NACOE
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# FINAL REPORT

Project Title: P15: Queensland Trial of High Standard Granular Base TrackStar Alliance Project

(Year 4 - 2016/17)

ARRB Project No: PRP16023

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Client: Queensland Department of Transport and Main Roads

Date: 09/02/2018

TC-710-4-4-8

AN INITIATIVE BY:
arrb Queensland Government

# SUMMARY

A significant portion of the Australian sealed road network is composed of unbound granular pavement layers with a sprayed seal surface. Traditionally, unbound granular pavements are used in rural or light to moderately traffic applications, with higher quality asphalt, stabilised or concrete pavements generally used in urban areas and in more heavily trafficked applications.

Growing demands on infrastructure budgets has led to the desire to investigate the use of unbound granular structures for heavy duty applications in Queensland. However, initial construction cost savings resulting from the provision of unbound granular pavements may be counteracted by increased maintenance requirements, the risk of premature distress development and the potential for rapid failure.

The Queensland Department of Transport and Main Roads (TMR) is trialing a heavy-duty unbound granular pavement with a sprayed seal surfacing (denoted as SG(HD) TMR(2017)) incorporating high-standard granular (HSG) basecourse as part of the Centenary Motorway duplication project. The proximity of the project to Brisbane makes it an ideal candidate for long-term evaluation and monitoring. The project also includes a number of non-standard requirement for Queensland, including additional specification controls, material characterisation techniques, and construction methods.

This report presents an overview of the Centenary Motorway duplication project, observations on material production and construction, and reports the results of regular surface and structural condition assessments.

Observation of the Centenary Motorway trial began in August 2013, and was followed by subsequent monitoring surveys conducted using the network survey vehicle (NSV) and the falling weight deflectometer (FWD). Based on the information available to-date, after being trafficked for approximately 40% of the pavements 10 year design life, the heavy duty unbound granular pavement constructed on the Centenary Highway as part of the TrackStar Alliance Project is performing satisfactorily.

While there are some signs of continuing pavement deterioration (e.g. increased roughness, increased rutting and increased deflection), the pavement is considered to be performing as expected. Throughout the four year monitoring period, the data collected and observations made on the pavement do not suggest earlier maintenance intervention is required.

FWD testing and back analysis of the deflection data shows the overall pavement strength has reduced since initial construction, however the modulus of the base course has generally increased or remained steady. Overall the remaining pavement life calculated still significantly exceeds the residual design life anticipated for the pavement.

It is suggested that the site is continued to be monitored under the current NACoE Long Term Pavement Performance (LTPP) project.

Based on the findings of this research project and other inputs from the industry, TMR has published the following in July 2017:

- An update to Technical Specification MRTS05 *Unbound Pavements*

- Technical Note 171 *Use of High Standard Granular (HSG) Bases in Heavy Duty Unbound Granular Pavements*



# ACKNOWLEDGEMENTS

The author would like to acknowledge the support of the National Asset Centre of Excellence (NACoE), an initiative of the Queensland Department of Transport and Main Roads (TMR) and the Australian Road Research Board (ARRB). Also, the significant contributions of time and effort, in addition to open sharing of information, from TMR and TrackStar Alliance personnel were instrumental to the development of this document.

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# 1 INTRODUCTION

## 1.1 Background

Australia has approximately 810 000 km of road transport infrastructure, some 250 000 km of which are sealed structures consisting of unbound granular layers with a sprayed seal surfacing (Yeo, Vuong & Sharp 2000). The widespread use of unbound granular pavements results from the relatively low initial capital investment requirements as compared to structures composed of asphalt or concrete pavements. However, the risk of premature distress development is greater for unbound granular structures, particularly when subjected to heavy load and high-volume traffic. Such distress can be sudden and dramatic, with significant impacts on the road users (Stevens & Salt 2011). The significant risks associated with premature distress highlight the importance of understanding the potential distress modes and effects, in addition to prioritising mitigation strategies.

