 –RS46 – 17965 – 17980 (increasing side)	SH24 –RS0 – 2093 - 2112	SH26 –RS80 – 13582 – 13592 (decreasing side)	SH27-46-17455-17471 (decreasing side)
General	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Digout	Digout	Digout then stabilised	AC	AC	AC
Maintenance Patch Type	3% Cement	3% Cement	3% Cement	1.5% Cement	1.5% Cement	1.5% Cement	Full depth granular	Full depth granular	Full depth granular	Mill and AC inlay	Mill and AC inlay	Mill and AC inlay
Site	1	2	3	1	2	3	1	2	3	1	2	3
Traffic ESA per year	360,000	126,000	431,000	360,000	126,000	431,000	360,000	126,000	431,000	360,000	126,000	431,000
Life in ESA (when failure occurred)	88,000	300,000	1,100,000	88,000	1,500,000	100,000	10,000,000	10,000,000	500,000	1,500,000	1,500,000	4,000,000
Years (when failure occurred)	0.5	2.5	2.5	0.5	10	0.5	25	25	1.5	3	10	10
Insufficient Pavement Depth (mm) additional overlay	200	100	100	200	100	100	200	100	100	200	100	100
Existing Pavement Depth	250	300	500	250	300	500	250	300	500	250	300	500
Existing Subgrade Scala CBR	6	6	6	6	6	6	6	6	6	6	6	6
Life based on Fig 8.4 Austroads (ESAs) & Scala CBR	72,000	260,000	2,700,000	72,000	260,000	2,700,000	72,000	260,000	2,700,000	72,000	260,000	2,700,000
RLT (Rut Resistance of BC) - Dry - MESA	8	5	2	8	5	2	8	5	2	8	5	2
RLT (Rut Resistance of BC) - Wet - MESA	0.01	0.001	0.01	0.01	0.001	0.01	0.01	0.001	0.01	0.01	0.001	0.01
RLT (Rut Resistance of SB) - Dry - MESA	5	8	7	5	8	7	5	8	7	5	8	7
PSD (Insitu BC)	Finer than M4	Inside M4	Finer than M4	Finer than M4	Inside M4	Finer than M4	Finer than M4	Inside M4	Finer than M4	Finer than M4	Inside M4	Finer than M4
PI (BC)	12	20	23	12	20	23	12	20	23	12	20	23
Four Day Soaked CBR	2	7	4	2	7	4	2	7	4	2	7	4
Cement Content (%)	3	3	3	1.5	1.5	1.5			1.5			
ITS - Dry (kPa)	656	191	345	296	242	205						
ITS - Soaked (kPa)	596	317	469	377	219	207						
Flexural Beam	1540	680	690	570	380	280						
Pavement Depth OK?	No	No	No	No	No	No	No	No	No	No	No	No
BC Quality	Below Average	Below Average	Poor	Below Average	Below Average	Poor	Below Average	Below Average	Poor	Below Average	Below Average	Poor
Cementitious Behaviour Expected	Bound/Brittle	Unbound/bound	Unbound/bound	Bound/Brittle	Unbound/bound	Unbound/bound			Bound? Stabilised new imported M4 with 1.5%			
D0 10th %ile (existing)	1.81	1.93	1.1	2.1	1.98	1.46	0.94	1.83	1.23	1.66	0.66	1.09
D0-D200 10th %ile (existing)	0.552	0.582	0.216	0.63	0.562	0.382	0.242	0.485	0.33	0.465	0.174	0.218
FWD Predicted Life (existing) - years	1	1	1	1	1	1	40	1	1	1	142	1
FWD Subgrade CBR	3	2	2	3	2	2	5	2	2	2	9	3

Table 5.3 Maintenance patch trial summary – short

Trial Location	SH24 –RS0 – 1405 – 1465 (increasing side)	SH26 –RS80 – 13612 – 13642 (decreasing side)	SH27 –RS46 – 17825 – 17839 (decreasing side)	SH24 –RS0 – 1465 – 1485 (increasing side)	SH26 –RS80 – 13304 - 13364 (decreasing side)	SH27 –RS46 – 17430-17466 (decreasing side)	SH24 –RS0 – 1975 – 1994 (increasing side)	SH26 –RS80 – 13394 – 13434 (decreasing side)	SH27 –RS46 – 17965 – 17980 (increasing side)	SH24 –RS0 – 2093 - 2112	SH26 –RS80 – 13582 – 13592 (decreasing side)	SH27-46-17455-17471 (decreasing side)
General	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Digout	Digout	Digout then stabilised	AC	AC	AC
Maintenance Patch Type	**3% Cement**	**3% Cement**	**3% Cement**	**1.5% Cement**	**1.5% Cement**	**1.5% Cement**	**Full depth granular**	**Full depth granular**	**Full depth granular**	**Mill and AC inlay**	**Mill and AC inlay**	**Mill and AC inlay**
Years (when failure occurred)	V. Short<6months	Short <3yrs	Short <3yrs	V. Short<6months	Medium 10yrs	V. Short<6months	Long 25yrs	Long 25yrs	Short <3yrs	Short <3yrs	Medium 10yrs	Medium 10yrs
Failure Mode	Cracked/rutted	Cracked	Cracked	Cracked/rutted	Cracked	Cracked/rutted	Rutted	Rutted	Cracked/rutted	Cracked	Rutted	Rutted
Life in ESA (when failure occurred)	Low	Low	Medium	Low	Medium	Low	High	High	Low	Medium	Medium	High
Traffic	Medium	Low	Medium	Medium	Low	Medium	Medium	Low	Medium	Medium	Low	Medium
Pavement Depth	very inadequate	inadequate	inadequate	very inadequate	inadequate	inadequate	very inadequate	inadequate	inadequate	very inadequate	inadequate	inadequate
Basecourse Quality Dry	Medium	Medium	Poor	Medium	Medium	Poor	Medium	Medium	Poor	Medium	Medium	Poor
Basecourse Quality Wet	Medium	Poor	Poor	Medium	Poor	Poor	Medium	Poor	Poor	Medium	Poor	Poor
Cementitious Strength	High	Medium	High	Medium	Medium	Low			High			
Pavement Deflection	High	High	Medium	High	High	Medium	Low	High	Medium	High	Low	Low
Pavement Curvature	High	High	Medium	High	High	Medium	Medium	High	Medium	High	Low	Low

5.3 In-situ stabilisation patches

The in-situ stabilised patches consisted of three trials with 1.5% cement and three trials with 3.0% cement and were combined for this assessment to determine if adding more cement resulted in better or worse performance.

5.3.1 Overall performance

- All stabilised patches were constructed with the same equipment and crew using a hoe towed by a tractor with a stabilised depth of 150 mm.
- Construction quality followed standard practice and although improvements in construction quality might have increased life it was observed in these trials that early failure of stabilised patches was due to high traffic and lack of pavement depth.
- All stabilised patches, except a 1.5% cement stabilised patch on SH26, had short lives of six months to 2.5 years.
- The 1.5% cement stabilised patch on SH26 had an estimated life of 10 years even though all the site's characteristics were similar to those of the sites with short lives and high deflections. The reason for the 10-year life estimate was because of low traffic volumes on this particular site. The estimate was based on a traffic loading of 1 MESA, which was the traffic load at which the other stabilised patches failed. Hence, it would take 10 years for this site to get the same traffic loading as occurred on SH24 and SH27 sites in 16 months.
- All stabilised sites failed at total cumulative traffic loadings of up to and less than 1 MESA.
- All stabilised sites had high deflections and inadequate pavement depth, indicating a short life could be expected.

5.3.2 Effect of 1.5% vs 3.0% cement

- On SH24, both 1.5% and 3% cement failed in three months, which was the shortest failure time. The main difference on SH24, compared with the other sites, was its very inadequate pavement depth (ie it needed another 200mm) whereas on SH26 and SH27 the shortfall in depth was only 100 mm.
- On SH26, the 1.5% cement stabilised section lasted five times longer (1.5 MESA) than the 3% cement stabilised section (0.3 MESA) with the only difference being the strength of the 1.5% cement section, which was half that of the 3% cement section. Both had very high deflections although the basecourse was medium quality which would have helped the 1.5% cement stabilised section where the behaviour was more unbound and relied on the aggregate interlock.
- On SH27, the 3% cement stabilised section lasted five times longer than the 1.5% cement stabilised section (table 5.4). The likely reason was that on the latter site the aggregate was poor quality, the deflections were low and it had insufficient strength to remain bound so the aggregate returned to its original poor quality and rutting resulted. The 3% cemented section on the other hand was able to remain bound to give strength to the poor quality aggregate.

Table 5.4 Results for SH27 stabilisation showing longer life (3 years) for 3% cement cf 1.5% cement on site with medium deflection and inadequate pavement depth

Years (when failure occurred)	0.5	2.5	2.5	0.5	10	0.5
Trial Location	SH24 –RS0 – 1405 – 1465 (increasing side)	SH26 –RS80 – 13612 – 13642 (decreasing side)	SH27 –RS46 – 17825 – 17839 (decreasing side)	SH24 –RS0 – 1465 – 1485 (increasing side)	SH26 –RS80 – 13304 - 13364 (decreasing side)	SH27 –RS46 – 17430-17466 (decreasing side)
General	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation	Stabilisation
Maintenance Patch Type	3% Cement	3% Cement	3% Cement	1.5% Cement	1.5% Cement	1.5% Cement
Years (when failure occurred)	V. Short<6months	Short <3yrs	Short <3yrs	V. Short<6months	Medium 10yrs	V. Short<6months
Failure Mode	Cracked/rutted	Cracked	Cracked	Cracked/rutted	Cracked	Cracked/rutted
Life in ESA (when failure occurred)	Low	Low	Medium	Low	Medium	Low
Traffic	Medium	Low	Medium	Medium	Low	Medium
Pavement Depth	very inadequate	inadequate	inadequate	very inadequate	inadequate	inadequate
Basecourse Quality Dry	Medium	Medium	Poor	Medium	Medium	Poor
Basecourse Quality Wet	Medium	Poor	Poor	Medium	Poor	Poor
Cementitious Strength	High	Medium	High	Medium	Medium	Low
Pavement Deflection	High	High	Medium	High	High	Medium
Pavement Curvature	High	High	Medium	High	High	Medium

5.4 Full depth granular reconstruction

In the full depth granular reconstruction an excavator dug out the existing pavement, often down 500 mm, due to a very large excavator bucket, a lack of level control and compact new quarried crush rock subbase and basecourse in the hole. A Scala penetrometer was used on the exposed subgrade soil at the bottom of the hole to check if a greater depth needed to be excavated based on Austroads' pavement thickness requirements. Usually the depth constructed is at least 100 mm more than required and following Austroads (2012) the life increases 10 fold (eg from 1 MESA to 10 MESA). The result of granular reconstruction is a brand new pavement, whose life is not influenced by the previous pavement, except for its depth which is determined by the strength of the in-situ subgrade. Long life is expected for full depth granular reconstruction and the three trials supported this except for the site where the new granular basecourse was stabilised. The following conclusions were made:

- Full depth granular reconstruction will result in a long-life pavement regardless of the existing pavement condition (supported by the good performance seen on trials on SH24 and SH26, table 5.5).
- 1.5% cement stabilisation of a new basecourse in the full granular reconstruction resulted in very high strengths and brittle behaviour occurred, which resulted in cracking and early failure as observed in the SH27 trial (table 5.5).
- All sites had some early rutting due to further compaction caused by traffic. The heavy compaction equipment used on large pavement construction projects is not used on small projects, which can result in the granular material not being properly compacted when open to traffic. Further

compaction/densification from trafficking of only 2% for 500 mm of granular material results in a 10 mm rut.

On reviewing the results in table 5.5 it should be noted the pavement depth, basecourse properties and deflections relate to the existing old pavement and are not fully relevant to the full depth granular reconstructed patch, which used new quarried crushed rock material at depths greater than the design depth. Hence, these basecourse properties and pavement depth are crossed out in table 5.5.

Table 5.5 Results from full depth granular construction trials

Trial Location	SH24 –RS0 – 1975 – 1994 (increasing side)	SH26 –RS80 – 13394 – 13434 (decreasing side)	SH27 –RS46 – 17965 – 17980 (increasing side)
General	Digout	Digout	Digout then stabilised
Maintenance Patch Type	Full depth granular	Full depth granular	Full depth granular
Years (when failure occurred)	Long 25yrs	Long 25yrs	Short <3yrs
Failure Mode	Rutted	Rutted	Cracked/rutted
Life in ESA (when failure occurred)	High	High	Low
Traffic	Medium	Low	Medium
Pavement Depth	very inadequate	inadequate	inadequate
Basecourse Quality Dry	Medium	Medium	Poor
Basecourse Quality Wet	Medium	Poor	Poor
Cementitious Strength			High
Pavement Deflection	Low	High	Medium
Pavement Curvature	Medium	High	Medium

The failure mode of rutting was applied to the two sites that had minimal rutting after 16 months of monitoring but were expected to last at least 25 years before failing from rutting. The SH26 site had 3 mm to 5 mm of rutting, the SH24 site had 6 mm to 8 mm of rutting, and the SH27 site that was 1.5% cement stabilised to a depth of 150 mm had 15 mm to 23 mm ruts in the left-hand wheel paths after 16 months (figure 5.1).

Figure 5.1 Rutting and cracking after 16 months in the SH27 full depth granular reconstruction site which was also stabilised with 1.5% cement

5.5 Mill and AC inlay

The mill and AC inlay sections performed well on SH26 and SH27 where the deflections of the existing pavement were low following the rule of thumb that deflections need to be below 1 mm to support an asphalt surfacing (table 5.6).

Table 5.6 Results from mill and AC inlay trials

Trial Location	SH24 –RS0 – 2093 - 2112	SH26 –RS80 – 13582 – 13592 (decreasing side)	SH27-46-17455-17471 (decreasing side)
General	AC	AC	AC
Maintenance Patch Type	Mill and AC inlay	Mill and AC inlay	Mill and AC inlay
Years (when failure occurred)	Short <3yrs	Medium 10yrs	Medium 10yrs
Failure Mode	Cracked	Rutted	Rutted
Life in ESA (when failure occurred)	Medium	Medium	High
Traffic	Medium	Low	Medium
Pavement Depth	very inadequate	inadequate	inadequate
Basecourse Quality Dry	Medium	Medium	Poor
Basecourse Quality Wet	Medium	Poor	Poor
Cementitious Strength			
Pavement Deflection	High	Low	Low
Pavement Curvature	High	Low	Low

- If pavement deflection is below 1 mm and curvature below 0.2 mm, long life can be expected for the mill and AC treatment.
- A poor quality in-situ basecourse as identified on SH27 can be protected by a 70 mm layer of asphalt and prevent shear failure of the poor basecourse.
- Expected life is 10 years as a typical life of an asphalt surface but after 10 years the site could be resurfaced again to achieve another 10 years.
- These trials have reinforced the Transport Agency message (presented at the 2017 NZ Transport Agency/NZIHT 18th Annual Conference in Tauranga) that sites with high curvature or deflection should not have an asphalt surface unless it is a holding treatment for one year. See table 5.7.

Table 5.7 – Deflection limits for thin asphaltic surfacing. (Martin Gribble, NZ Transport Agency, 18th Annual NZ Transport and NZIHT Conference)

Traffic volume	Heavy trafficked pavements (ADT > 5000)		Medium Trafficked pavements (ADT: 500 – 5000)		Lightly Trafficked pavements (ADT < 500)	
Deflection criteria Surfacing mix type	Maximum 95 Percentile Beam Reading ( )	Maximum 95 percentile curvature (–)	Maximum 95 Percentile Beam Reading ( )	Maximum 95 percentile curvature (–)	Maximum 95 Percentile Beam Reading ( )	Maximum 95 percentile curvature (–)
AC	0.70 mm	0.15 mm	1.00 mm	0.17 mm	1.60 mm	0.2 mm
OGPA	1.10 mm	0.17 mm	1.60 mm	0.19 mm	2.40 mm	0.22 mm
Slurry	0.70 mm	0.15 mm	1.00 mm	0.17 mm	1.60 mm	0.2 mm

6 Pothole mix trials

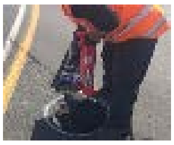
Three different pothole mixes were trialled and monitored as detailed in table 6.1. Asphalt plant mixes along with a proprietary mix bought in bags were trialled for pothole repair. Although the majority of the resources allocated to this research project went into the 12 maintenance patch trials, a small amount was reserved for testing pothole repair mixes. The aim was to determine the effectiveness of the current practice of repairing potholes and whether there was any difference in proprietary pothole repair mixes (CEMIX, QPR and QPR fine). However, the results were inconclusive as each pothole repair was done at a different location and in the shoulder outside the wheel paths.

Best practice was used for pothole repair involving the following steps:

1 Pick away loose material in hole

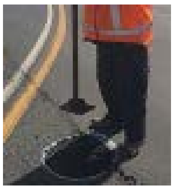
2 Sweep clean the hole

3 Place pothole repair mix



4 Leave mix proud of hole

5 Compact



6 Blind with sand/fines and sweep so not 'sticky'

Table 6.1 Summary of pothole mix trial with CEMIX

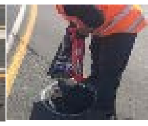
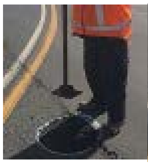
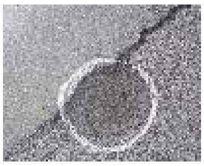
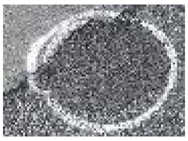
Pothole mix type	Trial location	Details
CEMIX  Cemix Bitupatch is a ready to use, no mixing required, bitumen cold mix asphalt for the repair of potholes in roads, driveways and paths.	SH22–RS0–13490 	Constructed 19 March 2015   **Monitoring**  3 weeks – 2 April 2015 Good condition some settlement  8 weeks – 14 May 2015 Same condition  Nearly 1 year (1 March 2016) Same good condition

Table 6.2 Summary of pothole mix trial with QPR Paeroa mix Hamilton Downer Plant

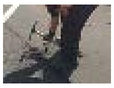
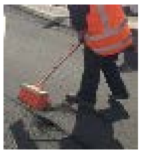
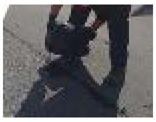
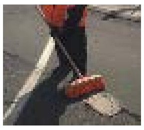
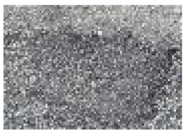
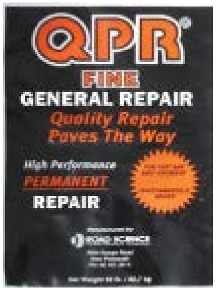
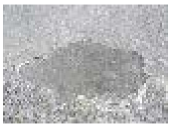
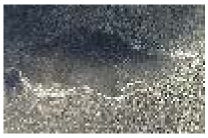
Pothole mix type	Trial location	Details
QPR Paeroa mix Hamilton Downer Plant 	SH22–RS0–13490 	Constructed 19 March 2015   **Monitoring**  3 weeks – 2 April 2015 Good condition  4 weeks – 16 April 2015 Some settlement  Nearly 1 year (1 March 2016) Settled and smooth on edges but good condition

Table 6.3 Summary of pothole mix trial with QPR fine mix Hamilton Downer Plant

Pothole mix type	Trial location	Details		
QPR Fine Mix Hamilton Downer Plant 	SH25–RS226–1900 	Constructed 19 March 2015  **Monitoring**		
		 3 weeks – 2 April 2015 Good condition	 2 months – 14 May 2015 No change	 Nearly 1 year (1 March 2016) Settled and smooth on edges – still good

Asphalt plant mixes along with a proprietary mix bought in bags were trialled for pothole repair. The potholes were constructed following best practice for preparation including sweeping clean the hole. All pothole mixes performed well and their performance was considered to be similar. However, the QPR fine mix Hamilton Plant pothole trial was in the shoulder and as there was not a large volume of traffic using the shoulder it was difficult to assess the performance of the repair compared with the other pothole mixes. A recent visit to the sites found the pothole repairs had not deteriorated any further.

7 Pavement maintenance treatment design

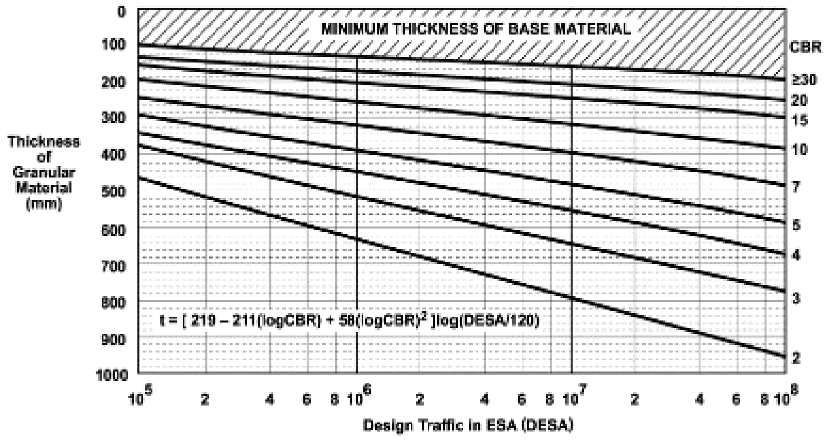
One of the aims of this project was to provide asset managers with a method for estimating the expected life of a maintenance patch treatment to enable them to make an informed decision on the best approach to treating a site. Current practice is often to patch pavement failures within six months of their occurring. The failed patches are re-patched either on the same patch or next to the patch on other failing pavement areas. Patches fail early when they do not address the root cause of failure which is likely to be due to water ingress causing the underlying soils to weaken and/or inadequate pavement depth for the chosen traffic. Another cause of failure is poor quality in-situ basecourse aggregate due to excess fines and lack of large stones which cannot be fixed by the low cement content to modify the basecourse. Multiple chipseal layers, often over 70 mm in thickness, are also difficult to treat. Re-patching a site leads to high maintenance costs recorded in RAMM for the treatment length and these high maintenance costs are used to justify the need for a full pavement renewal. If the designer/asset engineer knows how long a maintenance patch will last then they can make an informed choice not to patch and schedule the site for a pavement renewal, or patch the site using standard practice (ie predicted life is satisfactory), or apply a more robust maintenance patch to achieve the life required.

When estimating the life of the patch nothing beats knowing the history and having experience of how long patches have lasted. Past performance should be used cautiously as there could have been site characteristics that led to a long life of the patch, but these same characteristics might not be present for another site where the same patch is being applied. History of maintenance patch performance should be used to gather a database of life versus various pavement characteristics. The pavement characteristics required to estimate the life of the patch are summarised in table 7.1.

Poor workmanship or inadequate scoping of the area to repair can also lead to early failure of patches and if this is common (although it is preferable to improve the workmanship) it should be factored into the life prediction for patches, based on existing pavement characteristics. Poor workmanship in the 12 maintenance patches was not a problem as current best practice was used. Early failure of a site was due to a design issue such as lack of pavement depth and/or high pavement deflections.