Unbound granular structures are generally the most economic sealed pavement configuration. In Queensland, they are traditionally used for low to medium traffic volume rural applications. Road pavements in urban and heavily trafficked areas are usually designed and constructed with thick asphalt base layers. Some other Australian states have successfully employed unbound high-standard granular (HSG) base with a sprayed seal surfacing for heavily trafficked rural highways, resulting in significant savings. Heavy-duty unbound granular pavements compare favourably, with respect to cost and performance, to concrete and deep strength asphalt pavements (Roads Corporation Victoria 1997). HSG material is processed and controlled to tight tolerances and is composed of resilient igneous or metamorphic rock. The high quality of HSG base results in increased durability, strength and modulus, as compared to typical unbound granular material.

The use of unbound HSG base in a high traffic volume semi-rural application is currently being demonstrated as part of the Centenary Motorway (Road Number 910) duplication between Springfield Parkway and the Logan Motorway interchange. The Stage 2 Darra to Springfield Transport Corridor project is a $475 million road and rail upgrade, including 4.65 km of new road pavement consisting of unbound HSG base with a sprayed seal surfacing. The project introduced a number of innovations for Queensland including specification controls, material characterisation techniques, and construction methods. A key component of the project was the enhanced protocol for compliance testing from both unbound granular stockpiles and the formed pavement.

Increasing traffic loads, use of non-standard materials, lack of expertise, material variability, and complexity of granular behaviour have contributed to the rise in the underperformance of unbound granular pavements in Queensland (Creagh, Wijeyakulasuriya & Williams 2006). Evaluation of the performance of the Centenary Motorway HSG base trial is critical for ascertaining the viability of the technology as a cost-effective pavement alternative for heavily trafficked roads. While the technology has been successfully implemented in some other Australian states, as well as internationally, the associated production infrastructure, quality assurance techniques and construction experience were not readily available in Queensland. Evaluation and monitoring of the trial was undertaken to advance understanding of material selection, design, construction and quality control best practice for SG(HD) heavy-duty unbound granular pavement.

## 1.2 Previous Queensland HSG Trial

The use of HSG base in a heavily trafficked rural pavement was previously demonstrated in Queensland as part of the Gatton Bypass duplication project. The Gatton Bypass is a portion of the Warrego Highway (Road Number 18A) around Gatton township in southern Queensland. The Warrego Highway is a significant interregional route connecting the agricultural areas in south-western Queensland and northern New South Wales to the distribution centres in Toowoomba and Brisbane. Before the duplication, the Gatton Bypass was the subject of frequent user complaints due to the lack of overtaking opportunities. The goals of the duplication project were to reduce the frequency and severity of traffic accidents, increase freight efficiency, and develop consistent driver expectation by providing four continuous travel lanes between Brisbane and Toowoomba.

Unbound HSG base had not previously been utilised in Queensland. Technical guidance regarding material selection, construction, and conformance testing was adopted from VicRoads in Victoria. The project specification for the HSG base required improved cohesion and limited permeability through modified plasticity limits and fine material content. Innovations included impermeable verge construction before pavement construction, higher compaction standards, longitudinal subsoil drains, layer formation using a self-propelled mechanical spreader (paver), and extension of the sprayed seal surfacing over the verge (O’May 2007). The granular material was placed in multiple 100 mm lifts to promote greater compaction with less effort and better moisture control. The use of a paver for layer formation was specified to reduce segregation, increase consistency and provide reliable thickness control. A noteworthy deviation from Victorian practice was the determination of maximum dry density (MDD) using standard Proctor, as opposed to modified Proctor, compactive effort. The Victorian state road agency (VicRoads) requires a minimum characteristic compaction level of 100% of modified Proctor MDD. The specified minimum compaction level for the Gatton Bypass duplication HSG base was 102% of standard Proctor MDD, which is lower than the VicRoads level.