Table 7.1 Pavement characteristics needed to estimate maintenance patch treatment life

<table>
<tr><th>Pavement characteristic</th><th>Value required – either</th><th>Guideline to assist in appropriate value (note users can change criteria based on their experience while the numbers here reflect observations from the maintenance patch trials).</th></tr>
<tr><td>Deflection</td><td>High, medium or low</td><td>This is the peak pavement deflection and typically high is >1.7 mm, medium is 1 to 1.7 mm and low is less than 1 mm.</td></tr>
<tr><td>Curvature/ basecourse quality</td><td>Poor, medium or good</td><td>This is an assessment of the in-situ basecourse quality (top 180 mm) in terms of rut and shear resistance when dry. For in-situ stabilisation this should take into account the proportion of the mix that is chipseal layers – if >30% then the quality should be ‘poor’ as the high proportion of chipseal will reduce aggregate interlock. There are different ways of assessing in-situ basecourse quality. Guidelines are given below and the designer can estimate the quality based on investigations for nearby pavement renewals. The resulting basecourse quality will generally be the most common quality and/or the item where there is the most confidence of the correct value.
<table>
<tr><td>In-situ BC quality</td><td>PSD</td><td>PI</td><td>RLT (dry) – NZTA T15:2014 – slope first 5 stages</td><td>Curvature – D0-D200</td><td>Rutting on site</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Pavement characteristic</th><th>Value required – either</th><th>Guideline to assist in appropriate value (note users can change criteria based on their experience while the numbers here reflect observations from the maintenance patch trials).</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>Poor</td><td>Well outside M4</td><td>>14</td><td>>1.5 %/1M</td><td>>0.5</td><td>Shoving from in-situ basecourse shear failure</td></tr>
<tr><td>Medium</td><td>Just outside M4</td><td>Be-tween 5 and 14</td><td>Between 1.5 and 0.6%/1million</td><td>Between 0.25 and 0.5</td><td>In between poor and good</td></tr>
<tr><td>Good</td><td>Meets M4</td><td><5</td><td><0.6%/1million</td><td><0.25</td><td>Nil rutting or wide ruts associated with subgrade rutting only</td></tr>
</table>
</td></tr>
<tr><td>Pavement depth deficiency</td><td>0 mm; 100 mm; 200 mm</td><td>For the design traffic and subgrade strength, estimate how much extra pavement thickness is required based on the Austroads design chart (see figure below extracted from Austroads 2012, figure 8.4) or on local knowledge in terms of past test pits and digouts in the area to give an estimate of the lack of pavement depth and round to either 0, 100 or 200 mm depending on the closest value. Otherwise estimate whether or not the existing pavement depth is adequate (0 mm or existing depth OK for at least 10 years of future traffic); inadequate (100 mm extra needed); or grossly inadequate (200 mm extra needed).


</td></tr>
<tr><td>Maintenance treatment</td><td>Mill and AC inlay
Granular reconstruction
In-situ stabilisation</td><td>The type of maintenance treatment is needed to estimate its life based on pavement characteristics. At this stage the only treatments where an estimate of life is possible are those trialled in this research project. It should be noted that if granular reconstruction is used and the basecourse is cement stabilised, an assessment of the life of this new stabilised patch is also required based on characteristics of the new granular reconstructed pavement.</td></tr>
<tr><td>Stabilisation effect</td><td>Flexible/ unbound or brittle/bound</td><td>An estimate is needed to indicate if the in-situ stabilisation will result in brittle/bound behaviour where the mode of failure will likely be alligator fatigue cracking due to high cementitious strengths, or if the cementitious strengths will be low and the resulting failure mechanism caused by rutting. A guideline from the patch trials is that flexible/unbound behaviour is more likely if the indirect tensile strength measured as per NZTA T19:2016 specification is less than 200 kPa or the UCS is less than 2 MPa. Austroads recommends for modification a maximum UCS of 1.5 MPa but this test uses standard compaction for densities lower than typically used in New Zealand laboratories, where samples are</td></tr>
</table>

Pavement characteristic	Value required – *either*	Guideline to assist in appropriate value (*note users can change criteria based on their experience while the numbers here reflect observations from the maintenance patch trials*).
		compacted using vibrating compaction. For digouts if stabilisation is not conducted then change this input cell to 'flexible/unbound'.

The following sections use the above inputs combined with the results of the patch trials to estimate lives. There were two inspections at 3 and 16 months and as most of the patches were in a poor state, the life estimates are accurate. However, it is recognised these results apply to this area and may not reflect other areas. Monitoring of patch lives in other networks is needed to validate/calibrate the predictions of life. To cater for the limitations of this research the life predictions were kept in broad categories either: short (<3 years), medium (5 to 10 years) or long (>10 years). Common engineering sense is also applied to the life predictions, for example if pavement depth is very inadequate (lacking 200 mm) and in-situ basecourse quality is poor then the stabilised patch life predicted is 'short'. Conversely if the pavement depth is adequate and the in-situ basecourse quality is good then the stabilised patch life is 'long'.

The most fundamental task in any pavement repair and renewal is to determine the mechanism(s) causing the distress and to identify solutions that address and correct those mechanisms. This is where the designer's experience and judgement are important as there may be a number of contributing factors at play and they may not be easily listed in a table. However, this research is aimed at people who do not have the experience to determine the best treatment and thus use data and life predictions to determine the best treatment based on timing of the pavement renewal and economics. For example if the reason for the pavement failure is lack of pavement depth then to remedy this situation there is only one patch option, which is a full granular reconstruction to restore pavement depth. However, table 7.1 assists contractors to not only address the cause of the problem but also address the existing pavement characteristics needed to use the tool/framework spreadsheet in appendix D (available separately at www.nzta.govt.nz/resources/research/reports/635) to calculate how long each different patch treatment will last. This allows selection of the best treatment based on a range of factors like economics and when the pavement renewal will occur.

7.1 Life estimates for in-situ stabilisation

The five different pavement and material characteristics resulted in 54 different combinations for cement stabilised patches and to illustrate this using decision flowcharts was difficult. The easiest solution was a spreadsheet table with filters listing all possible combinations of pavement characteristics and the associated estimated life. Results from the maintenance patches were used to help estimate the resulting pavement life for some of the combinations relating to the pavement patches while the rest of the lives were estimated based on experience and interpolation of the maintenance patch performance. The accuracy of this method of estimating pavement life is questionable and hence a comment on whether the resulting life would be short, half or full is also given to show the life estimate is approximate. Life estimates are also given in terms of MESA loading to allow treatments that on average give short lives; high traffic roads could in fact result in a long life on a low-volume road. For example a life estimate of 1 MESA is a life of one year on a very high traffic state highway, but on a low-volume road it could take 25 years to load with 1 MESA. The pavement characteristics that result in a short life on an average state highway for a cement stabilised patch are listed below in table 7.2.

Table 7.2 Factors that result in short lives for in- situ stabilised patches

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
High	Poor	0mm	Insitu Stabilisation	Flexible/unbound	1.5	3.8	short
High	Poor	0mm	Insitu Stabilisation	Brittle/bound	1.5	3.8	short
High	Poor	100mm	Insitu Stabilisation	Flexible/unbound	0.75	1.9	short
High	Medium	100mm	Insitu Stabilisation	Flexible/unbound	1.5	3.8	short
Medium	Poor	100mm	Insitu Stabilisation	Flexible/unbound	1.5	3.8	short
Low	Poor	100mm	Insitu Stabilisation	Flexible/unbound	1.5	3.8	short
High	Poor	100mm	Insitu Stabilisation	Brittle/bound	0.25	0.6	short
High	Medium	100mm	Insitu Stabilisation	Brittle/bound	0.5	1.3	short
High	Good	100mm	Insitu Stabilisation	Brittle/bound	0.75	1.9	short
Medium	Poor	100mm	Insitu Stabilisation	Brittle/bound	0.5	1.3	short
Medium	Medium	100mm	Insitu Stabilisation	Brittle/bound	0.75	1.9	short
Medium	Good	100mm	Insitu Stabilisation	Brittle/bound	1	2.5	short
Low	Poor	100mm	Insitu Stabilisation	Brittle/bound	1	2.5	short
High	Poor	200mm	Insitu Stabilisation	Flexible/unbound	0.15	0.4	short
High	Medium	200mm	Insitu Stabilisation	Flexible/unbound	0.3	0.8	short
High	Good	200mm	Insitu Stabilisation	Flexible/unbound	0.45	1.1	short
Medium	Poor	200mm	Insitu Stabilisation	Flexible/unbound	0.3	0.8	short
Medium	Medium	200mm	Insitu Stabilisation	Flexible/unbound	0.45	1.1	short
Medium	Good	200mm	Insitu Stabilisation	Flexible/unbound	0.6	1.5	short
Low	Poor	200mm	Insitu Stabilisation	Flexible/unbound	0.3	0.8	short
Low	Medium	200mm	Insitu Stabilisation	Flexible/unbound	0.6	1.5	short
Low	Good	200mm	Insitu Stabilisation	Flexible/unbound	0.9	2.3	short
High	Poor	200mm	Insitu Stabilisation	Brittle/bound	0.05	0.1	short
High	Medium	200mm	Insitu Stabilisation	Brittle/bound	0.1	0.3	short
High	Good	200mm	Insitu Stabilisation	Brittle/bound	0.15	0.4	short
Medium	Poor	200mm	Insitu Stabilisation	Brittle/bound	0.1	0.3	short
Medium	Medium	200mm	Insitu Stabilisation	Brittle/bound	0.15	0.4	short
Medium	Good	200mm	Insitu Stabilisation	Brittle/bound	0.2	0.5	short
Low	Poor	200mm	Insitu Stabilisation	Brittle/bound	0.1	0.3	short
Low	Medium	200mm	Insitu Stabilisation	Brittle/bound	0.2	0.5	short
Low	Good	200mm	Insitu Stabilisation	Brittle/bound	0.3	0.8	short

The factors that result in a long life are detailed in table 7.3.

Table 7.3 Pavement characteristics that result in a long life for an in- situ stabilised patch

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
Medium	Good	0mm	Insitu Stabilisation	Flexible/unbound	6	15.0	full
Low	Medium	0mm	Insitu Stabilisation	Flexible/unbound	6	15.0	full
Low	Good	0mm	Insitu Stabilisation	Flexible/unbound	9	22.5	full
Medium	Good	0mm	Insitu Stabilisation	Brittle/bound	6	15.0	full
Low	Medium	0mm	Insitu Stabilisation	Brittle/bound	6	15.0	full
Low	Good	0mm	Insitu Stabilisation	Brittle/bound	9	22.5	full

The factors that result in a medium or half life for a stabilised patch are detailed in table 7.4.

Table 7.4 Pavement characteristics that result in a half life for an in- situ stabilised patch

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
High	Medium	0mm	Insitu Stabilisation	Flexible/unbound	3	7.5	half
High	Good	0mm	Insitu Stabilisation	Flexible/unbound	4.5	11.3	half
Medium	Poor	0mm	Insitu Stabilisation	Flexible/unbound	3	7.5	half
Medium	Medium	0mm	Insitu Stabilisation	Flexible/unbound	4.5	11.3	half
Low	Poor	0mm	Insitu Stabilisation	Flexible/unbound	3	7.5	half
High	Medium	0mm	Insitu Stabilisation	Brittle/bound	3	7.5	half
High	Good	0mm	Insitu Stabilisation	Brittle/bound	4.5	11.3	half
Medium	Poor	0mm	Insitu Stabilisation	Brittle/bound	3	7.5	half
Medium	Medium	0mm	Insitu Stabilisation	Brittle/bound	4.5	11.3	half
Low	Poor	0mm	Insitu Stabilisation	Brittle/bound	3	7.5	half
High	Good	100mm	Insitu Stabilisation	Flexible/unbound	2.25	5.6	half
Medium	Medium	100mm	Insitu Stabilisation	Flexible/unbound	2.25	5.6	half
Medium	Good	100mm	Insitu Stabilisation	Flexible/unbound	3	7.5	half
Low	Medium	100mm	Insitu Stabilisation	Flexible/unbound	3	7.5	half
Low	Good	100mm	Insitu Stabilisation	Flexible/unbound	4.5	11.3	half
Low	Medium	100mm	Insitu Stabilisation	Brittle/bound	2	5.0	half
Low	Good	100mm	Insitu Stabilisation	Brittle/bound	3	7.5	half

These results show the stabilisation of works intended on pavements that provide sufficient protection to the subgrade (sufficient pavement depth) and on better aggregates (well graded crushed rock with minimal plastic fines).

7.2 Life estimates for full depth granular reconstruction

Full depth granular reconstruction is effectively digging out and throwing away the old pavement and building a new one using fresh new compliant quarried crushed rock. Hence, the quality of the aggregate in the digout is expected to be always good which reduces the variables when estimating the life of a full depth digout treatment. Pavement characteristics are those that will occur for the newly constructed pavement and if done at the correct depth, as per Austroads (2012), the pavement depth deficiency will be 0 mm. However, the deflection input should be the deflection prior to the newly constructed digout as this reflects the stiffness of the underlying subgrade soil layers and affects the predicted life of the digout if the basecourse aggregate used has been stabilised. In most cases a full depth granular reconstruction is designed taking into account the subgrade strength (eg Scala penetrometer) to give a long life. However, if the granular reconstruction only replaces the same depth of granular material already there and the reason for failure was rutting and/or cracking due to insufficient depth then the resulting life is short. Factors that result in a short, half or full life are shown in tables 7.5 to 7.7.

Table 7.5 Factors that result in a short life for granular reconstruction

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if nil cement choose flexible/unbound)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
High	Good	200mm	Full Depth Granular Reconstruction	Flexible/unbound	0.1	0.3	short
Medium	Good	200mm	Full Depth Granular Reconstruction	Flexible/unbound	0.1	0.3	short
Low	Good	200mm	Full Depth Granular Reconstruction	Flexible/unbound	0.1	0.3	short
High	Good	100mm	Full Depth Granular Reconstruction	Flexible/unbound	1	2.5	short
Medium	Good	100mm	Full Depth Granular Reconstruction	Flexible/unbound	1	2.5	short
Low	Good	100mm	Full Depth Granular Reconstruction	Flexible/unbound	1	2.5	short
High	Good	200mm	Full Depth Granular Reconstruction	Brittle/bound	0.15	0.4	short
Medium	Good	200mm	Full Depth Granular Reconstruction	Brittle/bound	0.2	0.5	short
Low	Good	200mm	Full Depth Granular Reconstruction	Brittle/bound	0.3	0.8	short
High	Good	100mm	Full Depth Granular Reconstruction	Brittle/bound	0.75	1.9	short
Medium	Good	100mm	Full Depth Granular Reconstruction	Brittle/bound	1	2.5	short

Table 7.6 Factors that result in a half life for granular reconstruction

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if nil cement choose flexible/unbound)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
Low	Good	100mm	Full Depth Granular Reconstruction	Brittle/bound	3	7.5	half
High	Good	0mm	Full Depth Granular Reconstruction	Brittle/bound	4.5	11.3	half

Table 7.7 Factors that result in a full life for granular reconstruction

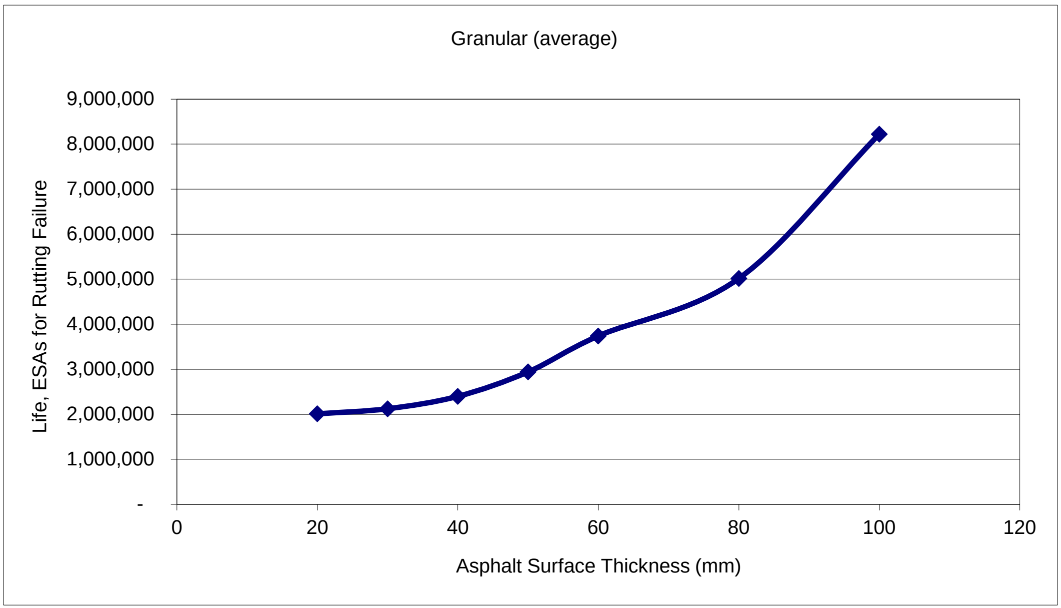
Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if nil cement choose flexible/unbound)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
High	Good	0mm	Full Depth Granular Reconstruction	Flexible/unbound	10	25.0	full
Medium	Good	0mm	Full Depth Granular Reconstruction	Flexible/unbound	10	25.0	full
Low	Good	0mm	Full Depth Granular Reconstruction	Flexible/unbound	10	25.0	full
Medium	Good	0mm	Full Depth Granular Reconstruction	Brittle/bound	6	15.0	full
Low	Good	0mm	Full Depth Granular Reconstruction	Brittle/bound	9	22.5	full

These predictions emphasise that full depth granular reconstruction will only achieve a full 25-year life if the granular reconstruction depth is enough for the design life as per Austroads (2012, figure 8.4). If the reason for failure is lack of pavement depth, simply replacing the granular pavement with the same depth of existing pavement will still result in inadequate pavement depth and a short life will result (or at least the same life as before).

7.3 Life estimates mill and AC inlay

There were three trials of mill and AC inlay with two on low deflecting pavements predicted to reach their expected life, while one was on a low deflecting pavement with a short life. The use of deflection to ascertain the suitability of an asphalt surfacing is well established and is supported by these trials. Modelling rutting under granular materials does show benefit in slowing down the rutting by applying a protective covering thickness of asphalt as shown in figure 7.1 using pavement design software CIRCLY along with basecourse strain criterion (Arnold 2010). The actual protection the asphalt gives depends on the modulus/stiffness in service. On hot days the modulus of the asphalt is low and for slow moving or stop vehicles the modulus is also very low, in which case the added protection against rutting is nil. A factor of five-fold improvement in life can be applied if the modulus is high for the asphalt and the thickness is at least 40 mm. An additional two requirements are applied to help estimate the life of the mill and AC inlay as detailed in table 7.8.

Figure 7.1 Asphalt surface thickness compared with rutting life of underlying granular layers



The AC inlay life is limited to a 'half' life of 10 to 15 years as it is expected to oxidise and fail like most bitumen-based surfacings. The mill and AC maintenance patches performed well in the trial and hence some of the life predictions for this treatment may appear higher than expected.

Table 7.8 Deciding the protective cover effect of the mill and AC either *nil* or *beneficial*

Treatment	Added protection to underlying pavement and subgrade layers?	Explanation
Mill and AC – no depth benefit	Nil	This occurs when the asphalt is either too thin (<40 mm) or the asphalt modulus is low due to slow moving vehicles and/or high temperatures. It also occurs if the asphalt mix binder is not suitable for the high stress and does not comply with the *NZTA M1-A:2016* specification.
Mill and AC – depth benefit	Beneficial	This occurs when the asphalt is at least 40 mm thick with the asphalt binder complying with *NZTA M1-A:2016* specification and the traffic is free flowing at a speed of at least 30 km/h with no chance of stationary or turning vehicles. Increasing the thickness of asphalt to 60 mm to 80 mm would reduce rutting in the subgrade and aggregate layers. This will, however, attract more strains and could fail in fatigue as a thicker layer is acting as a structural asphalt where, if designed correctly, the thickness should be at least 150 mm. Nevertheless, the maintenance patches trialled were all 80 mm thick and classed as heavy duty asphalt patches. To reduce risk of failure of the patch the curvature should be less than 0.2 mm.

Factors that give a full life or 15 years for mill and AC are detailed in table 7.9. Half and short life pavement characteristics are given in tables 7.10 and 7.11.

Actual asphalt performance is also heavily dependent on mix properties, thickness and level of support, which can all be modelled in CIRCLY to predict pavement life using Austroads pavement design procedures for asphalt. The asphalt mix should meet the requirements of *NZTA M10:2014* specification including maximum and minimum layer thicknesses to ensure a long life. Therefore an experienced pavement designer should also review life predictions and model the actual asphalt mixes used to give a more accurate prediction of life. In some cases a short life prediction could be overcome by a polymer modified asphalt that is more flexible.

Table 7.9 Pavement characteristics to ensure a full or long life for a mill and AC maintenance patch

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbounc	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
Medium	Good	0mm	Mill and AC - No depth benefit	Flexible/unbound	6	15.0	full
Low	Medium	0mm	Mill and AC - No depth benefit	Flexible/unbound	6	15.0	full
Low	Good	0mm	Mill and AC - No depth benefit	Flexible/unbound	6	15.0	full
High	Poor	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
High	Medium	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
High	Medium	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
High	Good	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
High	Good	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Poor	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Poor	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Medium	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Medium	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Good	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Good	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Poor	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Poor	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Medium	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Medium	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Good	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Low	Good	0mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full

Table 7.10 Pavement characteristics for a half life for mill and AC maintenance patch

Deflecti	Curvature/Base course Quali	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbounc	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, ful
High	Medium	0mm	Mill and AC - No depth benefit	Flexible/unbound	3	7.5	half
High	Good	100mm	Mill and AC - No depth benefit	Flexible/unbound	2.25	5.6	half
High	Good	0mm	Mill and AC - No depth benefit	Flexible/unbound	4.5	11.3	half
Medium	Poor	0mm	Mill and AC - No depth benefit	Flexible/unbound	3	7.5	half
Medium	Medium	100mm	Mill and AC - No depth benefit	Flexible/unbound	2.25	5.6	half
Medium	Medium	0mm	Mill and AC - No depth benefit	Flexible/unbound	4.5	11.3	half
Medium	Good	100mm	Mill and AC - No depth benefit	Flexible/unbound	3	7.5	half
Low	Poor	0mm	Mill and AC - No depth benefit	Flexible/unbound	3	7.5	half
Low	Medium	100mm	Mill and AC - No depth benefit	Flexible/unbound	3	7.5	half
Low	Good	100mm	Mill and AC - No depth benefit	Flexible/unbound	4.5	11.3	half
High	Poor	100mm	Mill and AC - Depth benefit	Flexible/unbound	3.75	9.4	half
High	Good	200mm	Mill and AC - Depth benefit	Flexible/unbound	2.25	5.6	half
Medium	Medium	200mm	Mill and AC - Depth benefit	Flexible/unbound	2.25	5.6	half
Medium	Good	200mm	Mill and AC - Depth benefit	Flexible/unbound	3	7.5	half
Low	Medium	200mm	Mill and AC - Depth benefit	Flexible/unbound	3	7.5	half
Low	Good	200mm	Mill and AC - Depth benefit	Flexible/unbound	4.5	11.3	half

Table 7.11 Pavement characteristics for a short life for a mill and AC maintenance patch

Deflection	Curvature/Base course Quality	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, full
High	Poor	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.15	0.4	short
High	Poor	100mm	Mill and AC - No depth benefit	Flexible/unbound	0.75	1.9	short
High	Poor	0mm	Mill and AC - No depth benefit	Flexible/unbound	1.5	3.8	short
High	Medium	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.3	0.8	short
High	Medium	100mm	Mill and AC - No depth benefit	Flexible/unbound	1.5	3.8	short
High	Good	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.45	1.1	short
Medium	Poor	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.3	0.8	short
Medium	Poor	100mm	Mill and AC - No depth benefit	Flexible/unbound	1.5	3.8	short
Medium	Medium	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.45	1.1	short
Medium	Good	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.6	1.5	short
Low	Poor	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.3	0.8	short
Low	Poor	100mm	Mill and AC - No depth benefit	Flexible/unbound	1.5	3.8	short
Low	Medium	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.6	1.5	short
Low	Good	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.9	2.3	short
High	Poor	200mm	Mill and AC - Depth benefit	Flexible/unbound	0.75	1.9	short
High	Medium	200mm	Mill and AC - Depth benefit	Flexible/unbound	1.5	3.8	short
Medium	Poor	200mm	Mill and AC - Depth benefit	Flexible/unbound	1.5	3.8	short
Low	Poor	200mm	Mill and AC - Depth benefit	Flexible/unbound	1.5	3.8	short

7.4 Treatment selection

A lookup spreadsheet has been developed (available at [URL to be inserted by HC]) to allow the user to estimate the life of a chosen treatment to manage expectations of life and determine whether it is economic to proceed with the chosen treatment. This method is detailed in the above sections where the treatment is already chosen and the life is predicted. The other way to use the spreadsheet is to put in the pavement characteristics to determine the treatment options that give a full life. For example a very difficult pavement to treat is one that is extremely deficient in depth and has poor quality in-situ aggregates. In this case the only treatment to get a 25-year life for a high-trafficked state highway is a full granular reconstruction as shown in table 7.12. For low-volume roads where a full 25-year life is a cumulative traffic loading of only 0.1 MESA then a range of other treatments is possible for this very weak existing pavement as shown in table 7.13.

Table 7.12 Treatment to obtain a 25- year life for a maintenance patch for a very weak existing pavement on a high- trafficked state highway

Deflection	Curvature/Basecourse Quality	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if not stabilising or only modifying)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, full
High	Poor	200mm	Full Depth Granular Reconstruction - correcting pavement depth deficiency and restoring aggregate quality	Flexible/unbound	10	25.0	full

Table 7.13 Treatment to obtain a 25- year life for a maintenance patch for a very weak existing pavement on a low- volume road where the 25- year design traffic is 0.1 MESA

Deflection	Curvature/Basecourse Quality	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if not stabilising or only modifying)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, full
High	Poor	200mm	Mill and AC - No depth benefit	Flexible/unbound	0.15	0.4	short
High	Poor	200mm	Mill and AC - Depth benefit	Flexible/unbound	0.75	1.9	short
High	Poor	200mm	Insitu Stabilisation	Flexible/unbound	0.15	0.4	short
High	Poor	200mm	Full Depth Granular Reconstruction - correcting pavement depth deficiency and restoring aggregate quality	Flexible/unbound	10	25.0	full
High	Poor	200mm	Full Depth Granular Reconstruction - correcting pavement depth deficiency and restoring aggregate quality	Brittle/bound	4.5	11.3	half

7.5 Drainage improvement

In the above treatments there is no mention of drainage improvement; however, drainage improvement can be incorporated into the life estimate of the various treatments by making improvements to the in-situ pavement characteristics. Improving drainage should dry out the subgrade soil and pavement aggregates and result in a pavement that is not deficient in depth (or not as deficient as before) and the aggregate quality is improved. Table 7.14 details the pavement characteristics that benefit from using drainage improvement as part of the maintenance patch treatment life estimate spreadsheet. These improvements in pavement characteristics are based on engineering estimates and will need validation as this research project did consider improvements in pavement drainage as another variable.

Table 7.15 demonstrates how improving the drainage of a very weak pavement on a high-trafficked road gives more treatment options than the example in table 7.12.

Table 7.14 Existing pavement characteristics that benefit from drainage improvement

Existing pavement characteristic	Existing pavement characteristic value	New improved pavement characteristic value due to drainage improvement
Deflection	High	Medium
Deflection	Medium	Low
Curvature/basecourse quality	Poor	Medium
Curvature/basecourse quality	Medium	Good
Pavement depth (deficiency)	200mm	100mm *(possibly zero if certain can dry out subgrade and keep it dry)*
Pavement depth (deficiency)	100mm	0mm

Table 7.15 Treatments available and life estimates if improving drainage from the worst possible in- situ pavement characteristics

Deflection	Curvature/Basecourse Quality	Pavement Depth (deficiency)	Maintenance Treatment	Cement Stabilisation brittle causing cracking or flexible/unbound (if not stabilising or only modifying)	Life estimate (MESA)	Life estimate (years) - for average SH with 400k ESAs per year	Life estimate - short, half, full
Medium	Medium	100mm	Mill and AC - No depth benefit	Flexible/unbound	2.25	5.6	half
Medium	Medium	100mm	Mill and AC - Depth benefit	Flexible/unbound	6	15.0	full
Medium	Medium	100mm	Insitu Stabilisation	Flexible/unbound	2.25	5.6	half
Medium	Medium	100mm	Full Depth Granular Reconstruction - correcting pavement depth deficiency and restoring aggregate quality	Flexible/unbound	10	25.0	full
Medium	Medium	100mm	Full Depth Granular Reconstruction - correcting pavement depth deficiency and restoring aggregate quality	Brittle/bound	6	15.0	full

8 Construction best practice

The best construction practices reside in the Transit NZ[1]/NZ Transport Agency specifications used for large pavement rehabilitation projects. These specifications have been reviewed by industry and are considered to achieve the best possible performance of the chosen pavement treatment. Ideally the best practices in these specifications should be applied to small maintenance patches on state highways. For example, for granular reconstruction *TNZ B/02: 2005* should be used, while for in-situ stabilised patches *TNZ B/5:2008* specification should be used. Each of these specifications requires a nuclear density meter (NDM) to check the construction has been compacted sufficiently to prevent any further rutting. The *TNZ B/5:2008* specification details time limits for compaction after stabilisation and has procedures to check for binder application rate and quality of binder. These quality assurance (QA) requirements are equally important for small maintenance patches as they are for large pavement rehabilitations. However, because of the small scale of the maintenance patches, perhaps costing $2,500 to build a typical 100 square metre in-situ stabilised patch, it is not cost effective to pay an International Accreditation New Zealand accredited laboratory to visit the site and do NDM and other QA tests. However, if first-coat seal failures and early rutting of patches are occurring it will be beneficial to start using a NDM to ensure the compaction and watering methods used will meet the required targets for compaction (dry density) and degree of saturation prior to sealing as per *TNZ B/02:2005* specification. Given these limitations, some suggestions on best practice for maintenance patches (to accompany contractor guidelines) are given in the following sections.

It should be noted that many thin maintenance patches fail early because of poor workmanship, particularly around the edge of the patch which can be difficult to compact. The failure probably occurs soon after construction and migrates both outside and inside the patch. However, failure at or around the edges was not observed for the 12 maintenance patches monitored in this research as there was either complete failure of the patch (cracking and/or rutting), a small/tiny amount of cracking in the middle of the patch or the patch showed no signs of pavement distress. Therefore it is considered best construction practice was employed for these patches and the reasons for early failure were lack of design and choosing the wrong treatment. To remedy this a maintenance patch treatment selection and design guide has been developed as appendix D using inputs on pavement characteristics as per table 7.1 (see www.nzta.govt.nz/resources/research/reports/635). The maintenance patch treatments explored in this research (in-situ stabilisation, full depth granular reconstruction or mill and AC inlay) are the most common types.

8.1 In-situ stabilisation

This construction practice is the most common due to speed and low cost as new imported aggregates are not required. The following steps represent best practice for constructing an in-situ stabilised patch:

1. Review the *TNZ B/5:2008* specification and aim to meet its requirements as best as is practically possible for a small patch by considering lining up a series of stabilised patches to be constructed on the same day.
2. Mark out the site and ensure the stabilised longitudinal join is not on a wheel path.

[1] Transit NZ merged with Land Transport NZ on 1 August 2008 to form the NZ Transport Agency.

3 Apply appropriate traffic management for the site and safety inductions for all workers with hazards identified and mitigated.

4 Spread cement/lime at correct spread rates, usually 1.5% by dry mass of aggregate which for 150 mm depth stabilisation is approximately 4.5 kg of cement per 1 m^2. Carry out the spread test by placing mats or trays with ideally 1 m^2 in size and weigh to check the required application rate is achieved.

5 Mill cement/lime into pavement at depth of 150 mm to 200 mm and check water content (use experience and a squeeze test for this). Note if sufficient pavement depth stabilising to a depth of 250 mm results in a longer life.

6 Compact with a vibrating roller.

7 Carry out appropriate density tests, eg plateau testing as per the *TNZ B/5:2008* specification although for patches getting a NDM on site may not be practical and thus compaction should be immediately after stabilisation using the correct-sized compaction equipment for at least six passes. Further, a check on whether or not sufficient compaction has been applied is to ensure the hoed-up material is compacted back into the hole. Any excess material cast to waste will mean the compacted stabilised pavement has less density than the in-situ pavement prior to stabilising.

8 Grade and shape to match the surrounding pavement and have the required cross-fall.

9 Apply running course (if required) and maintain traffic control until sealed and swept of loose stones.

10 Consider programming a second-coat seal one month later over the patch to improve its life.

11 Restore the required road markings.

8.2 Full depth granular reconstruction

Full depth granular construction is the most expensive and time consuming but also a treatment that works when nothing else does as it involves digging out the existing pavement and replacing with new crushed rock complying with Transit NZ/NZ Transport Agency specifications for material quality (eg *TNZ M/4:2006*) and for construction (*TNZ B/2:2005).* The following steps represent best practice for constructing a full depth granular reconstruction patch:

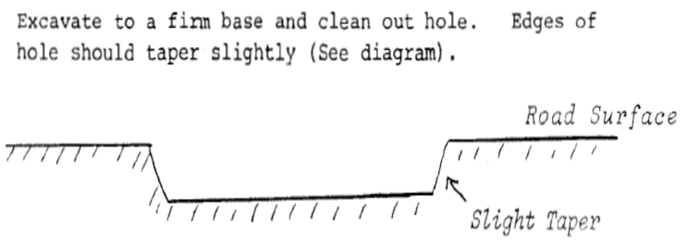
1 Review *TNZ B/2:2005* and *TNZ HM13:2006* specifications and aim to meet their requirements as best as is practicably possible for a small patch by considering lining up a series of stabilised patches to be constructed on the same day.

2 Mark out the site and ensure the longitudinal join is not on a wheel path.

3 Apply appropriate traffic management for the site and safety inductions for all workers with hazards identified and mitigated.

4 Decide whether to excavate a half road width or the whole depending on traffic requirements.

5 Excavate to a finished base and clean out the hole, which should taper slightly downwards.



6 Normally do not excavate more than 350 mm depth unless the design requires a different depth, where a minimum depth of 175 mm of *TNZ M/4 AP40:2006* is used in the top/final layer of the patch.

7 Excavate the digout and where appropriate the drainage trench so the sides have a slight taper towards the centre of the digout (1:6 approximately) and the base slopes towards the nearest accessible drainage facility. The base slope should not be less than 3%+- 1% (Ferry 1981; Roads Research Unit: NZ Institute of County Engineers 1983; Transit NZ 1988).

8 Investigate cause of distress and if drainage is needed, slope the bottom of the excavation to the outer pavement edge.

   a If required, lay subsoil·drain pipes and filter material.

   b Use a Scala penetrometer to determine the required design depth based on the results and traffic loading. Table 8.1 gives guidance on the minimum digout or pavement depth required based on Austroads (2012, figure 8.4).

Table 8.1 Pavement digout depth guide based on Scala penetrometer results (rounded to the nearest 100 mm)

Scala blows per 100 mm		Low traffic 1 MESA	Med traffic 5 MESA	High traffic 10 MESA
	CBR	Pavement depth (mm)	Pavement depth (mm)	Pavement depth (mm)
0.5	1	1,000	1,100	1,200
1	2	700	800	900
1.5	3	500	600	700
2	4	500	500	600
2.5	5	400	500	500
3	6	400	400	500
3.5	7	300	400	400
4	8	300	300	400
4.5	9	300	300	300
5	10	300	300	300
6	13	200	300	300

   c Compact the base and if not sealed on the same day apply a water proofing coat of emulsion to the sides and bottom of the excavation (note this practice is not common and may be skipped unless considered beneficial).

   d Spread coarse aggregate (normal construction base course being compliant with *TNZ M/4:2006* and shape to allow for compaction. A loose depth of layers before compaction should not be more than 200 mm maximum.

   e Compact aggregate checking with a straight edge to achieve a true surface conforming with the adjacent seal.

   f Grade and shape to match the surrounding pavement and have the required cross-fall.

   g Carry out appropriate density tests, eg plateau testing as per *TNZ B2:2005* specification, although for patches getting a NDM on site may not be practical and thus compaction should be immediately after stabilisation using the correct-sized compaction equipment for at least six passes.

h Apply running course (if required) and maintain traffic control until sealed and swept of loose stones.
i Consider programming a second-coat seal one to two months later over the patch to improve its life.
j Restore the required road markings.

8.3 Mill and AC inlay

The mill and AC method follows section 11 of the C-series specifications (Transit NZ 1995) and *TNZ/HM13:2006*. A mill is used to mill off the required depth to accommodate the new asphalt surface without changing the level of the pavement. Asphalt mix commonly used is a mix10 (DG7 as per *NZTA M10:2014* specification) which can be easily hand spread, laid and compacted. A mix 10 (DG7 as per *NZTA M10:2014* specification) has the benefits of being readily available (ie used regularly for other surfaces in a city, precluding the need to make a special brew requiring a small volume for a patch), and of having higher bitumen content for better fatigue resistance, waterproofness and durability. The disadvantages of a mix 10 are insufficient surface texture for skid resistance, and being prone to shoving and rutting under heavy traffic, particularly at intersections and roundabouts. Other potentially more suitable asphalt mixes need another job to justify making the mix, as well as specialist paving equipment, and are not often used unless a significant number of patches are paved with asphalt all at once. There are procedures for the design of asphalt surfaces using deflection curvature or CIRCLY mechanistic design and fatigue criteria following Austroads (2012) that could be used at least for some initial desktop designs for the roading network. For example, 70 or 80 mm of asphalt when designed following procedures in Austroads (2012) show very short lives as at this depth a lot of tensile strain develops; a 30 mm surfacing achieves a longer fatigue life although this does not slow down the rutting of the underlying granular pavement. The following improvements on mill and AC inlay construction should be considered as follows:

- Conduct a desktop pavement design following Austroads (2012) for a range of available asphalt mixes at different thicknesses of 20, 30, 40, 50, 60, 70 and 80 mm and even up to 200 mm to determine suitable asphalt mixes for mill and AC inlay construction and typical lives.
- Use pavement deflection and curvature from FWD or traffic speed deflectometer to determine expected fatigue of the asphalt mix prior to the mill and AC inlay construction.

9 Conclusions

This report presents the results of 12 maintenance patch trials monitored over 16 months. The maintenance patches trialled were the most commonly used: in-situ stabilisation; full depth granular reconstruction and mill and AC inlay. Conclusions from these trials are listed below and were used to shape the treatment selection spreadsheet (see appendix D at www.nzta.govt.nz/resources/research/reports/635 to download the spreadsheet tool for predicting life of maintenance patches) with estimated lives of the patches dependent on some basic pavement characteristics.

- In-situ stabilised patches all had short lives of six months to 2.5 years with the exception of the stabilised patch on the low-volume road which was predicted to have a 10-year life. The main reason for early failure of the stabilised patch was due to lack of pavement depth/cover over the subgrade soil.
- The full depth granular reconstruction patches all resulted in a long-life pavement of at least 10 years regardless of the existing pavement condition as new aggregates were used at the required design depth; however, cement stabilising the new basecourse in the patch resulted in early cracking failure.
- Current practice in terms of choice of treatment and design for small maintenance patches showed the lives of the majority were less than five years and sometimes a little as three months.
- If pavement deflection was below 1 mm and curvature below 0.2 mm, a long life of 10 years resulted for the mill and AC patches trialled in this project.
- Asphalt plant mixes along with a proprietary mix bought in bags were trialled for pothole repair. The potholes were constructed following best practice for preparation including sweeping clean the hole. All pothole mixes performed well to a similar degree.
- Basic pavement characteristics can be used to choose the best maintenance patch treatment and/or to estimate the life of the chosen maintenance patch treatment. These pavement characteristics are explained in table 9.1.

Table 9.1 Pavement characteristics required to predict maintenance patch life

Pavement characteristic	Value required – *either*
Deflection	High, medium or low
Curvature/basecourse quality	Poor, medium or good
Pavement depth deficiency	0mm; 100 mm; 200 mm
Maintenance treatment	Mill and AC inlay Granular reconstruction; in-situ stabilisation
Stabilisation effect	Flexible/unbound or brittle/bound
Mill and AC inlay pavement depth benefit	Either benefit to provide extra cover to aggregate layers or nil benefit

- Pavement maintenance patches (one side of the road usually up to 20 m in length) are just small pavement renewals (where a full road width 0.3 to 2 km length of existing pavement is repaired/treated to renew the pavement to ensure a 25-year life). The same construction methods, design and specifications should be used, although this is not always practical, for example minimum roller passes and the type of roller should be specified to ensure the required density is achieved rather than use a NDM.

10 Recommendations

Prior to applying a maintenance patch, an economic assessment of the life of the pavement treatment should be undertaken using the treatment selection design spreadsheet developed in this research project, available at www.nzta.govt.nz/resources/research/reports/635. This will determine the most cost-effective treatment, which could be a low-cost maintenance patch, a full depth granular reconstruction patch or an accelerated full pavement renewal treatment. Currently, the practice is to first spend a significant amount on patches due to their early failure and then undertake a full pavement renewal. The pavement renewal is justified by the road section becoming too expensive to maintain. However, if the high cost of maintenance patching could be predicted then these predictions could be used to justify the pavement renewal and thus save on maintenance costs.

Although early failures in the research trials were not surface related, it would be beneficial to use a NDM and follow the pavement construction specifications, such as *TNZ B/02:2005* and *TNZ B/5:2008*, as technically a patch is simply a small pavement renewal and to achieve the best result the same best practice should apply.

There are benefits of a treatment selection process but there is also the risk it could replace the engineering judgement component of the design consideration. The designer must go through the process of identifying the distress mechanisms and what options are available to mitigate those mechanisms – this can be lost in an automated, or more prescribed type of design process. In addition, most patch repair sites will not have any test information to work with – the process will be dependent on the designer's interpretation of the visual inspection and local knowledge. Therefore, this treatment process should be validated/calibrated with the local designer so it can be used to good effect in the local area without needing an experienced designer to assess each patch. Further, the treatment selection process is a reminder of the important characteristics the designer must consider when predicting the life of the patch.

As asset managers or network inspectors without pavement design experience have to make decisions on the best patch type, the treatment selection spreadsheet will be an improvement on current practice in determining the best patch type.

11 References

Arnold, G (2010) Development of a basecourse/sub-base design criterion. *NZ Transport Agency research report 429*.

Ferry, A (1981) *A manual of pavement repairs*. Wellington: National Roads Board.

Henning, T, D Alabaster, G Arnold and W Liu (2014) Relationship between traffic loading and environmental factors and low-volume road deterioration. *Transportation Research Record Journal of the Transportation Research Board*. December 2014.

NZ Transport Agency (2005) *Chipsealing in New Zealand*. Wellington: NZ Transport Agency.

Roads Research Unit: NZ Institute of County Engineers (1983) *Maintenance manuals for workmen. Part D Sealed pavement maintenance*. Wellington: National Roads Board. Roads Research Unit.

11.1 Specifications

Austroads (2012) *Guide to pavement technology part 2: pavement structural design*. Sydney: Austroads.

NZTA T10:2010 Specification for state highway skid resistance management. Wellington: NZ Transport Agency.

NZTA T15:2014 Specification for repeated load triaxial (RLT) testing for pavement materials. Wellington: NZ Transport Agency.

NZTA M10:2014 Specification for dense graded and stone mastic asphalt. Wellington: NZ Transport Agency.

NZTA M1–A:2016 Performance specification for asphalt binders. Wellington: NZ Transport Agency.

NZTA T19:2016 Specification for indirect tensile strength testing of modified and bound pavement materials. Draft document. Wellington: NZ Transport Agency.

TNZ B/02:2005 Specification for construction of unbound granular pavement layers. Wellington: NZ Transport Agency.

TNZ M4:2006 Specification for basecourse aggregate. Wellington: NZ Transport Agency.

TNZ HM13:2006 Depressions. Wellington: NZ Transport Agency.

TNZ B/5:2008 Specification for in-situ stabilisation of modified pavement layers. Wellington: NZ Transport Agency.

Transit NZ (1988) R-series maintenance specifications. Wellington: Transit New Zealand.

Transit NZ (1995) C-series maintenance specifications. Wellington: Transit New Zealand. Accessed 24 November 2017. www.nzta.govt.nz/resources/general-maint-c-series-specs/

Appendix A: Maintenance of patch trials – investigation prior to construction

A1 Maintenance patch trials – investigation

Prior to construction of the maintenance patch trials, test pits and laboratory testing were undertaken similar to the investigation and testing conducted for pavement renewals on the state highway network. This involved test pits, Scala penetrometer tests and laboratory tests on the in-situ aggregates. The aim was to treat the maintenance patches as small pavement renewals to determine if their performance/life could have been predicted using already established pavement design methodologies.

A2 Site 1 – SH24 RS 00

A2.1 Design traffic (ESAs)

This is a medium to high-trafficked site with an AADT of 9,029 and with 13% heavy commercial vehicles (HCV) where the calculated equivalent standard axles (ESA) for the inspection times and theoretical design traffic for 10 and 25-year lives are shown below:

- first visual inspection, three months total cumulative traffic = 88,445 ESA
- second inspection using Hawkeye with lasers for rutting and video cameras for visual assessment, 16 months total cumulative traffic = 479,350
- 10-year design traffic = 4.1 MESA
- 25-year design traffic = 13.04 MESA.

Table A.1 Traffic calculations

Years	10
R (growth)	3.00
Cumulative growth factor (CGF)	11.46
Years	25
R (growth)	3.00
CGF	36.46
ADT	9029
Lane	0.5
% HCV	13
Days per year	365
ESA per HCV	1.67
ESA 1st year	357,736
ESA 10 years	4,101,039
ESA 25 years	13,042,782

A2.2 Test pits

Four test pits were undertaken on SH24. Test pit one was the weakest with 220 mm of aggregate cover over a subgrade CBR of 6%. All other test pits were strong with at least 470 mm of aggregate cover over a CBR of 8%.

The results of the test pits were compared with the Austroads (2012) thickness design chart (figure A.1) to determine if the existing pavement depth is adequate for the future design traffic. This shows test pit 1 has insufficient pavement depth with a life of less than one year while the three other tests pits have more than enough pavement depth with a life predicted of greater than 100 years (table A.3).