Traffic estimates for the Gatton Bypass prior to the duplication project (2002) included an annual average daily traffic (AADT) of 10 130 vehicles, 19.7% of which were heavy vehicles, and a projected annual growth rate of 5%. The high traffic volume, heavy vehicle proportion and political profile of the project led to the provision of a SG(HD) high standard unbound granular pavement. The pavement has a sprayed seal surfacing applied to an unbound granular structure, with a design life of 20 years or approximately $1.8 \times 10^7$ equivalent standard axles (ESA). The pavement support varied across the project, with expansive black soils at the eastern limit and sandy/loam at the western end, with subgrade design California Bearing Ratio (CBR) values of 5% and 10% respectively. The design pavement cross-section included a double/double 14/10 mm sprayed seal, 200 mm thickness of HSG base, 200 mm of HSG upper subbase, 140 mm of Type 2.5 lower subbase, and 300-500 mm of select fill subgrade over the subgrade (O’May 2007).

The Gatton Bypass duplication pavement began showing signs of distress in mid-2004, six months after opening, primarily in the form of isolated rutting and stripping of the surface seal. By mid-2007 significant portions of the project had severe rutting and shoving. O’May (2007) observed that distress locations correlated with areas constructed in cuttings, at cut/fill transitions and in the vicinity of drainage structures. Forensic testing revealed that the in situ material properties of the HSG base did not meet the project specifications; in particular, the maximum plasticity index (PI) limit. Additionally, the appropriateness of the adopted design CBR values has been questioned (O’May 2007). Subsequent pavement condition assessments have revealed that accelerated structural deterioration is occurring across the alignment, but is most significant in areas subject to variable moisture conditions (cuttings, cut/fill transitions, drainage structures, and bridge abutments).

## 1.3 Project Descriptions

The *Evaluate and Monitor High-Standard Granular Base and Seal Trial (TrackStar Alliance Project)* is a joint research effort between the TMR and ARRB. The goal of the project is to improve current unbound granular pavement design, material selection and construction practice based on learnings obtained from observation and benchmarking of the construction and early-life performance of the Centenary Motorway duplication project. Anticipated benefits of evaluating and monitoring the project include:

- increasing the reliability of pavement performance and managing cost through reduced conservatism
- reducing the risk of premature failure
- cost savings through the appropriate use of unbound HSG materials in high traffic volume applications.

Opportunities to increase reliability, better manage cost, and reduce the risk of premature failure will be identified through:

- evaluating key construction activities for both the HSG base and bituminous sprayed seal
- documenting material property and construction practice variations from Main Roads Technical Specification (MRTS05), *Unbound Pavements* (TMR 2011a), and MRTS11, *Sprayed Bituminous Surfacing (Excluding Emulsion)* (TMR 2010a)
- developing a structural capacity and surface condition performance baseline
- monitoring early-life surface condition and structural capacity progression
- determining reliability and risk associated with unbound HSG pavements in high traffic volume applications.

*Evaluate and Monitor High-Standard Granular Base and Seal Trial (TrackStar Alliance Project)* has been a 4 year research project initiated in July 2013. At the time of commencing the project, the expected outcomes of the investigation included:

- research report documenting the current state of practice, observations of HSG material production, construction of the base and bituminous sprayed seal, details of post construction and early-life (12 to 36 months) surface and structural assessments, predictions of long-term performance and the investigation of cost-benefit relationships
- provisional technical specification annexure for the utilisation of unbound HSG basecourse in road pavements
- recommendations for modification of current TMR technical guidance documents such as MRTS05 (TMR 2011a), MRTS11 (TMR 2010a) and the Pavement Design Supplement (TMR 2013a).

# 2 UNBOUND GRANULAR PAVEMENTS

## 2.1 Introduction

The primary function of a road pavement is to facilitate the safe and efficient transport of people and goods. Sealed unbound granular pavements are flexible structures composed of an unbound granular pavement overlaid by bituminous surfacing (Austroads 2012). Aggregates are particles of rock that, when brought together in either a bound or unbound configuration, form part of an engineering structure (Smith & Collis 1993). Unbound aggregates do not provide the same level of support in structural pavement layers as bound aggregates. Examples of bound materials include stabilised aggregates and asphalt. However, the comparatively low cost of unbound granular materials has resulted in widespread use in road pavement construction (Smith & Collis 1993).