Figure A.1 Austroads pavement thickness design chart (Austroads 2012, figure 8.4)

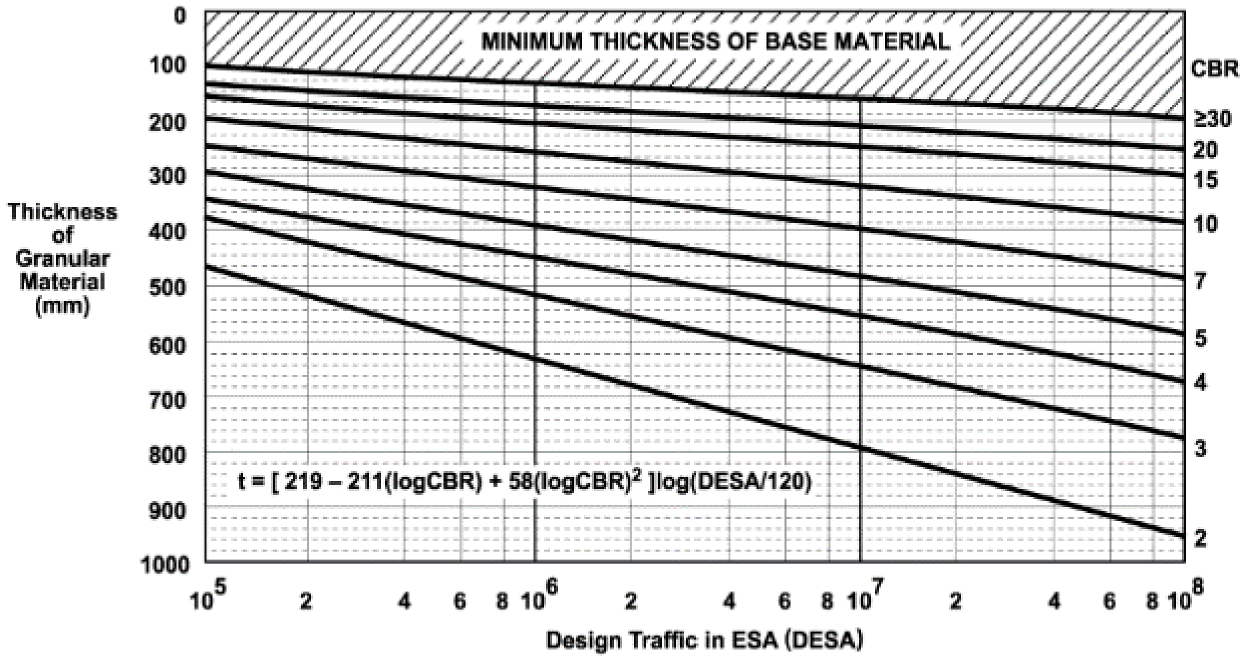


Table A.2 Test pit summary SH24

SH24	
RP00 / 1.45 RHS	
TP1	
Depth (mm)	Material
0-40mm	Chipseal: Worn, flushed, rutted, sound
40-220mm	AP40 Basecourse: Silty GRAVEL (Greywacke), moderately dense, moist, angular, crushed
220 - 350mm	Subbase 1: SAND (Pumice), light brown, loose, moist - Scala CBR 6%
350 - 500mm	Subbase 2: Sandy SILT (Pumice), firm to soft, moist - Scala CBR 6%
500 - 600+mm	Subgrade: SILT, some fine Sand, orangish brown, soft, moist, slightly plastic - SCALA CBR 4%

SH24	
RP00 / 1.43 RHS	
TP2	
Depth (mm)	Material
0-40mm	Chipseal: Worn, flushed, rutted, sound
40-220mm	AP40 Basecourse: Silty GRAVEL (Greywacke), moderately dense, moist.
220 - 400mm	Subbase: Silty SAND, some Gravel, moderately dense, moist - SCALA CBR 20%
400 - 800mm	Subgrade: SAND (Pumice), minor Gravel, light brown, moderately dense, moist. - SCALA CBR 18% (400 to 800mm) - >800mm CBR = 8%

SH24	
RP00 / 1.48 RHS	
TP3	
Depth (mm)	Material
0-40mm	Chipseal: Worn, flushed, rutted, sound
40-230mm	AP40 Basecourse: Silty GRAVEL (Greywacke), moderately dense, moist, angular, crushed
230 - 440mm	Subbase: Fine SAND, light brown, dense, moist, slightly bound / cemented (not stabilized) - SCALA CBR =26%
440 - 600 mm	Subgrade: Silty SAND, orangish brown, moderately dense, moist. - SCALA CBR = 13% (440 to 600mm) and >600mm CBR = 8%

SH24	
RP00 / 2.10 RHS	
TP4	
Depth (mm)	Material
0-35mm	Chipseal: Worn, flushed, rutted, sound
35-230mm	AP40 Basecourse: Silty GRAVEL (Greywacke), some Sand dense, moist, angular, crushed
230 - 470mm	Subbase: Gravelly SAND, light brown, moderately dense, moist - SCALA CBR =16%
470 - 600+mm	Subgrade: Sandy SILT, orangish brown, firm, moist. - SCALA CBR = 8% (470 to 600mm) - >600mm CBR=6%

Table A.3 Test pit summary SH24 analysis of pavement depth and life from Austroads design chart (figure A.1)

					Austroads life	
			Depth (mm)	CBR	ESAs	Years
SH24	RP00/1.45 RHS	TP1	220	6	<100,000	<1
SH24	RP00/1.43 RHS	TP2	400	18	>100 million	>100
SH24	RP00/1.48 RHS	TP3	440	13	>100 million	>100
SH24	RP00/2.10 RHS	TP4	470	8	>100 million	>100

Table A.4 Test pit summary SH24 analysis of pavement depth and life from Austroads design chart (figure A.1)

SH24	RP00 / 1.45 RHS					RP00 / 1.43 RHS					RP00 / 1.48 RHS					RP00 / 2.10 RHS				
ESA 25 years	1.30E+07					1.30E+07					1.30E+07					1.30E+07				
ESA per year	5.22E+05					5.22E+05					5.22E+05					5.22E+05				
	TP1 - overlay calculations (mm)					TP2 - overlay calculations (mm)					TP3 - overlay calculations (mm)					TP4 - overlay calculations (mm)				
		7.2E+04	0.1		**203**		5.3E+09	10231.5		**0**		4.5E+11	######		**0**		2.0E+09	3886.7		**0**
Start Depth					300					450					500					300
Depth (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)
0																				
50																				
100																				
150																				
200																				
250	6	7.23E+04	0.1	453	203															
300	6	2.60E+05	0.5	453	153	23	5.34E+09	10231.5	198	0										
350	6	9.36E+05	1.8	453	103	23	1.00E+11	192590.9	198	0	26	4.48E+11	858357	184	0					
400	6	3.37E+06	6	453	53	23	1.89E+12	3625212.5	198	0	26	1.04E+13	20002511	184	0					
450	6	1.21E+07	23	453	3	20	4.25E+12	8142448.0	215	0	20	4.25E+12	8142448	215	0	16	1.81E+11	347304	247	0
500	6	4.36E+07	83	453	0	18	1.15E+13	22072547.0	229	0	18	1.15E+13	22072547	229	0	16	1.90E+12	3635748	247	0
550	6	1.57E+08	300	453	0	20	9.38E+14	##########	215	0	16	1.99E+13	38060817	247	0	10	2.59E+10	49555	332	0
600	6	5.64E+08	1080	453	0	23	2.37E+17	##########	198	0	13	6.41E+12	12295696	282	0	8	1.00E+10	19161	381	0
650	5	3.88E+08	743	503	0	20	2.07E+17	##########	215	0	16	2.18E+15	#########	247	0	6	2.03E+09	3887	453	0
700	4	1.88E+08	361	569	0	18	2.85E+17	##########	229	0	18	2.85E+17	#########	229	0	6	7.29E+09	13982	453	0
750	4	5.21E+08	999	569	0	17	9.40E+17	##########	238	0	13	3.08E+15	#########	282	0	7	1.64E+11	313424	414	0
800	4	1.44E+09	2768	569	0	16	2.50E+18	##########	247	0	8	4.37E+12	8368454	381	0	8	4.37E+12	8368454	381	0
850	4	4.00E+09	7667	569	0	10	9.08E+14	##########	332	0	8	2.00E+13	38256138	381	0	7	2.70E+12	5176652	414	0
900	4	1.11E+10	21239	569	0	8	9.12E+13	##########	381	0	8	9.12E+13	#########	381	0	6	1.22E+12	2341594	453	0
950	4	3.07E+10	58837	569	0	10	2.97E+16	##########	332	0	8	4.17E+14	#########	381	0	5	3.92E+11	751043	503	0
1000	4	8.50E+10	162995	569	0	16	3.00E+22	##########	247	0	8	1.91E+15	#########	381	0	4	8.50E+10	162995	569	0
1050	8	8.72E+15	#########	381	0	16	3.14E+23	##########	247	0	8	8.72E+15	#########	381	0	5	3.93E+12	7535798	503	0
1100	13	5.59E+21	#########	282	0	16	3.29E+24	##########	247	0	8	3.98E+16	#########	381	0	6	2.05E+14	#########	453	0
1150											8	1.82E+17	#########	381	0	5	3.94E+13	75612540	503	0
1200											8	8.33E+17	#########	381	0	4	5.01E+12	9599693	569	0

A2.3 RLT tests on in-situ basecourse aggregate

The repeated load triaxial (RLT) tests on the in-situ basecourse (figure A.3) and subbase (figure A.2) show the material is around average to just below average in rut resistance when compared with a *TNZ M/4:2006* basecourse. However, the test repeated after soaking the aggregate showed rapid failure (figure A.4) and indicates the aggregate is more moisture sensitive than a new M4 aggregate.

Figure A.2 SH24 RP0/1.08 subbase blend of TP1-4 RLT lab ref T15/0813A

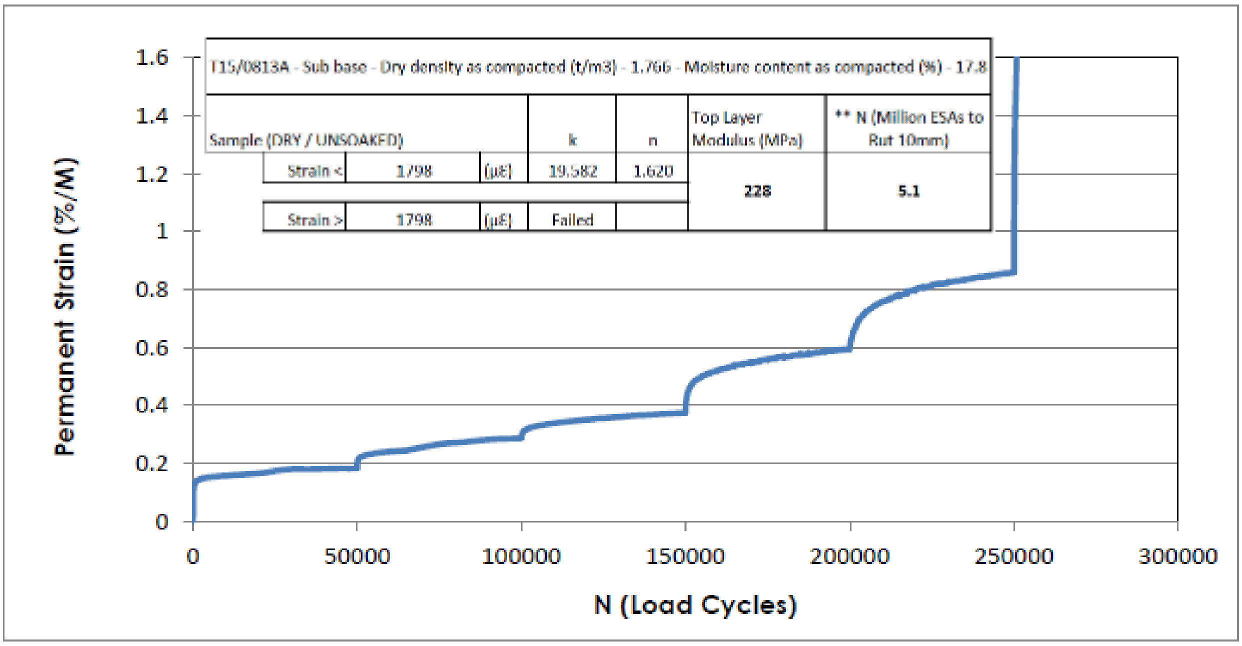


Figure A.3 SH24 RP0/1.08 in- situ basecourse dry, drained RLT blend of TP1-4 RLT ref T15/0824A

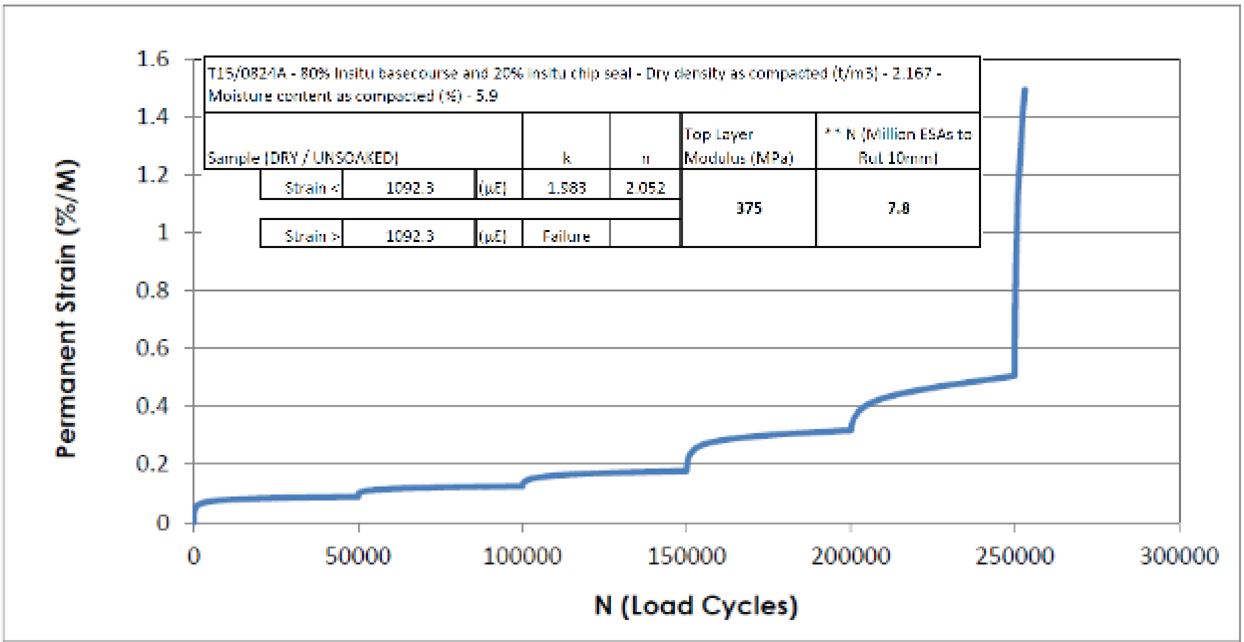
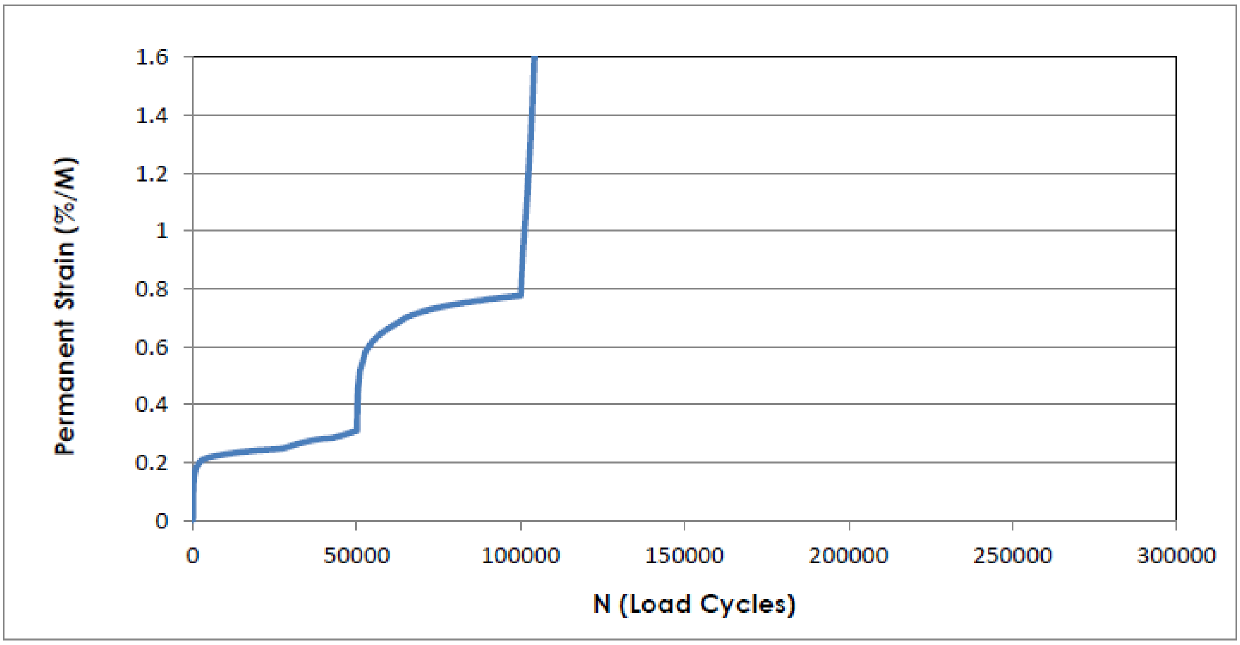


Figure A.4 SH24 RP0/1.08 basecourse soaked, undrained RLT blend of TP1-4 RLT ref T16/0824B

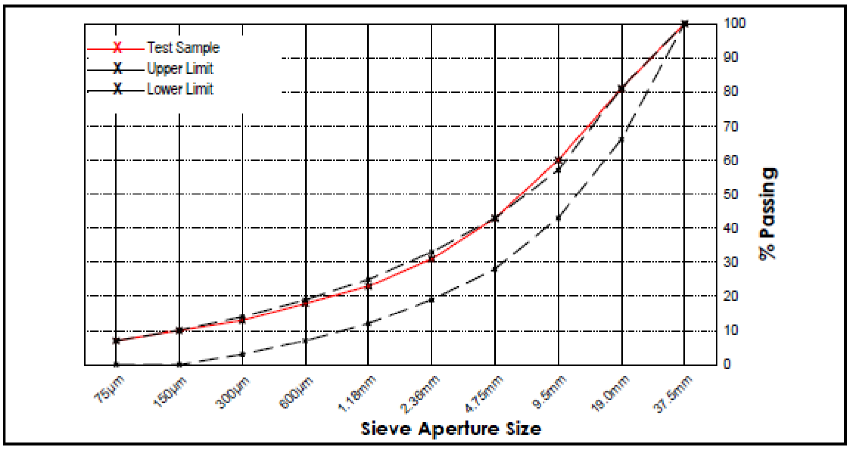


A2.4 Other laboratory test results on in-situ aggregates

Particle size distribution (PSD), Plasticity Index (PI) tests were conducted on the in-situ aggregate. Results show the aggregate is finely graded (figure A.5) and has some clay particles with a PI of 12.

Figure A.5 Particle size distribution in- situ basecourse SH24 TP1-4

Sieve Size (BSS)	Percent passing	Specification
37.5mm	100	100
19.0mm	81	66 - 81
9.5mm	60	43 - 57
4.75mm	43	28 - 43
2.36mm	31	19 - 33
1.18mm	23	12 - 25
600µm	18	7 - 19
300µm	13	3 - 14
150µm	10	0 - 10
75µm	7	0 - 7



Test Date: 20/03/2015

A2.5 Four-day soaked CBR test on in-situ subgrade

The laboratory four-day soaked CBR test on the in-situ subgrade resulted in a value of 2%.

A2.6 Cement reactivity testing (indirect tensile stress – ITS)

Cement reactivity tests were conducted on a mixture of in-situ basecourse aggregate and seal layers to replicate in-situ stabilisation. The results show good reactivity with the likely result of a strong bound pavement, which if not well supported will crack. Note that UCS is around 3 MPa for 1.5% cement and 6 MPa for 3% cement as ITS is around 10% of the UCS. Austroads (2012) recommends the UCS to be less than 1.5 MPa to ensure unbound granular behaviour to prevent cracking.

Table A.5 ITS and flexural beam results for 1.5% and 3% cement contents for site 1 SH24 (3 days @ 60 degrees)

Reference no.	Cement content (%)	Condition	Dry density	Maximum indirect tensile stress (kPa)	Maximum flexural beam stress (kPa)	Estimated design tensile stress (50% of flexural beam strength)
T15/0827	1.5	Dry – ITS	2,137	296		296
	1.5	Wet – ITS	2,099	377		377
	1.5	Flexural beam	2,127 (6.6%)		570	285
T15/0828	3.0	Dry – ITS	2,105	656		656
	3.0	Wet – ITS	2,065	596		596
	3.0	Flexural beam	2,109 (7.5%)		1,540	770

A3 Site 2 – SH26 RS 80

A3.1 Design traffic (ESAs)

This is a medium to high-trafficked site with an AADT of 4,014 and with 9% HCV where the calculated ESA for the inspection times and theoretical design traffic for 10 and 25-year lives are shown below:

- first visual inspection three months total cumulative traffic = 27,221 ESA
- second inspection using Hawkeye with lasers for rutting and video cameras for visual assessment, 16 months total cumulative traffic = 147,533
- 10-year design traffic = 1.26 MESA
- 25-year design traffic = 4.01 MESA.

A3.2 Test pits

Four test pits were undertaken on SH26. Test pit one was the weakest with 220 mm of aggregate cover.

Table A.6 Test pit summary SH26

SH26	
RP80 / 13.326 RHS	
TP5	
Depth (mm)	Material
0-50mm	Chipseal: Worn, flushed, sound
50-200mm	AP65 Basecourse 1: Silty GRAVEL (Greywacke), medium dense, moist - wet, sub angular.
200 - 270mm	AP40 Basecourse 2: Silty GRAVEL (Greywacke), medium dense, moist - wet, sub angular.
270 - 320mm	AP40 Subbase: Silty GRAVEL, medium dense, moist, sub rounded
320 - 420mm	Subgrade 1: SILT , grey, firm, moist, slightly plastic.
420 - 600mm	Subgrade 2: SILT , orange, firm to soft, moist, slightly plastic.

SH26	
RP80 / 13.358 RHS	
TP6	
Depth (mm)	Material
0-40mm	Chipseal: Good
40-100mm	AP40 Basecourse: Sandy Silty GRAVEL (Greywacke), dense, angular, crushed, moist, **cement stabilized**.
100-270mm	AP40 Basecourse 2: Sandy Silty GRAVEL (Greywacke), dense, angular, crushed, moist.
270 - 300mm	Old seal layer
300 - 400mm	Subgrade: SILT, dark greyish green, stiff - firm, moist, slightly plastic.

SH26	
RP80 / 13.580 RHS	
TP7	
Depth (mm)	Material
0-40mm	Chipseal: Worn, flushed.
40-230mm	AP40 Basecourse: Silty GRAVEL (Greywacke), medium dense, angular, crushed, moist - wet, **cement stabilized.**
230 - 450mm	AP65 Subbase: Silty GRAVEL (Greywacke), angular, crushed, medium dense, moist.
450 - 480mm	Old seal layer
480 - 600mm	AP65 Subbase 2: Silty GRAVEL (Greywacke), angular, crushed, medium dense, moist.
600 - 700mm	Subgrade: Silty GRAVEL, light brown, dense, moist.

SH26	
RP80 / 13.637 RHS	
TP8	
Depth (mm)	Material
0-40mm	Chipseal: Worn, flushed, cracked.
40-200mm	AP40 Basecourse: SandyGRAVEL (Greywacke), medium dense, moist - wet, angular, crushed
200 - 300mm	AP65 Subbase: Sandy GRAVEL (Greywacke), medium dense, moist - wet, crushed, angular.
300 - 500mm	Subgrade: SILT, dark grey, firm - soft, moist, slightly plastic.

Table A.7 Scala CBR results along with Austroads design depth compared with actual depth (if overlay calculated then existing pavement depth is inadequate)

SH26	RP80 / 13.326 RHS					RP80 / 13.358 RHS					RP80 / 13.580 RHS					RP80 / 13.637 RHS				
ESA 25 years	4.10E+06					4.10E+06					4.10E+06					4.10E+06				
ESA per year	1.64E+05					1.64E+05					1.64E+05					1.64E+05				
	TP5 - overlay calculations (mm)					TP6 - overlay calculations (mm)					TP7 - overlay calculations (mm)					TP8 - overlay calculations (mm)				
		1.9E+08	1147.2		0		2.6E+05	1.6		108		1.8E+12	######		0		2.8E+07	169.2		0
Start Depth					350					300					600					300
Depth (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)
0																				
50																				
100																				
150																				
200																				
250																				
300						6	2.60E+05	1.6	408	108						13	2.77E+07	169	254	0
350	13	2.17E+08	1325	254	0	6	9.36E+05	5.7	408	58						13	2.17E+08	1325	254	0
400	13	1.70E+09	10383	254	0	6	3.37E+06	20.5	408	8						13	1.70E+09	10383	254	0
450	13	1.33E+10	81347	254	0	6	1.21E+07	73.8	408	0						13	1.33E+10	81347	254	0
500	13	1.05E+11	637293	254	0	6	4.36E+07	265.6	408	0						13	1.05E+11	637293	254	0
550	10	2.59E+10	157642	299	0	4	8.85E+06	54.0	512	0						8	2.19E+09	13334	343	0
600	8	1.00E+10	60955	343	0	4	2.45E+07	149.5	512	0	18	1.81E+15	#########	206	0	6	5.64E+08	3437	408	0
650	6	2.03E+09	12364	408	0	4	6.79E+07	414.1	512	0	18	2.27E+16	#########	206	0	6	2.03E+09	12364	408	0
700	4	1.88E+08	1147	512	0	4	1.88E+08	1147.2	512	0	18	2.85E+17	#########	206	0	6	7.29E+09	44479	408	0
750	4	5.21E+08	3178	512	0	4	5.21E+08	3178.0	512	0	13	3.08E+15	#########	254	0	6	2.62E+10	160007	408	0
800	6	9.44E+10	575605	408	0	2	1.14E+07	69.4	729	0	10	1.59E+14	#########	299	0	6	9.44E+10	575605	408	0
850	6	3.40E+11	2070672	408	0	2	2.33E+07	142.0	729	0	10	9.08E+14	#########	299	0	4	4.00E+09	24389	512	0
900	8	9.12E+13	#########	343	0	2	4.77E+07	290.7	729	0	28	5.10E+27	#########	159	0	4	1.11E+10	67564	512	0
950	6	4.39E+12	26796903	408	0	2	9.76E+07	595.1	729	0	28	1.35E+29	#########	159	0	4	3.07E+10	187171	512	0
1000	6	1.58E+13	96398728	408	0	2	2.00E+08	1217.9	729	0	28	3.59E+30	#########	159	0	4	8.50E+10	518513	512	0
1050	6	5.69E+13	#########	408	0	2	4.09E+08	2492.8	729	0	15	4.36E+22	#########	232	0	2	4.09E+08	2493	729	0
1100	6	2.05E+14	#########	408	0	2	8.37E+08	5102.1	729	0	6	2.05E+14	#########	408	0	2	8.37E+08	5102	729	0
1150	4	1.81E+12	11023579	512	0	2	1.71E+09	10442.7	729	0	4	1.81E+12	11023579	512	0	2	1.71E+09	10443	729	0
1200	4	5.01E+12	30538220	512	0	2	3.51E+09	21373.5	729	0	4	5.01E+12	30538220	512	0	4	5.01E+12	30538220	512	0

Table A.8 Test pit summary SH26 analysis of pavement depth and life from Austroads design chart (see figure A.1)

					Austroads life	
			Depth (mm)	CBR	ESAs	Years
SH26	RP80/13.326 RHS	TP5	350	13	>100 million	>100
SH26	RP80/13.358 RHS	TP6	300	6	260,000	1.6
SH26	RP80/13.580 RHS	TP7	600	8	>100 million	>100
SH26	RP00/13.637 RHS	TP8	300	6	28 million	>100

A3.3 RLT tests on in-situ basecourse aggregate

The RLT tests on the in-situ basecourse (figure A.3) and subbase (figure A.2) show the material is around average to just below average in rut resistance when compared with a *TNZ M/4:2006* basecourse. However, the test repeated after soaking the aggregate showed rapid failure (figure A.4) and indicates the aggregate is more moisture sensitive than a new M4 aggregate.

Figure A.6 SH26 RP80/13.7 subbase blend of TP7 lab ref T15/0818A

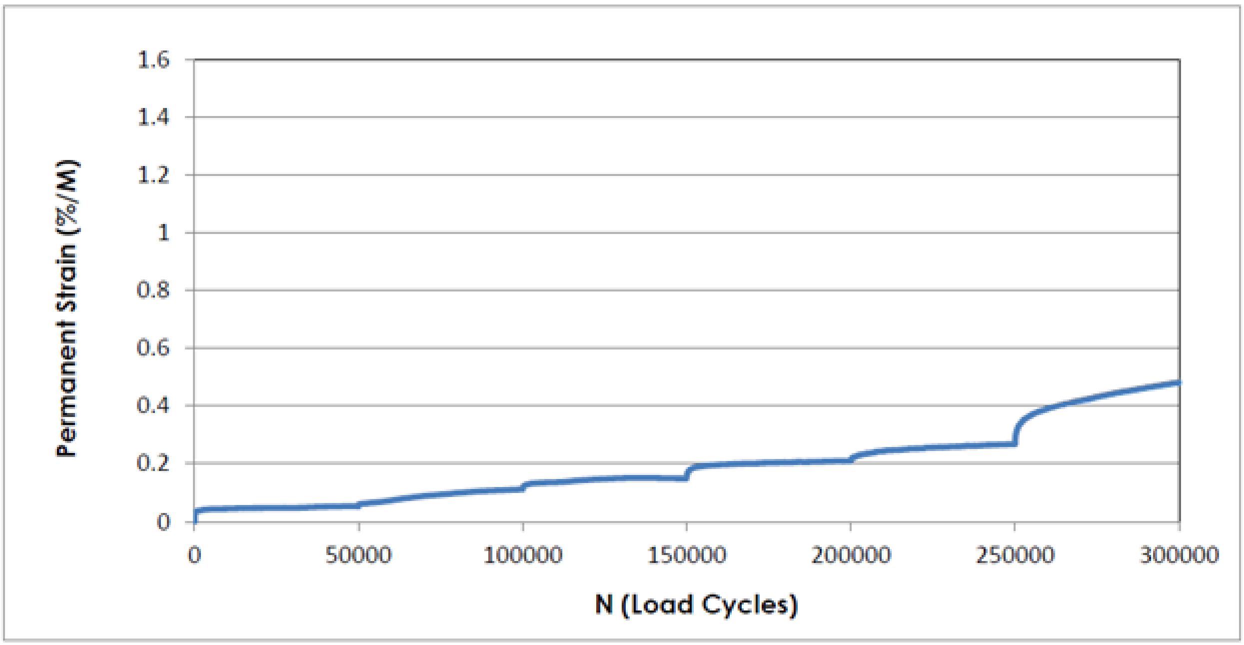


Figure A.7 SH26 RP80 in- situ basecourse dry, drained RLT blend of TP5-8 RLT ref T15/0825A

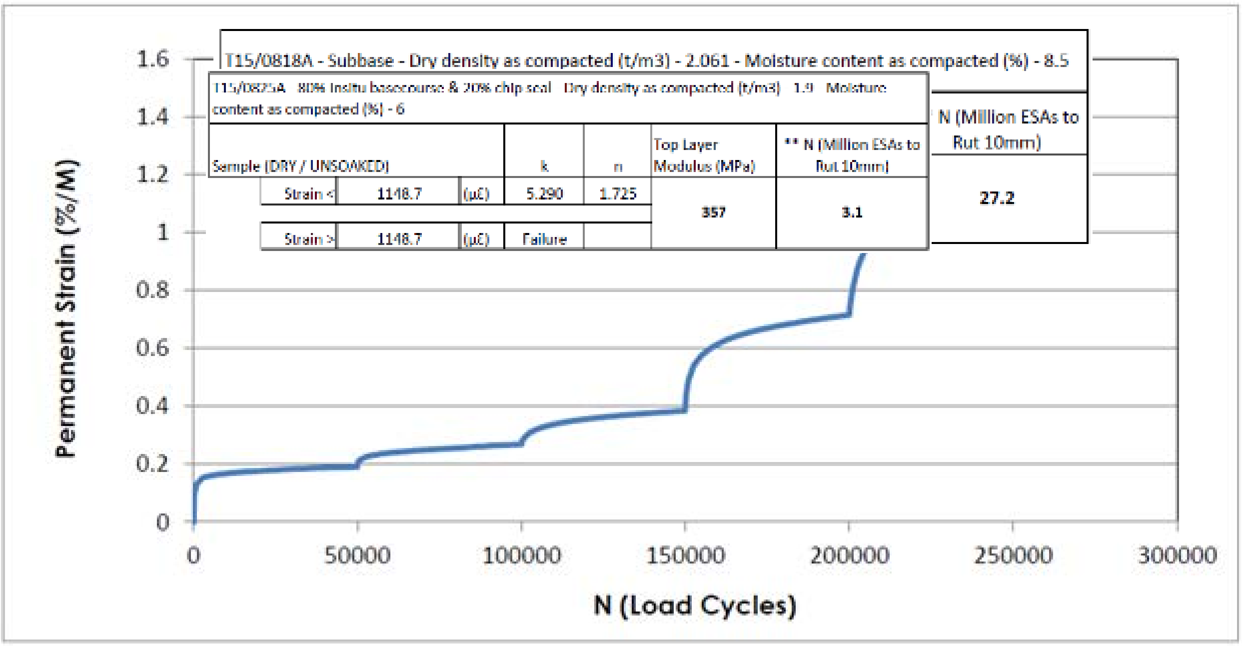
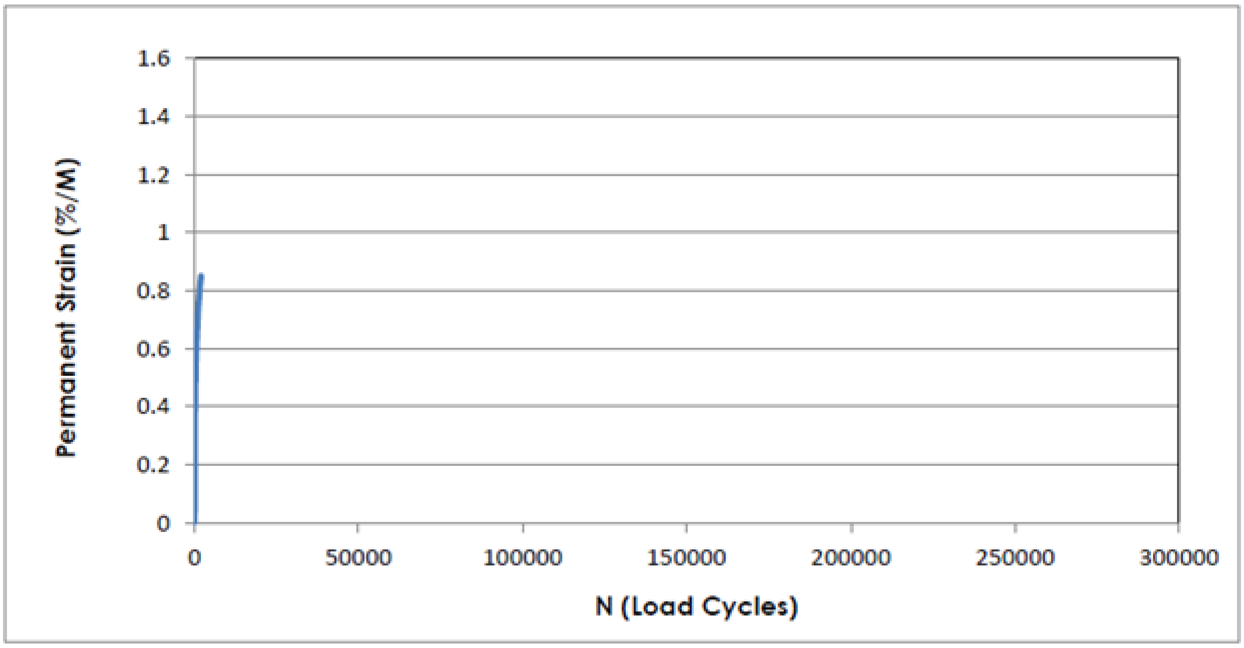


Figure A.8 SH26 RP80 in- situ basecourse soaked, undrained RLT blend of TP5-8 RLT ref T15/0825B

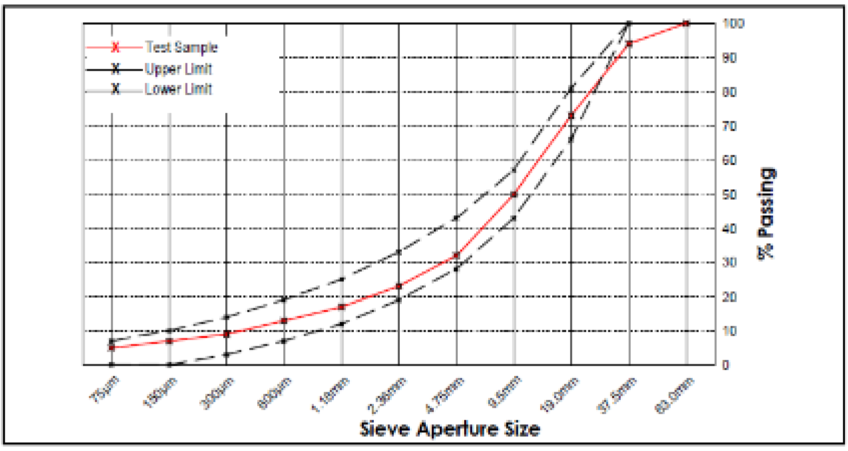


A3.4 Other laboratory test results on in-situ aggregates

PSD, PI tests were conducted on the in-situ aggregate. Results show the aggregate is well graded (figure A.9) and has excessive clay particles with a PI of 20.

Figure A.9 Particle size distribution in- situ basecourse SH26 TP5-8

Sieve Size (BSS)	Percent passing	Specification
63.0mm	100	
37.5mm	94	100
19.0mm	73	66 - 81
9.5mm	50	43 - 57
4.75mm	32	28 - 43
2.36mm	23	19 - 33
1.18mm	17	12 - 25
600µm	13	7 - 19
300µm	9	3 - 14
150µm	7	0 - 10
75µm	5	0 - 7



Test Date: 01/04/2015

A3.5 Four-day soaked CBR test on in-situ subgrade

The laboratory four-day soaked CBR test on the in-situ subgrade resulted in a value of 7% for the subgrade from SH26 RS80 TP6, and 12% for the soaked CBR from TP8.

A3.6 Cement reactivity testing (ITS)

Cement reactivity tests were conducted on a mixture of in-situ basecourse aggregate and seal layers to replicate in-situ stabilisation. The results show good reactivity with the likely result of a strong bound pavement, which if not well supported will crack. Note that UCS is around 2 MPa for 1.5% cement and 3 MPa for 3% cement as ITS is around 10% of the UCS. Austroads (2012) recommends the UCS to be less than 1.5 MPa to ensure unbound granular behaviour to prevent cracking.

Table A.9 ITS and flexural beam results for 1.5% and 3% cement contents for site 1 SH26 (3 days @ 60 degrees)

Reference no.	Cement content (%)	Condition	Dry density	Maximum indirect tensile stress (kPa)	Maximum flexural beam stress (kPa)	Estimated design tensile stress (50% of flexural beam strength)
T15/0829	1.5	Dry – ITS	1853	242		242
	1.5	Wet - ITS	1856	219		219
	1.5	Flexural beam	1930 (9.3%)		380	190
T15/0830	3.0	Dry – ITS	1781	191		191
	3.0	Wet - ITS	1804	317		317
	3.0	Flexural beam	1918 (9.8%)		680	340

A4 Site 3 – SH27 RS 46

A4.1 Design traffic (ESAs)

This is a medium to high-trafficked site with an AADT of 5,870, and 21% HCV where the calculated ESA for the inspection times and theoretical design traffic for 10 and 25-year lives is shown below:

- first visual inspection, three months total cumulative traffic = 92,886 ESA
- second inspection using Hawkeye with lasers for rutting and video cameras for visual assessment 16 months total cumulative traffic = 503,416
- 10-year design traffic = 4.31 MESA
- 25-year design traffic = 13.70 MESA.

A4.2 Test pits

Four test pits were undertaken on SH27. Each measured Scala inferred CBR was checked for adequate cover and it was found the weak subgrade with a CBR of 2 at a depth of 700 mm was the critical layer needing another 100 mm of cover. All other test pits had adequate cover according to Austroads (2012, figure 8.4).

Table A.10 Test pit summary SH27

SH27	
RP46 / 17.448 LHS	
TP10	
Depth (mm)	Material
0-60mm	Chipseal: Worn, flushed, sound
60-190mm	AP40 Basecourse 1: Silty GRAVEL, dense, moist, crushed, angular.
190 - 220mm	Old seal layer
220 - 300mm	AP40 Basecourse 2: Silty GRAVEL, medium dense, moist, crushed, angular.
300 - 500mm	Subgrade, SILT, brown, firm, wet.

SH27	
RP46 / 17.484 LHS	
TP11	
Depth (mm)	Material
0-60mm	Chipseal: Flushed, sound
60-190mm	AP40 Basecourse 1: Silty GRAVEL, dense, moist, crushed, angular.
190 - 220mm	Old seal layer
220 - 330mm	AP40 Basecourse 2: Silty GRAVEL, medium dense, moist, crushed, angular.
330 - 450mm	Subbase: SILT with AP50 river run GRAVEL, medium dense, moist
450 - 600mm	Subgrade, SILT, brown, firm, moist - wet.

SH27	
RP46 / 17.510 LHS	
TP9	
Depth (mm)	Material
0-60mm	Chipseal: Flushed, worn
60-190mm	AP40 Basecourse 1: Silty GRAVEL, dense, moist, crushed, angular.
190 - 220mm	Old seal layer
220 - 350mm	AP40 Basecourse 2: Silty GRAVEL, medium dense, moist, crushed, angular.
350 - 480mm	Subbase: SILT with AP60 river run GRAVEL, medium dense, moist
480 - 600mm	Subgrade, SILT, brown, firm to soft, moist.

SH27	
RP46 / 17.830 LHS	
TP12	
Depth (mm)	Material
0 - 40mm	Chipseal: Worn, flushed, cracked.
40 - 210mm	AP40 Basecourse 1: Silty GRAVEL, **cement stabilised**, dense, dry to moist, crushed, angular (Greywacke).
210 - 300mm	SAND, medium, orange brown, medium dense, moist.
300 - 320mm	Old seal layer
320 - 400mm	Subbase: Silt with Gravel, medium dense, moist.
400 - 550mm	Subgrade, SILT with fine Sand, grey, firm, moist.
550 - 600mm	Subgrade, SILT, orange brown, firm, moist.

Table A.11 Test pit summary SH27 analysis of pavement depth and life from Austroads design chart (figure A.1)

SH27	RP46 / 17.448 LHS					RP46 / 17.484 LHS					RP46 / 17.510 LHS					RP46 / 17.830 LHS				
ESA 25 years	1.37E+07					1.37E+07					1.37E+07					1.37E+07				
ESA per year	5.48E+05					5.48E+05					5.48E+05					5.48E+05				
	TP10 - overlay calculations (mm)					TP11 - overlay calculations (mm)					TP9 - overlay calculations (mm)					TP12 - overlay calculations (mm)				
		2.7E+06	5.0		113		1.1E+07	20.8		13		1.1E+07	21		13		1.9E+08	343.3		0
Start Depth					300					450					500					300
Depth (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)	CBR	Austroads Calc Life (ESA)	Life (years)	Austroads Depth (mm)	Additional Overlay (mm)
0																				
50																				
100																				
150																				
200																				
250																				
300	30	8.61E+10	157036	171	0															
350	30	2.57E+12	4698214	171	0															
400	30	7.70E+13	########	171	0											30	7.70E+13	########	171	0
450	18	9.18E+11	1676069	230	0	10	7.90E+08	1440.7	334	0						30	2.30E+15	########	171	0
500	6	4.36E+07	79	455	0	10	4.52E+09	8244.4	334	0	6	4.36E+07	79	455	0	30	6.89E+16	########	171	0
550	5	3.87E+07	71	505	0	10	2.59E+10	47177.4	334	0	6	1.57E+08	286	455	0	23	1.26E+16	########	198	0
600	4	2.45E+07	45	571	0	10	1.48E+11	269966.4	334	0	6	5.64E+08	1029	455	0	6	5.64E+08	1029	455	0
650	3	1.05E+07	19	665	15	6	2.03E+09	3700.2	455	0	5	3.88E+08	708	505	0	5	3.88E+08	708	505	0
700	2	2.72E+06	5	813	113	4	1.88E+08	343.3	571	0	4	1.88E+08	343	571	0	4	1.88E+08	343	571	0
750	3	6.04E+07	110	665	0	3	6.04E+07	110.3	665	0	3	6.04E+07	110	665	0	4	5.21E+08	951	571	0
800	4	1.44E+09	2635	571	0	2	1.14E+07	20.8	813	13	2	1.14E+07	21	813	13	4	1.44E+09	2635	571	0
850	3	3.48E+08	635	665	0	3	3.48E+08	635.0	665	0	3	3.48E+08	635	665	0	4	4.00E+09	7299	571	0
900	2	4.77E+07	87	813	0	4	1.11E+10	20220.0	571	0	4	1.11E+10	20220	571	0	4	1.11E+10	20220	571	0
950	3	2.00E+09	3656	665	0	4	3.07E+10	56014.6	571	0	4	3.07E+10	56015	571	0	4	3.07E+10	56015	571	0
1000	4	8.50E+10	155175	571	0	4	8.50E+10	155175.3	571	0	4	8.50E+10	155175	571	0	4	8.50E+10	155175	571	0
1050	3	1.15E+10	21053	665	0	3	1.15E+10	21053.4	665	0	5	3.93E+12	7174290	505	0	4	2.36E+11	429877	571	0
1100	2	8.37E+08	1527	813	0	2	8.37E+08	1526.9	813	0	6	2.05E+14	########	455	0	4	6.53E+11	1190871	571	0
1150	2	1.71E+09	3125	813	0	4	1.81E+12	3299027.4	571	0	8	1.82E+17	########	383	0	4	1.81E+12	3299027	571	0
1200	2	3.51E+09	6396	813	0	6	2.65E+15	########	455	0	13	3.43E+23	########	283	0	4	5.01E+12	9139175	571	0

Table A.12 Test pit summary SH27 analysis of pavement depth and life from Austroads design chart (figure A.1)

					Austroads life	
			Depth (mm)	CBR	ESAs	Years
SH27	RP46/17.448 LHS	TP10	500 700	6 2	2,700,000	5
SH27	RP46/17.484 LHS	TP11	450 800	10 2	11,000,000	21
SH27	RP46/17.510 LHS	TP9	500 800	6 2	11,000,000	21
SH27	RP46/17.830 LHS	TP12	400 700	30 4	>100 million	>100

A4.3 RLT tests on in-situ basecourse aggregate

The RLT tests on the in-situ basecourse (figure A.11) and subbase (figure A.10) show the material is below average in rut resistance when compared with a *TNZ M/4:2006* basecourse. However, the test repeated after soaking the aggregate showed rapid failure (figure A.12) and indicated the aggregate was more moisture sensitive than a new M4 aggregate.