The long-term performance of unbound granular pavements is determined by the quality of the composing aggregate, employed construction practices and moisture management techniques, in addition to traffic and environmental loading. Response to traffic and environmental loading is dependent upon the intrinsic properties of the composing material (Creagh, Wijeyakulasuriya & Williams 2006). The quality of aggregate for road transport applications is typically defined by the modulus, strength, durability and workability characteristics. Aggregates used in road base construction must exhibit the requisite characteristics during construction operations and throughout the service life of the pavement (Austroads 2008b). An ideal unbound granular pavement should provide safe and comfortable passage of vehicles, function without significant distress, achieve minimum whole-of-life (WOL) cost, resist effects of climate, minimise environmental impact, be easily maintained, and be amenable to future staged construction (Bartley Consultants 1997).

Road pavements are essential for the transport of people and goods, and are an important factor for economic development (Bartley Consultants 1997). Selection of the optimal pavement structure should consider the nature of anticipated traffic (configuration, mass, and volume), climate, environment, available construction and maintenance expertise, and WOL cost (Austroads 2009a). The vast, yet sparsely populated, Australian continent has required the development of economical road construction and maintenance techniques (Austroads 2009b). The result has been the widespread construction of unbound granular pavements with a thin bituminous seal. Unbound granular pavements are typically used in light-to-moderate traffic volume (< $5.0 \times 10^6$ ESA) rural applications, but may also provide satisfactory performance in high traffic volume rural applications and low volume urban applications when high-quality materials, construction practices, and maintenance techniques are employed (Austroads 2009a).

## 2.2 Granular Material Requirements

Sand, gravel and crushed rock are fundamental to the provision of road transport infrastructure and represent the dominant proportion of pavement construction materials (Smith & Collis 1993). The properties of the granular material have a profound effect on the functional and structural performance of the pavement (Austroads 2008a). Requirements for unbound granular material in pavement applications include sufficient modulus, strength, durability, and workability. Modulus defines the elastic response of the material to applied loads. Strength can be defined as the ability to withstand repeated load applications (Austroads 2008b). Long-term durability includes components of hardness, or resistance to abrasion; toughness, or resistance to crushing; and soundness, or resistance to weathering (Smith & Collis 1993). Workability defines the ease with which an even surface, dense packing and uniform distribution of particle sizes can be achieved and maintained. These attributes are not mutually exclusive, as some properties of the granular material may influence two or more of the characteristics.

### 2.2.1 Specifications

Factors that should be considered when selecting granular materials for pavement applications include the physical properties and production method, in addition to available quality control and assurance techniques (Austroads 2008a). Material specifications are utilised to ensure that the end product performs as designed, and was produced reliably in a cost effectively manner. Characteristics influencing pavement performance factors vary by location and over time. Therefore, laboratory index tests are specified to reduce the risk of unsatisfactory performance. Effective specifications provide guidance on what is required to ensure long-term performance without unnecessary testing (Austroads 2008b).

Laboratory testing is required to describe the physical, mechanical and chemical properties of aggregate for prediction of in-service performance, comparison of alternative materials, ensuring specification compliance; and to provide control of material quality (Collis & Fox 1985). Specification limits are typically established from empirical relationships between laboratory characterisation testing and in service performance. Due to the empirical nature, limits should not be extrapolated outside the range of the data set used in the development of the relationship (Austroads 2008b). Properties of granular materials that are typically specified include mineralogy, particle shape, size (nominal maximum and distribution), surface texture, plasticity, hardness/toughness, soundness, permeability and bearing capacity. TMR specification requirements for unbound granular materials are presented in Table 2.1 and Table 2.2.

Note that in July 2017 MRTS05 Unbound Pavements was substantially revised (partly as a results of this project) and some of the requirements or terminology mentioned in this report may have been superseded as a result.