Figure A.10 SH27 RP46 subbase RLT lab ref T15/0822A

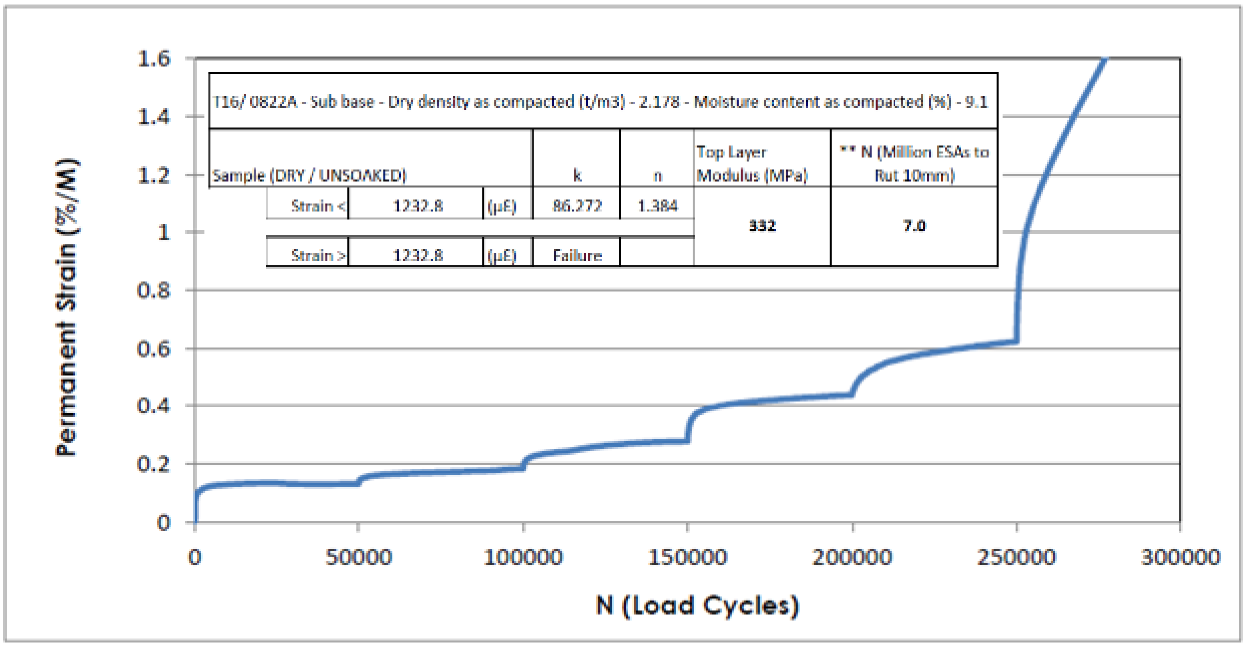


Figure A.11 SH27 RP46 in- situ basecourse and seal dry, drained RLT blend of TPs RLT ref T15/0826A

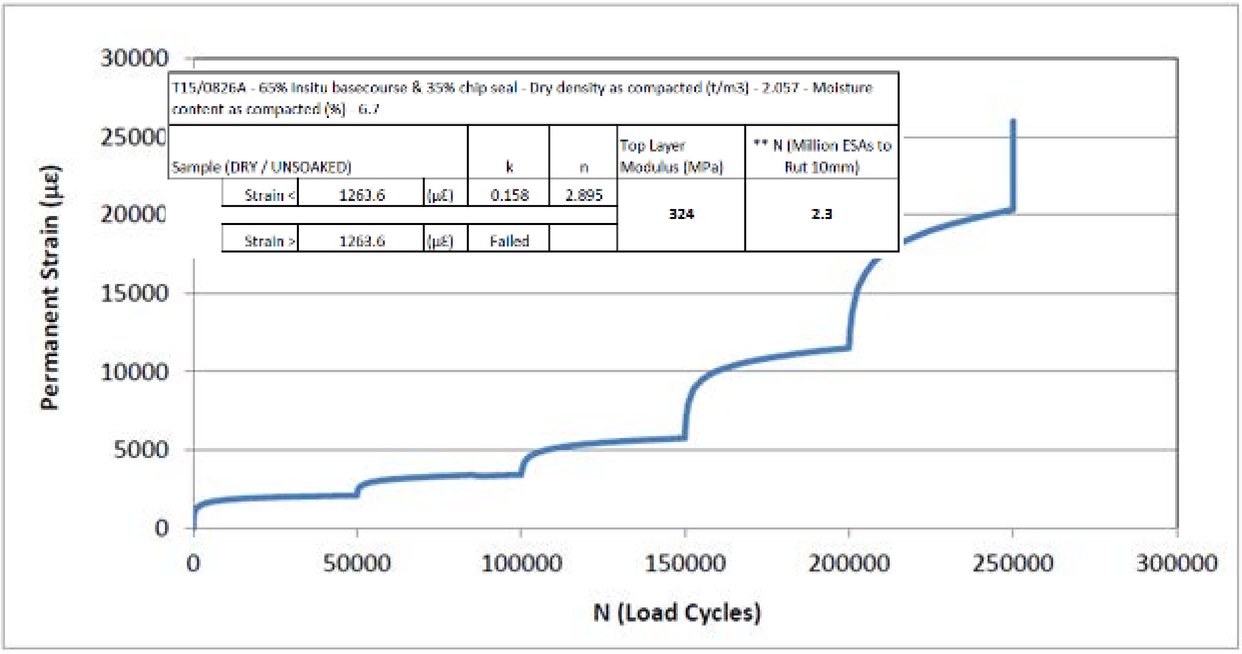
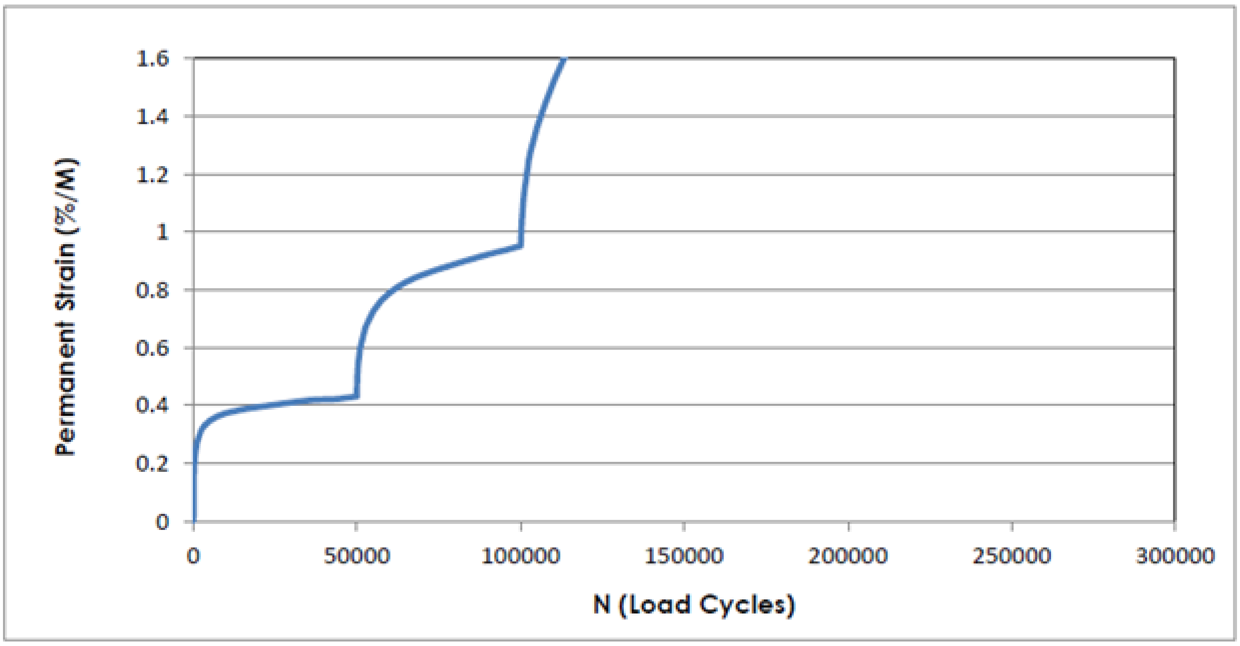


Figure A.12 SH27 RP46 in- situ basecourse and seal soaked, undrained RLT blend of TPs RLT ref T15/0826B

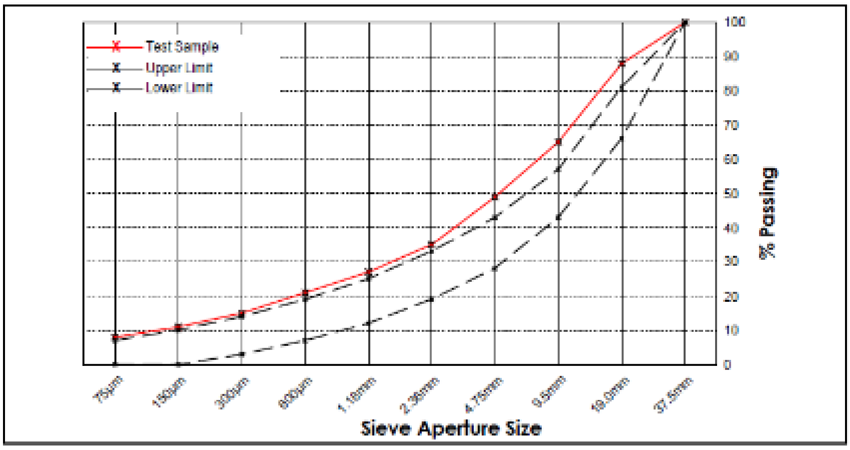


A4.4 Other laboratory test results on in-situ aggregates

PSD PI tests were conducted on the in-situ aggregate. Results show the aggregate is very finely graded (finer than M4, figure A.13) and is high in clay particles with a PI of 23.

Figure A.13 Particle size distribution in- situ basecourse SH27 TP9-12

Sieve Size (BSS)	Percent passing	Specification
37.5mm	100	100
19.0mm	88	66 - 81
9.5mm	65	43 - 57
4.75mm	49	28 - 43
2.36mm	35	19 - 33
1.18mm	27	12 - 25
600µm	21	7 - 19
300µm	15	3 - 14
150µm	11	0 - 10
75µm	8	0 - 7



Test Date: 13/04/2015

A4.5 Four-day soaked CBR test on in-situ subgrade

The laboratory four-day soaked CBR test on the in-situ subgrade resulted in a value of 8% from SH27 TP10 and 4% from TP12.

A4.6 Cement reactivity testing (ITS)

Cement reactivity tests were conducted on a mixture of in-situ basecourse aggregate and seal layers to replicate in-situ stabilisation. The results show good reactivity with the likely result of a strong bound pavement which if not well supported will crack. Note that UCS is around 2 MPa for 1.5% cement and 4 MPa for 3% cement, as ITS is around 10% of the UCS. Austroads (2012) recommends the UCS to be less than 1.5 MPa to ensure unbound granular behaviour to prevent cracking.

Table A.13 ITS and flexural beam results for 1.5 and 3% cement contents for site 1 SH27

Reference no.	Cement content (%)	Condition	Dry density	Maximum indirect tensile stress (kPa)	Maximum flexural beam stress (kPa)	Estimated design tensile stress (50% of flexural beam strength)
T15/0831	1.5	Dry – ITS	1,938	205		205
	1.5	Wet - ITS	1,883	207		207
	1.5	Flexural beam	1,999 (7.3%)		280	140
T15/0832	3.0	Dry – ITS	2,063	345		345
	3.0	Wet - ITS	2,046	469		469
	3.0	Flexural beam	2,136 (6.3%)		690	345

Appendix B: Maintenance patch trials – falling weight deflectometer tests prior to construction

B1 Falling weight deflectometer testing

All maintenance patches prior to construction were tested using the falling weight deflectometer (FWD) with the aim of characterising the sites to assist in predicting the lives of the various maintenance treatments. As the maintenance patches were small in length the FWD testing was conducted in 1 m increments. The traffic speed deflectometer that reports deflections every 2 m along the state highways can possibly be used instead of FWD testing as it is not practical or cost effective to do FWD surveys to assist in treatment selection and design for maintenance patches.

B2 Site 1 – SH24–RS00

B2.1 3% in-situ stabilisation – SH24–RS0–1405–1465

Table B.1 summarises the FWD results, which showed the 10th percentile deflections were very high and the predicted lives of the existing pavement based on pavement depth and subgrade strength were one year over the whole site. Evidently when this site was stabilised with 3% cement the resulting life was one year. This treatment simply restored shape and did not increase the pavement strength as the short life of one year was obtained with 3% cement in-situ stabilisation being the same as the existing pavement.

Table B.1 3% in- situ stabilisation – SH24-RS0-1405-1465 deflection summary

		Average	1.420	0.398	1	4
		Median	1.340	0.370	1	4
		25th	1.630	0.460	1	3
		10th %ile	1.808	0.552	1	3
(km)	**Side**	**WP**	**Cent. Defl**	**Curv. Func.**	**Life (yrs) - Subgrade Strain**	**Subgrade CBR**
1.407	R1	L	2.600	0.700	1	2
1.417	R1	L	1.680	0.450	1	3
1.418	R1	L	1.610	0.380	1	3
1.419	R1	L	1.390	0.350	1	3
1.420	R1	L	1.270	0.320	1	4
1.421	R1	L	1.340	0.380	1	5
1.422	R1	L	1.370	0.330	1	3
1.423	R1	L	1.630	0.400	1	2
1.424	R1	L	1.540	0.430	1	3
1.425	R1	L	1.790	0.540	1	3
1.426	R1	L	1.750	0.490	1	3
1.427	R1	L	1.570	0.460	1	3
1.428	R1	L	1.660	0.460	1	3
1.429	R1	L	1.640	0.440	1	4
1.430	R1	L	1.840	0.570	1	3
1.431	R1	L	1.880	0.580	1	3
1.432	R1	L	1.950	0.550	1	2
1.433	R1	L	1.420	0.440	1	5
1.434	R1	L	1.250	0.370	1	6
1.435	R1	L	1.220	0.370	1	7
1.436	R1	L	1.320	0.410	1	5
1.437	R1	L	1.800	0.560	1	3
1.438	R1	L	1.860	0.550	1	3
1.439	R1	L	1.760	0.620	1	4
1.440	R1	L	1.360	0.420	1	4
1.441	R1	L	1.130	0.310	1	6
1.442	R1	L	1.240	0.390	1	6
1.443	R1	L	1.130	0.290	1	5
1.444	R1	L	1.140	0.280	1	5
1.445	R1	L	1.020	0.300	1	7
1.446	R1	L	1.020	0.260	1	7
1.447	R1	L	1.010	0.280	1	6
1.448	R1	L	1.110	0.360	1	6
1.449	R1	L	1.110	0.340	1	6
1.450	R1	L	1.070	0.250	1	5
1.451	R1	L	1.140	0.280	1	4
1.452	R1	L	1.230	0.330	1	5
1.453	R1	L	1.200	0.340	1	5
1.454	R1	L	1.250	0.370	1	5
1.455	R1	L	1.280	0.380	1	5
1.456	R1	L	1.450	0.490	1	5
1.457	R1	L	1.310	0.320	1	4
1.458	R1	L	1.310	0.340	1	5
1.459	R1	L	1.180	0.310	1	5
1.460	R1	L	1.110	0.260	1	5
1.461	R1	L	1.160	0.290	1	4
1.462	R1	L	1.410	0.320	1	3
1.463	R1	L	1.590	0.500	1	3
1.464	R1	L	1.460	0.330	1	3

Table B.2 1.5% in- situ stabilisation – SH24-RS0-1465-1485

		Average	1.795	0.524	1	3
		Median	1.790	0.530	1	3
		25th	1.920	0.590	1	3
		10th %ile	2.090	0.630	1	3
(km)	**Side**	**WP**	**Cent. Defl**	**Curv. Func.**	**Life (yrs) - Subgrade Strain**	**Subgrade CBR**
1.465	R1	L	1.350	0.410	1	5
1.466	R1	L	1.310	0.380	1	5
1.467	R1	L	1.550	0.400	1	3
1.468	R1	L	1.720	0.500	1	3
1.469	R1	L	1.790	0.500	1	3
1.470	R1	L	1.750	0.480	1	4
1.471	R1	L	1.660	0.450	1	3
1.472	R1	L	1.900	0.600	1	3
1.473	R1	L	2.170	0.680	1	3
1.474	R1	L	2.090	0.630	1	3
1.475	R1	L	1.920	0.590	1	3
1.476	R1	L	1.700	0.520	1	4
1.477	R1	L	1.770	0.550	1	4
1.478	R1	L	1.930	0.610	1	3
1.479	R1	L	2.130	0.580	1	3
1.480	R1	L	1.630	0.460	1	4
1.481	R1	L	1.830	0.580	1	3
1.482	R1	L	1.850	0.560	1	3
1.483	R1	L	1.700	0.330	1	3
1.484	R1	L	2.030	0.660	1	3
1.485	R1	L	1.920	0.530	1	3

Table B.3 Full depth granular reconstruction – SH4-RS0-1975-1994

		Average	0.760	0.193	72	6
		Median	0.700	0.185	79	6
		25th	0.743	0.213	67	6
		10th %ile	0.943	0.242	40	5
(km)	**Side**	**WP**	**Cent. Defl**	**Curv. Func.**	**Life (yrs) - Subgrade**	**Subgrade CBR**
1.975	R1	L	1.220	0.270	1	2
1.976	R1	L	1.060	0.240	11	3
1.977	R1	L	0.930	0.240	43	5
1.978	R1	L	0.730	0.160	78	5
1.979	R1	L	0.670	0.140	95	6
1.980	R1	L	0.670	0.190	110	9
1.981	R1	L	0.700	0.190	85	7
1.982	R1	L	0.730	0.190	72	6
1.983	R1	L	0.750	0.220	67	6
1.984	R1	L	0.690	0.170	90	7
1.985	R1	L	0.650	0.170	95	6
1.986	R1	L	0.670	0.170	93	7
1.987	R1	L	0.640	0.150	87	6
1.988	R1	L	0.680	0.190	87	7
1.989	R1	L	0.670	0.170	80	6
1.990	R1	L	0.740	0.180	72	6
1.991	R1	L	0.740	0.210	72	6
1.992	R1	L	0.680	0.170	98	8
1.993	R1	L	0.700	0.180	66	5
1.994	R1	L	0.880	0.260	45	6

Figure B.4 AC mix 10 mill and inlay – SH24-RS0-2102-2122

		Average	1.459	0.388	3	3
		Median	1.455	0.385	1	3
		25th	1.518	0.423	1	3
		10th %ile	1.655	0.465	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
2.103	R1	L	1.390	0.320	1	3
2.104	R1	L	1.390	0.340	1	3
2.105	R1	L	1.360	0.360	1	3
2.106	R1	L	1.380	0.280	1	3
2.107	R1	L	1.380	0.340	1	3
2.108	R1	L	1.480	0.440	1	2
2.109	R1	L	1.440	0.380	1	3
2.110	R1	L	1.450	0.400	1	3
2.111	R1	L	1.540	0.430	1	3
2.112	R1	L	1.460	0.420	1	3
2.122	R1	L	1.510	0.390	1	3
2.132	R1	L	1.480	0.400	1	4
2.142	R1	L	1.650	0.510	1	3
2.152	R1	L	1.660	0.350	1	2
2.162	R1	L	1.850	0.490	1	2
2.172	R1	L	0.920	0.360	31	10

B3 Site 2 – SH26–RS80

Figure B.5 3% in- situ stabilisation – SH26-RS80-13612-13642

		Average	1.589	0.407	7	3
		Median	1.730	0.450	1	2
		25th	1.865	0.515	1	2
		10th %ile	1.930	0.582	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
13.361	R1	L	2.080	0.570	1	2
13.362	R1	L	1.950	0.520	1	2
13.363	R1	L	1.850	0.500	1	2
13.364	R1	L	1.770	0.380	1	2
13.365	R1	L	1.810	0.510	1	2
13.366	R1	L	1.880	0.590	1	2
13.367	R1	L	1.550	0.250	1	3
13.368	R1	L	1.070	0.240	20	4
13.369	R1	L	0.930	0.140	36	4
13.370	R1	L	0.930	0.160	31	4
13.380	R1	L	1.900	0.620	1	2
13.390	R1	L	1.640	0.450	1	2
13.400	R1	L	1.200	0.340	5	4
13.410	R1	L	1.540	0.340	1	2
13.420	R1	L	1.730	0.500	1	2

Figure B.6 1.5% in- situ stabilisation – SH26-RS80-13304-13364 (decreasing side)

		Average	1.287	0.331	16	4
		Median	1.160	0.290	8	4
		25th	1.420	0.380	1	3
		10th %ile	1.984	0.562	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
13.306	R1	L	1.270	0.330	1	3
13.307	R1	L	1.260	0.320	1	4
13.308	R1	L	1.020	0.240	20	4
13.309	R1	L	1.030	0.280	19	3
13.310	R1	L	1.090	0.260	16	5
13.311	R1	L	1.130	0.270	12	4
13.312	R1	L	1.130	0.260	13	4
13.313	R1	L	1.110	0.260	10	4
13.314	R1	L	1.120	0.280	11	4
13.315	R1	L	1.160	0.280	5	4
13.316	R1	L	1.230	0.270	1	3
13.317	R1	L	1.330	0.310	1	3
13.318	R1	L	1.430	0.340	1	3
13.319	R1	L	1.400	0.400	1	3
13.320	R1	L	1.410	0.380	1	3
13.321	R1	L	1.580	0.400	1	2
13.322	R1	L	1.590	0.370	1	3
13.323	R1	L	1.800	0.420	1	3
13.324	R1	L	1.710	0.460	1	3
13.325	R1	L	1.500	0.390	1	3
13.326	R1	L	1.530	0.340	1	3
13.327	R1	L	1.310	0.260	1	3
13.328	R1	L	1.180	0.190	5	3
13.329	R1	L	0.950	0.180	35	4
13.330	R1	L	0.920	0.220	40	4
13.331	R1	L	0.760	0.140	80	5
13.332	R1	L	0.780	0.170	71	5
13.333	R1	L	0.850	0.200	54	5
13.334	R1	L	0.890	0.210	54	6
13.335	R1	L	0.780	0.180	66	5
13.336	R1	L	0.980	0.240	28	5
13.337	R1	L	0.960	0.220	38	5
13.338	R1	L	0.930	0.260	38	6
13.339	R1	L	0.870	0.220	50	6
13.340	R1	L	0.960	0.250	32	6
13.341	R1	L	1.030	0.290	22	5
13.342	R1	L	1.200	0.310	4	4
13.343	R1	L	1.100	0.270	8	4
13.344	R1	L	1.100	0.310	11	4
13.345	R1	L	1.120	0.340	13	5
13.346	R1	L	1.090	0.310	23	6
13.347	R1	L	1.000	0.220	22	4
13.348	R1	L	1.150	0.290	13	5
13.349	R1	L	1.330	0.380	1	3
13.350	R1	L	0.980	0.250	29	5
13.351	R1	L	1.210	0.370	10	5
13.352	R1	L	1.210	0.330	4	4
13.353	R1	L	1.350	0.420	1	4
13.354	R1	L	1.840	0.590	1	2
13.355	R1	L	2.110	0.620	1	2
13.356	R1	L	2.130	0.620	1	2
13.357	R1	L	2.480	0.680	1	1
13.358	R1	L	2.180	0.600	1	2
13.359	R1	L	2.160	0.700	1	2
13.360	R1	L	2.080	0.520	1	2

Figure B.7 Full depth granular reconstruction – SH26-RS80-13394-13434 (decreasing side)

		Average	1.627	0.420	2	2
		Median	1.685	0.435	1	2
		25th	1.768	0.465	1	2
		10th %ile	1.825	0.485	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
13.390	R1	L	1.640	0.450	1	2
13.400	R1	L	1.200	0.340	5	4
13.410	R1	L	1.540	0.340	1	2
13.420	R1	L	1.730	0.500	1	2
13.430	R1	L	1.780	0.470	1	2
13.440	R1	L	1.870	0.420	1	2

Figure B.8 AC mix 10 mill and inlay – SH26-RS80-13582-13592 (decreasing side)

		Average	0.593	0.150	150	11
		Median	0.620	0.150	150	11
		25th	0.645	0.165	145	10
		10th %ile	0.660	0.174	142	9
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
13.604	R1	L	0.490	0.120	160	13
13.612	R1	L	0.620	0.180	150	11
13.614	R1	L	0.670	0.150	140	8

B4 Site 3 – SH27–RS46

Figure B.9 3% in- situ stabilisation – SH27-RS46-17825-17839

		Average	0.957	0.159	15	3
		Median	0.930	0.150	11	3
		25th	1.025	0.175	5	3
		10th %ile	1.098	0.216	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
17.825	L1	L	0.890	0.150	23	3
17.826	L1	L	0.790	0.110	44	3
17.827	L1	L	0.840	0.120	32	3
17.828	L1	L	0.860	0.120	26	3
17.829	L1	L	0.960	0.160	10	3
17.830	L1	L	1.050	0.160	1	2
17.831	L1	L	1.120	0.210	1	2
17.832	L1	L	0.960	0.130	11	3
17.833	L1	L	1.080	0.220	1	3
17.834	L1	L	0.930	0.140	11	2
17.835	L1	L	0.930	0.140	14	3
17.836	L1	L	0.900	0.110	23	3
17.837	L1	L	0.930	0.170	12	3
17.838	L1	L	1.110	0.260	1	3
17.839	L1	L	1.000	0.180	9	3

Figure B.10 1.5% in- situ stabilisation – SH27-RS46-17430-17466 (decreasing side)

		Average	1.121	0.252	2	3
		Median	1.100	0.230	1	3
		25th	1.340	0.300	1	2
		10th %ile	1.464	0.382	1	2
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
17.430	L1	L	0.930	0.180	1	3
17.431	L1	L	0.870	0.180	1	5
17.432	L1	L	0.930	0.220	1	4
17.433	L1	L	0.830	0.200	4	4
17.434	L1	L	0.830	0.170	2	4
17.435	L1	L	1.010	0.230	1	4
17.436	L1	L	1.120	0.230	1	3
17.437	L1	L	1.130	0.250	1	3
17.438	L1	L	1.100	0.230	1	3
17.439	L1	L	1.080	0.230	1	3
17.440	L1	L	1.110	0.230	1	3
17.441	L1	L	1.190	0.250	1	3
17.442	L1	L	1.340	0.260	1	2
17.443	L1	L	1.400	0.300	1	2
17.444	L1	L	1.410	0.340	1	2
17.445	L1	L	1.490	0.350	1	2
17.446	L1	L	1.360	0.280	1	2
17.447	L1	L	1.470	0.420	1	2
17.448	L1	L	1.610	0.520	1	3
17.449	L1	L	1.460	0.480	1	2
17.450	L1	L	1.500	0.400	1	2
17.451	L1	L	1.430	0.370	1	2
17.452	L1	L	1.310	0.310	1	2
17.453	L1	L	1.240	0.310	1	3
17.454	L1	L	1.110	0.260	1	3
17.455	L1	L	1.080	0.190	1	3
17.456	L1	L	1.240	0.280	1	3
17.457	L1	L	1.100	0.260	1	3
17.458	L1	L	0.980	0.180	1	3
17.459	L1	L	1.010	0.170	1	4
17.460	L1	L	0.790	0.130	6	3
17.461	L1	L	0.790	0.130	8	3
17.462	L1	L	0.900	0.160	1	3
17.463	L1	L	0.800	0.130	5	3
17.464	L1	L	0.820	0.150	2	4
17.465	L1	L	0.840	0.160	1	4
17.466	L1	L	0.860	0.170	1	4

Figure B.11 Full depth granular reconstruction – SH27-RS46-17965-17980 (increasing side)

		Average	1.098	0.282	6	3
		Median	1.115	0.270	1	3
		25th	1.170	0.305	1	3
		10th %ile	1.225	0.330	1	2
17.965	L1	L	1.000	0.300	10	4
17.966	L1	L	1.000	0.250	7	3
17.967	L1	L	1.080	0.260	1	3
17.968	L1	L	1.100	0.270	1	3
17.969	L1	L	1.100	0.240	1	2
17.970	L1	L	1.160	0.250	1	2
17.971	L1	L	1.240	0.330	1	3
17.972	L1	L	1.210	0.260	1	2
17.973	L1	L	1.260	0.370	1	3
17.974	L1	L	1.130	0.270	1	3
17.975	L1	L	1.170	0.280	1	2
17.976	L1	L	1.170	0.300	1	3
17.977	L1	L	1.170	0.330	1	3
17.978	L1	L	0.980	0.320	14	4
17.979	L1	L	0.860	0.210	32	5
17.980	L1	L	0.940	0.270	18	5

Figure B.12 AC mix 10 mill and inlay – SH27-46-17455-17471 (decreasing side)

		Average	0.910	0.170	3	3
		Median	0.860	0.160	1	3
		25th %ile	0.980	0.180	1	3
		10th %ile	1.088	0.218	1	3
km	**Side**	**WP**	**Cent.**	**Curv.**	**Life (yrs) -**	**Subgrade**
17.455	L1	L	1.080	0.190	1	3
17.456	L1	L	1.240	0.280	1	3
17.457	L1	L	1.100	0.260	1	3
17.458	L1	L	0.980	0.180	1	3
17.459	L1	L	1.010	0.170	1	4
17.460	L1	L	0.790	0.130	6	3
17.461	L1	L	0.790	0.130	8	3
17.462	L1	L	0.900	0.160	1	3
17.463	L1	L	0.800	0.130	5	3
17.464	L1	L	0.820	0.150	2	4
17.465	L1	L	0.840	0.160	1	4
17.466	L1	L	0.860	0.170	1	4
17.467	L1	L	0.870	0.190	1	4
17.468	L1	L	0.850	0.160	3	3
17.469	L1	L	0.800	0.110	10	3
17.470	L1	L	0.900	0.180	1	4
17.471	L1	L	0.840	0.140	6	3

Appendix C: Maintenance patch trials – monitoring

Three different state highways representing three different traffic volumes were chosen to trial four different standard maintenance patch treatments:

1 3% cement in-situ stabilisation to a depth of 150mm
2 1.5% cement in-situ stabilisation to a depth of 150mm
3 Full depth granular reconstruction (digout and replace)
4 Mill and AC inlay.

This resulted in 12 maintenance patches constructed before the end of June 2015 to monitor over three years with the results shown below. Two inspections were conducted, the first being three months after construction on 14 October 2015 and the second inspection on 24 November 2016. At the time of the final inspection, there had been 16 months of trafficking.

C1 Site 1 – SH24–RS00

C1.1 3% in-situ stabilisation – SH24–RS0–1405–1465

Due to errors in reference location the Hawkeye survey at the 16th month inspection located this site at SH24-RS0-1440-1500.

Three-month inspection – 14th October 2015 after 88,000 ESA

Alligator cracking in left-hand outside wheel path and no rutting.

Figure C.1 3% in- situ stabilisation – SH24-RS0-1417-1440 – three month inspection

16-month inspection – 24 November 2016 after 479,000 ESA

Rutting occurred in all wheel tracks with alligator cracking in 100% of left-hand outside wheel path and 80% in right-hand inside wheel path. The last 80% of the site has been repaired using asphalt to cover the rutted and cracked wheel paths.

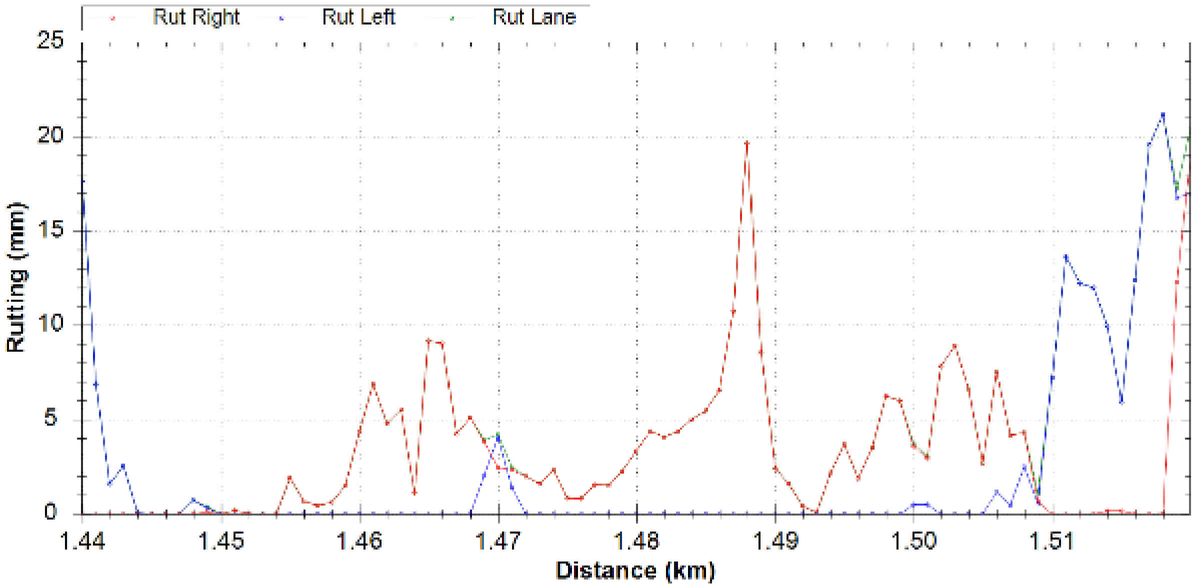
Figure C.2 3% in-situ stabilisation – SH24-RS0-1417-1440 – 16-month inspection

Figure C.3 3% in-situ stabilisation – SH24-RS0-1417-1440 – 16-month inspection

Hawkeye rut depth measurements – 16-month inspection

This site was rut filled with asphalt and hence as shown from the Hawkeye rut measurements the rutting is minimal (figure C.4 – distance 1.44 to 1.50 km).

Figure C.4 Hawkeye rut measurement for 3% cement in-situ stabilisation at 16-month inspection



C1.2 1.5% in-situ stabilisation – SH24–RS0–1465–1485

Due to errors in reference location the Hawkeye survey at the 16-month inspection located this site at SH24-RS0-1500-1520.

Three-month inspection – 14 October 2015 after 88,000 ESA

Alligator cracking in both wheel paths with minor rutting.

Figure C.5 1.5% in-situ stabilisation – SH24-RS0-1465-1485 – 3-month inspection

16-month inspection – 24 November 2016 after 479,000 ESA

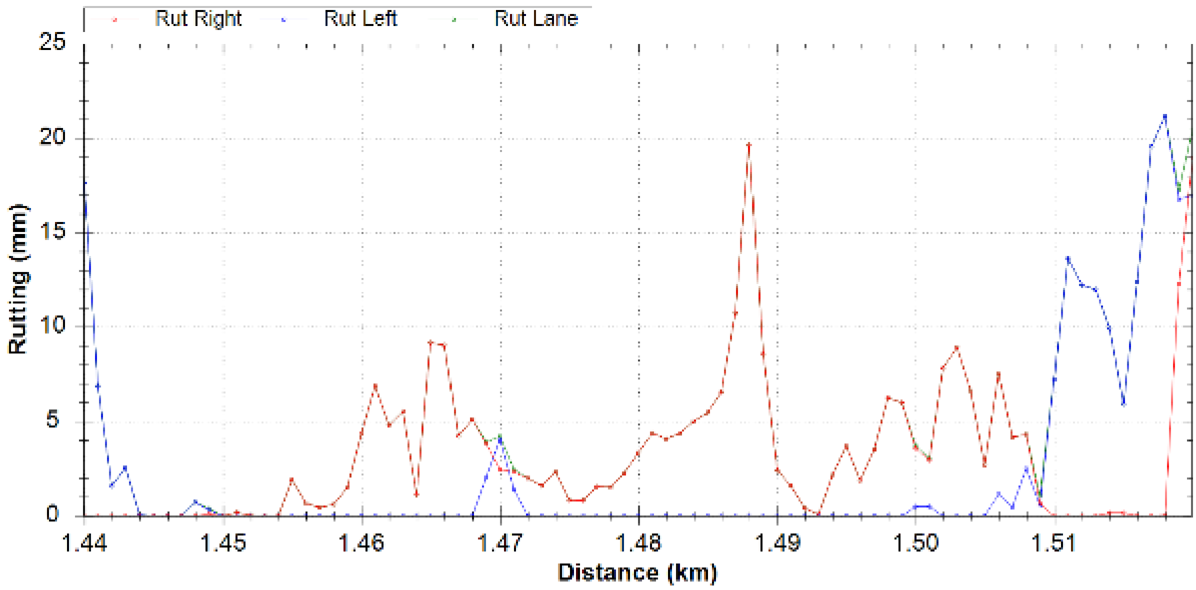
Rutting in all wheel tracks with alligator cracking in 100% of both wheel paths that has since been repaired using asphalt to cover the rutted and cracked wheel paths. Cracks have also now reflected through the asphalt repair.

Figure C.6 1.5% in-situ stabilisation – SH24 –RS0 – 1465 – 1485 – 16-month inspection

Hawkeye rut depth measurements – 16-month inspection

This site was rut filled with asphalt and hence as shown from the Hawkeye rut measurements the rutting is minimal (distance 1.50 to 1.52 km).

Figure C.7 Hawkeye rut measurement for 1.5% cement in-situ stabilisation at 16-month inspection (1.50 to 1.52 km)



C1.3 Full depth granular reconstruction – SH24–RS0 –1975–1994

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH24 –RS0 –1992–2011.

Three-month inspection – 14 October 2015 after 88,000 ESA

No pavement damage.

Figure C.8 Full depth granular reconstruction – SH24-RS0-1975-1994-3- month inspection

16-month inspection – 24 November 2016 after 479,000 ESA

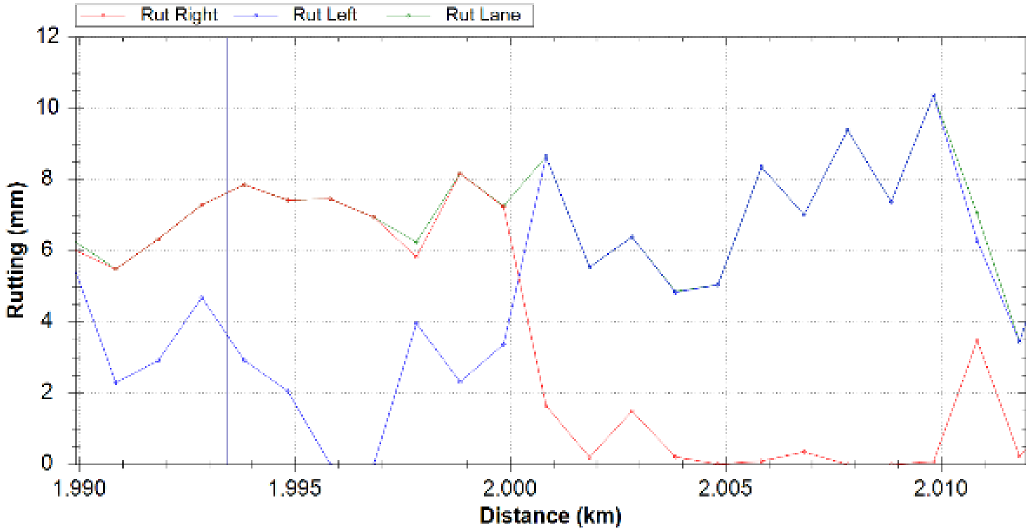
No pavement damage but some flushing in the wheel track.

Figure C.9 Full depth granular reconstruction – SH24-RS0-1975-1994 – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

In the Hawkeye rut measurements the rutting is as high as 10 mm at the far end of the site as shown by the blue line for the ‘rut left’ in figure C.10 (distance 1.992 to 2.011 km).

Figure C.10 Hawkeye rut measurement for granular full depth construction at 16- month inspection (1.992 to 2.011 km)



C1.4 AC mix 10 mill and inlay – SH24–RS0–2102–2122

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH24-RS0-2123-2143.

Three-month inspection – 14 October 2015 after 88,000 ESA

No pavement damage.

Figure C.11 Mill and AC inlay - SH24-RS0-2093-2112 - 3- month inspection

16-month inspection – 24 November 2016 after 479,000 ESA

No pavement damage except a pothole at start edge of the AC patch and some cracking on far right-hand side of the patch just past the turning bay.

Figure C.12 Mill and AC patch – SH24-RS0-1975-1994 – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

In the Hawkeye rut measurements the rutting is as high as 5 mm as shown by the blue line for the 'rut right' in figure C.13 (distance 2.123 to 2.143 km).

Figure C.13 Hawkeye rut measurement for mill and AC inlay at 16- month inspection (2.123 to 2.143 km)

C2 Site 2 – SH26–RS80

C2.1 3% in-situ stabilisation – SH26–RS80–13612–13642

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH26–RS80–13625–13655 (decreasing side).

Three-month inspection – 14 October 2015 after 27,221 ESA

No pavement damage after three months as shown in figure C.14.

Figure C.14 3% in- situ stabilisation – SH26–RS80–13577–13584 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 147,533 ESA

No pavement damage except some alligator cracking in the first 2 m of the outside wheel path as shown in figures C.15 and C.16.

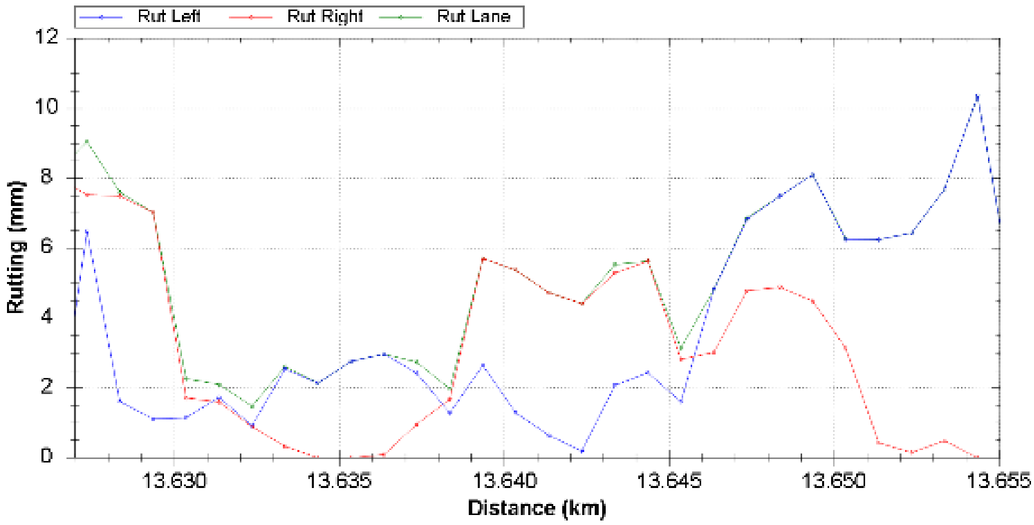
Figure C.15 3% in- situ stabilisation – SH26–S80–13577–13584 (decreasing side) – 16- month inspection

Figure C.16 3% in-situ stabilisation – SH26-RS80-13577-13584 (decreasing side) – 16-month inspection

Hawkeye rut depth measurements – 16-month inspection

The Hawkeye rut measurements shows the rutting ranges from 2 mm to 10 mm as shown in figure C.17 (distance 13.625 to 13.655 km).

Figure C.17 Hawkeye rut measurement for 3% cement in-situ stabilisation at 16 month inspection (SH26 – RS80-13625-13655 (decreasing side)



C2.2 1.5% in-situ stabilisation – SH26–RS80 –13304–13364 (decreasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH26-RS80-13317-13377 (decreasing side).

Three-month inspection – 14 October 2015 after 27,221 ESA

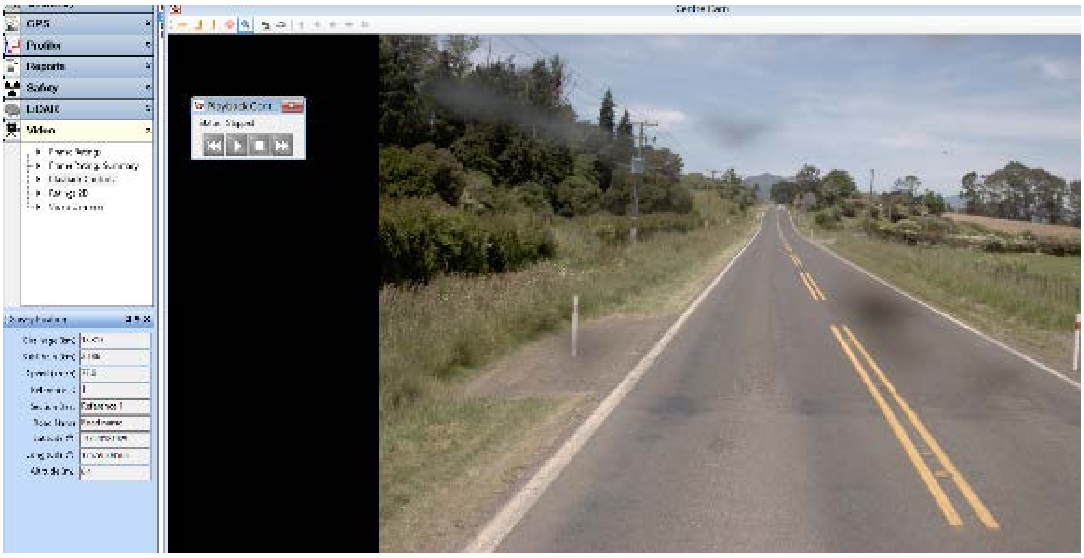
No pavement damage.

Figure C.18 1.5% in- situ stabilisation – SH26-RS80-13304-13364 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 147,533 ESA

No pavement damage.

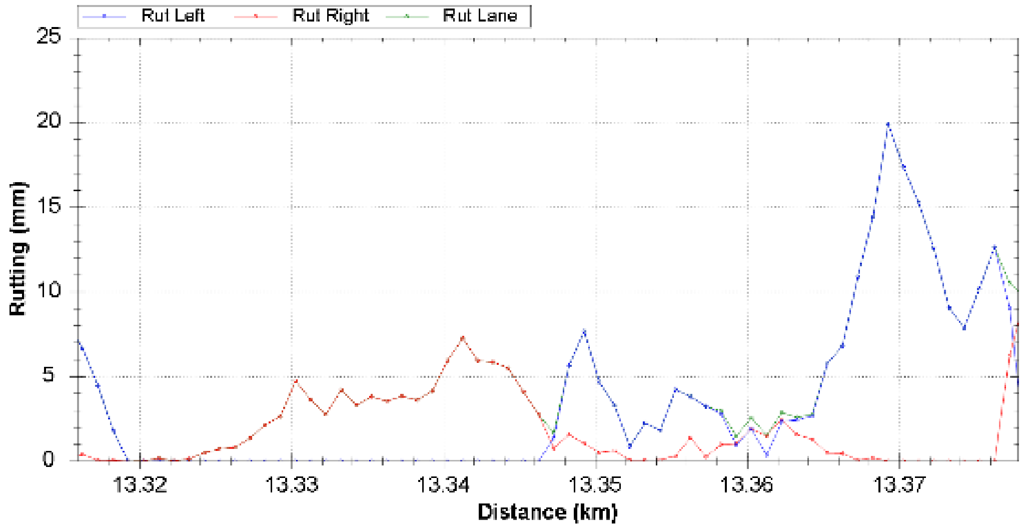
Figure C.19 1.5% in- situ stabilisation – SH26-RS80-13304-13364 (decreasing side) – 16- month inspection



Hawkeye rut depth measurements – 16-month inspection

This site has minimal rutting (<5 mm) and as shown from the Hawkeye rut measurements the rutting is minimal (distance 13.204 to 13.364 km)

Figure C.20 Hawkeye rut measurement for 1.5% cement in- situ stabilisation at 16- month inspection (SH26 – RS80-13304-13364 – decreasing side)



C2.3 Full depth granular reconstruction – SH26 –RS80 –13394–13434 (decreasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH26-RS80-13407-13447 (decreasing side).

Figure C.21 Full depth granular reconstruction – SH26-RS80-13394-13434 (decreasing side) – construction

Three-month inspection – 14 October 2015 after 27,221 ESA

No pavement damage.

Figure C.22 Full depth granular reconstruction – SH26-RS80-13394-13434 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 147,533 ESA

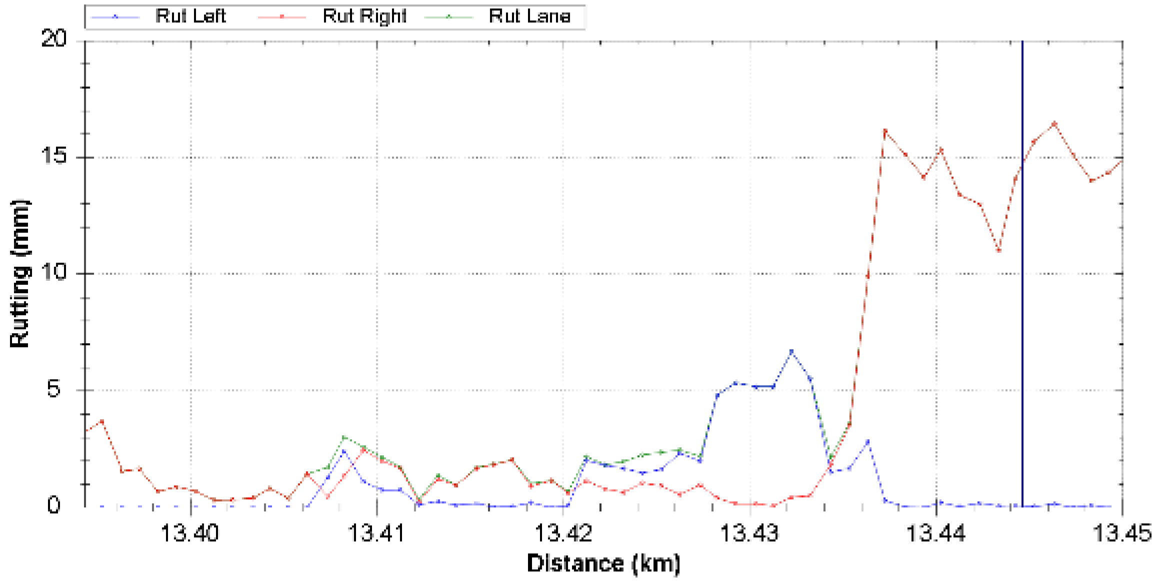
No pavement damage but some minor rutting in the right-hand wheel track.

Figure C.23 Full depth granular reconstruction – SH26-RS80-13394-13434 (decreasing side) – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

Rutting from the Hawkeye Survey in November 2016 shows within the patch only (13.407 to 13.447 km) there is some rutting (15 mm deep) at the very beginning of the patch in the inside wheel path (13.435 to 13.447 km). In the rest of the patch the rutting is very low – less than 3 mm.

Figure C.24 Hawkeye rut measurement for granular full depth construction at 16- month inspection (13.407 to 13.447 km)



C2.4 AC mix 10 mill and inlay – SH26–RS80–13582–13592 (decreasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH26 –RS80–13596–13606 (decreasing side).

Three-month inspection – 14 October 2015 after 27,221 ESA

No pavement damage after three months as shown in figure C.25.

Figure C.25 Mill and AC inlay – SH26-RS80-13596-13606 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 147,533 ESA

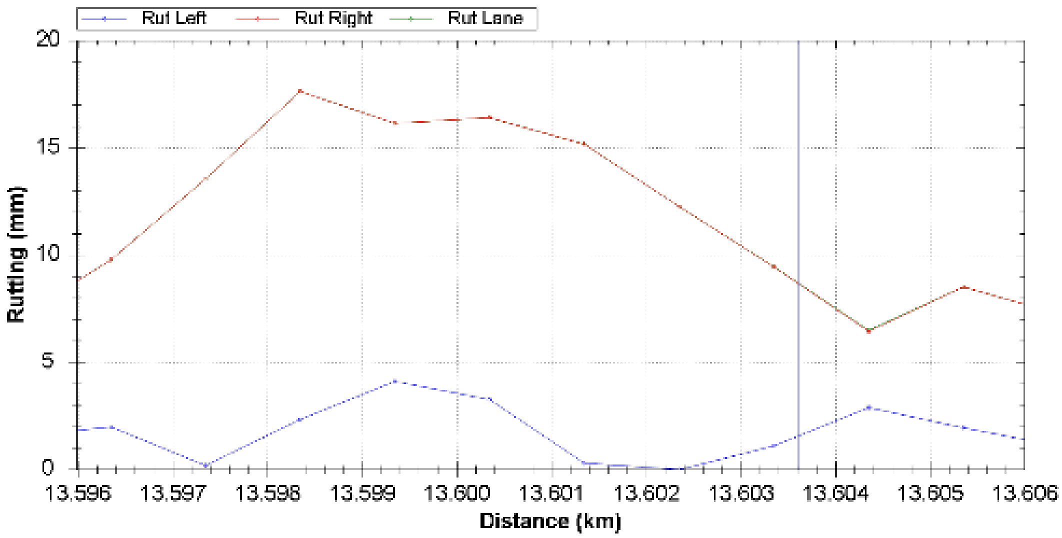
No pavement damage.

Figure C.26 Mill and AC patch – SH26-RS80-13596-13606 (decreasing side) – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

In the Hawkeye rut measurements the rutting is as high as 18 mm as shown by the red line for the 'rut right' in figure C.27 (distance 13.596 to 13.606 km).

Figure C.27 Hawkeye rut measurement for mill and AC inlay at 16- month inspection SH26-RS80-13.596-13.606 (decreasing side)



C.3 Site 3 – SH27–RS–46

C3.1 3% in-situ stabilisation – SH27–RS46–17825–17839

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH27–RS46 –17982–18012– (decreasing side).

Three-month inspection – 14 October 2015 after 92,886 ESA

No pavement damage after three months as shown in figure C.28.

Figure C.28 3% in- situ stabilisation – SH27–RS46–17982–18012 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 503,416 ESA

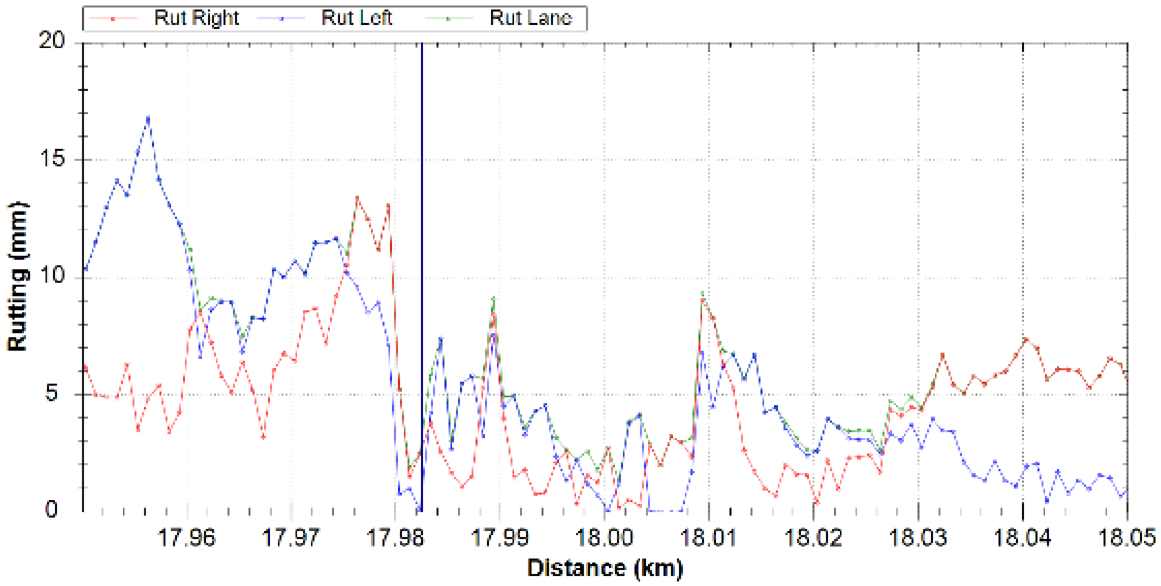
No pavement damage except some large block cracks around 1 m in length in middle of inside wheel tracks as shown in figure C.29.

Figure C.29 3% in- situ stabilisation – SH27–RS46–17982–18012 (decreasing side) – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

The Hawkeye rut measurements show the rutting ranges from 2 mm to 9 mm with most of the rutting under 5 mm as shown in figure C.30 (distance 17.982 to 18.012 km).

Figure C.30 Hawkeye rut measurement for 3% cement in-situ stabilisation at 16-month inspection (SH27-RS46-17982-18012 (decreasing side))



C3.2 1.5% in-situ stabilisation – SH27–RS46–17430–17466 (decreasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH27-RS46-17430-7466 (decreasing side).

Three-month inspection – 14 October 2015 after 92,886 ESA

Some cracking in the wheel paths.

Figure C.31 – 1.5% in-situ stabilisation – SH27-RS46-17430-17466 (decreasing side) – 3 month inspection

16-month inspection – 24 November 2016 after 503,416 ESA

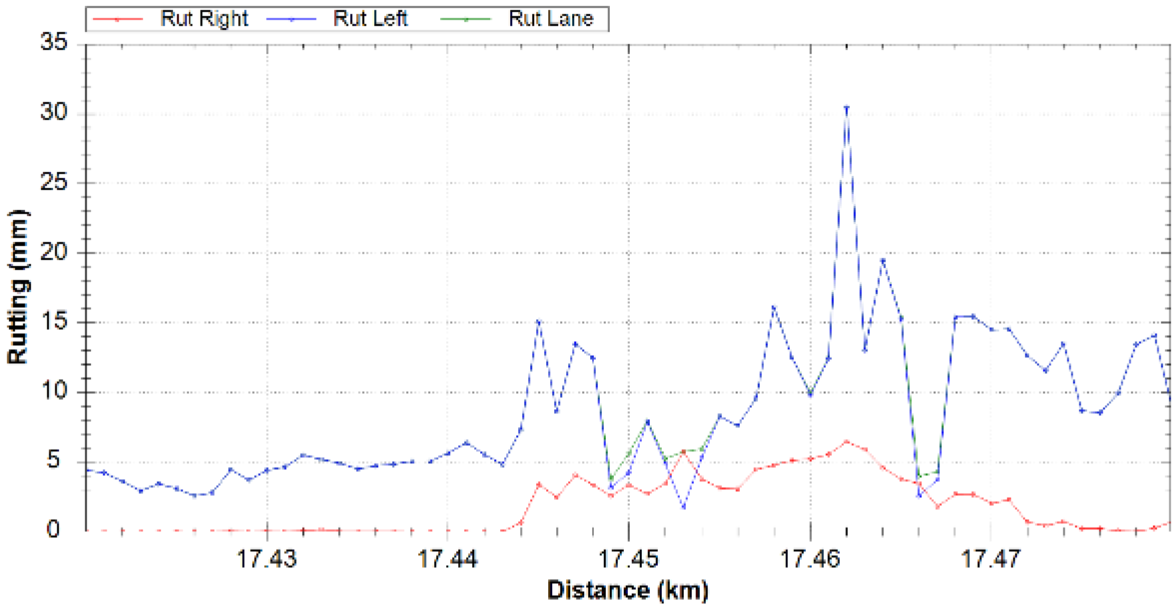
Alligator cracking in 100% of the outside wheel paths with some asphalt patching.

Figure C.32 1.5% in- situ stabilisation – SH27-RS46-17430-17466 (decreasing side) – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

This site has some points in the outside wheel path with rutting as high as 15 mm but most of the rutting is less than 5 mm. As shown in the Hawkeye rut measurements the rutting is minimal (SH27–RS46–17430–17466 (decreasing side)).

Figure C.33 Hawkeye rut measurement for 1.5% cement in- situ stabilisation at 16- month inspection (SH27-RS46-17430-17466 (decreasing side))



C3.3 Full depth granular reconstruction – SH27–RS46 –17965–17980 (increasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH27-RS46-17971-17991 (increasing side).

Three-month inspection – 14 October 2015 after 92,886 ESA

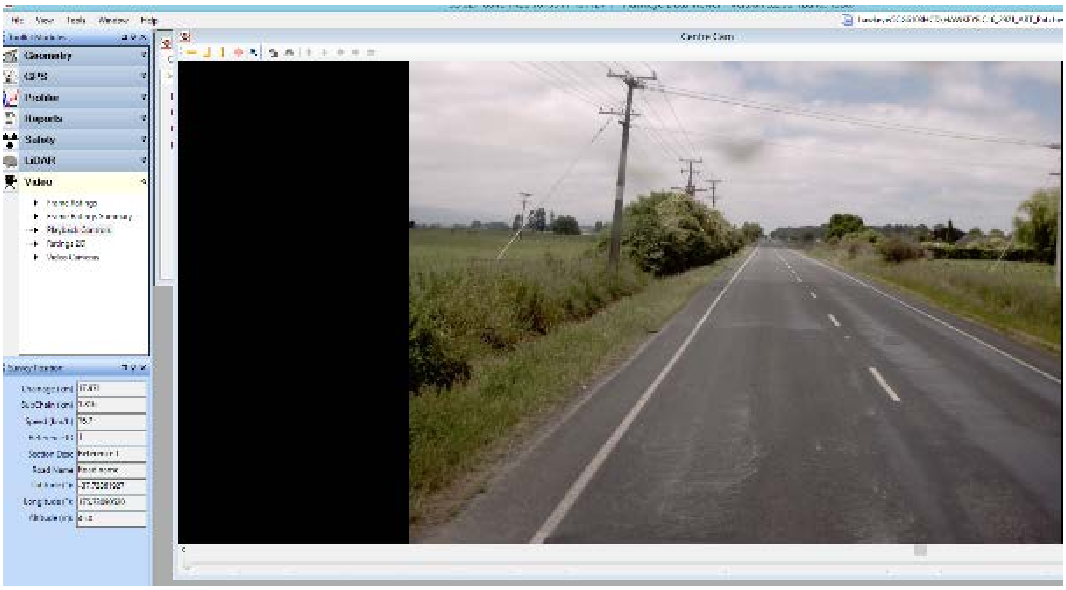
There was cracking in half of the left-hand wheel path.

Figure C.34 – Full depth granular reconstruction – SH27-RS46-17965-17980 (increasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 503,416 ESA

Cracking and rutting in most of both wheel paths.

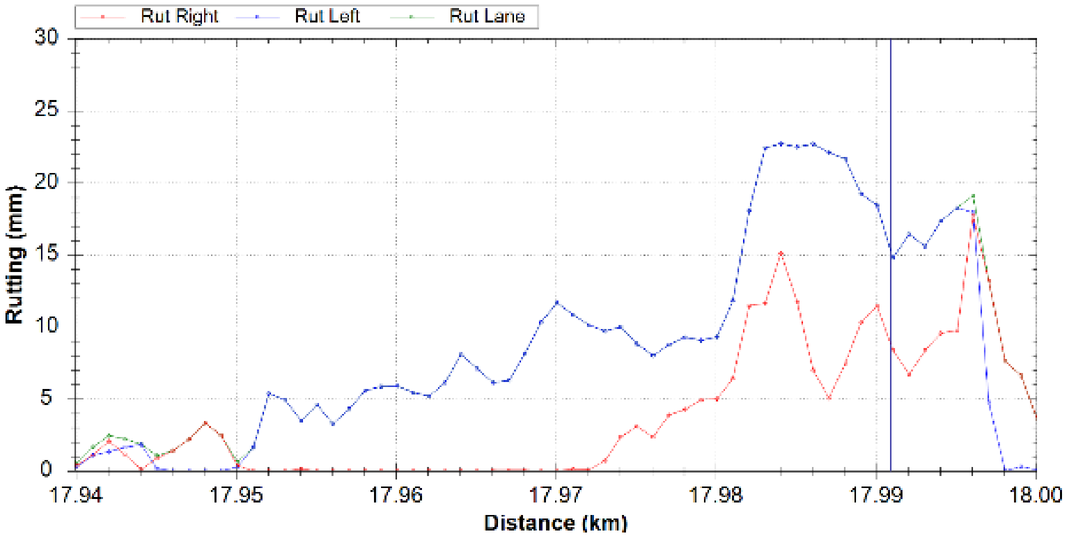
Figure C.35 Full depth granular reconstruction – SH27-RS46-17965-17980 (increasing side) – 16- month inspection



Hawkeye rut depth measurements – 16-month inspection

Rutting from the Hawkeye Survey in November 2016 shows within the patch only (17.971 to 17.991 km) there is significant rutting in the outside wheel path of 15 to 23 mm and the inside wheel path 5 to 15 mm (17.971 to 17.991 km).

Figure C.36 Hawkeye rut measurement for granular full depth construction at the 16- month inspection (SH27–RS46–17971–17991 (increasing side))



C3.4 AC mix 10 mill and inlay – SH27–46–17455–17471 (decreasing side)

Due to errors in reference location, the Hawkeye survey at the 16-month inspection located this site at SH27–RS46–17445–17485 (decreasing side).

Three-month inspection – 14 October 2015 after 92,886 ESA

No pavement damage after three months as shown in figure C.37.

Figure C.37 Mill and AC inlay – SH27–46–17455–17471 (decreasing side) – 3- month inspection

16-month inspection – 24 November 2016 after 503,416 ESA

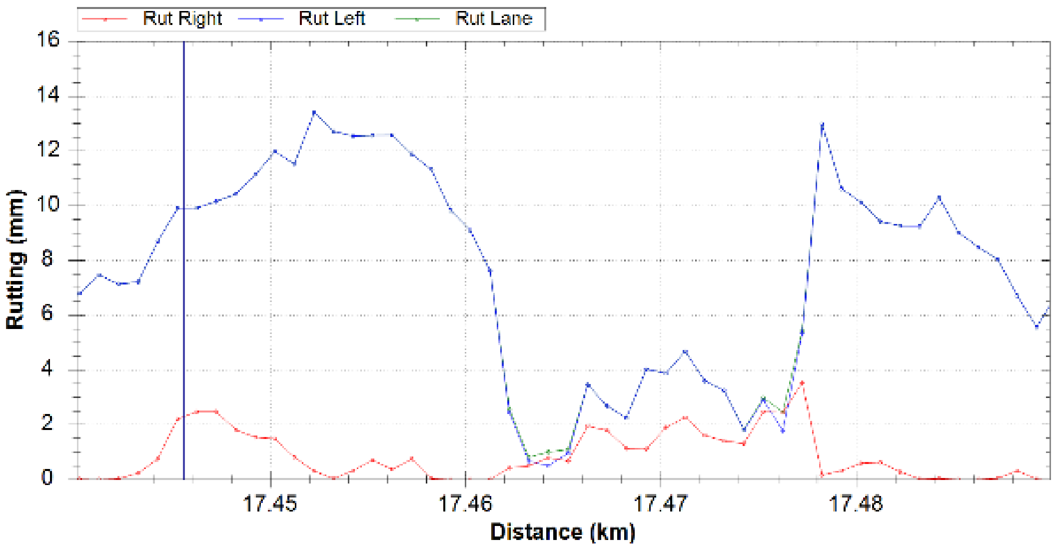
No pavement damage.

Figure C.38 Mill and AC patch – SH27-46-17455-17471 (decreasing side) – 16- month inspection

Hawkeye rut depth measurements – 16-month inspection

In the Hawkeye rut measurements the rutting is as high as 13 mm as shown by the blue line for the 'rut left' in figure C.39 (distance 17.445 to 17.485 km), although there is a section in the middle of the patch where the rutting is less than 4 mm.

Figure C.39 Hawkeye rut measurement for mill and AC inlay at 16- month inspection SH27-RS46-17445-17485 (decreasing side)



Appendix D: Framework for maintenance patch treatment design and selection

Appendix D can be accessed at www.nzta.govt.nz/resources/research/reports/635.

.