**Table 2.1: Required material properties for TMR Type 1 and Type 2 granular materials (Pre-July 2017)**

| Property | TMR subtype | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1.1 | 1.2 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 |
| Minimum wet 10% fines value (kN)[a] | 130 - 150 | 95 - 110 | 115 - 135 | 100 - 115 | 85 - 100 | 70 - 85 | - |
| Maximum wet/dry variation (%)[a] | 30 - 40 | 35 - 45 | 30 - 40 | 30 - 40 | 35 - 45 | 35 - 45 | - |
| Minimum degradation factor[a] | 40 - 50 | 30 - 40 | 40 - 50 | 40 - 50 | 30 - 40 | 30 - 40 | - |
| Minimum crushed particles (%) | 70 | 70 | - | - | - | - | - |
| Maximum flakiness index (%) | 35 | 35 | 35 | 35 | 40 | 40 | - |
| Maximum liquid limit | 25 | 28 | 25 | 25 | 28 | 35 | 40 |
| Maximum plasticity index | 4 | 6 | 6 | 6 | 8 | 12 | 14 |
| Maximum WPI[b] | - | - | 150 | 150 | 200 | 360 | - |
| Maximum linear shrinkage | 2.5 | 3.0 | 3.5 | 3.5 | 4.5 | 6.5 | 7.5 |
| Maximum WLS[c] | - | - | 85 | 85 | 110 | 195 | - |
| Fines ratio | 0.30 - 0.55 | 0.30 - 0.55 | 0.30 - 0.55 | 0.30 - 0.65 | 0.30 - 0.65 | - | - |
| Minimum soaked CBR (%) | - | - | 80 | 60 | 45 | 35 | 15 |

[a] Value varies dependent upon source aggregate mineralogy.

[b] Weighted plasticity index (WPI) is the product of the plasticity index (PI) value and percentage (by mass) of material passing the 0.425 mm sieve opening.

[c] Weighted linear shrinkage (WLS) is the product of the linear shrinkage (LS) value and percentage (by mass) of material passing the 0.425 mm sieve opening.

**Table 2.2: Required material properties for TMR Type 3 and Type 4 granular materials**

| Property | TMR subtype | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 |
| Minimum wet 10% fines value (kN)[a] | 100 - 115 | 80 - 95 | 70 - 85 | 60 - 70 | - | - | - | - | - | - |
| Maximum wet/dry variation (%)[a] | - | - | - | - | - | - | - | - | - | - |
| Minimum degradation factor [a] | - | - | - | - | - | - | - | - | - | - |
| Minimum crushed particles (%) | - | - | - | - | - | - | - | - | - | - |
| Maximum flakiness index (%) | 35 | 35 | 40 | 40 | - | - | - | - | - | - |
| Maximum liquid limit | 25 | 28 | 35 | 35 | 40 | - | - | - | - | - |
| Maximum plasticity index | 6 | 8 | 12 | 12 | 14 | - | - | - | - | - |
| Maximum WPI[b] | 150 | 200 | 360 | - | - | - | - | - | - | - |
| Maximum linear shrinkage | 3.5 | 4.5 | 6.5 | 6.5 | 7.5 | - | - | - | - | - |
| Maximum WLS[c] | 85 | 110 | 195 | - | - | - | - | - | - | - |
| Fines ratio | 0.35 - 0.55 | 0.35 - 0.65 | 0.35 - 0.65 | - | - | - | - | - | - | - |
| Minimum unsoaked CBR (%) | 80 | 60 | 45 | 35 | 15 | 80 | 60 | 45 | 35 | 15 |

[a] Value varies dependent upon source aggregate mineralogy.

[b] Weighted plasticity index (WPI) is the product of the plasticity index (PI) value and percentage (by mass) of material passing the 0.425 mm sieve opening.

[c] Weighted linear shrinkage (WLS) is the product of the linear shrinkage (LS) value and percentage (by mass) of material passing the 0.425 mm sieve opening.

### 2.2.2 Mineralogy

The mineralogy or geological classification of the source rock defines the nature of the material. Aggregates are broadly characterised as igneous, metamorphic or sedimentary, according to chemical composition, crystalline structure and physical characteristics. Igneous rocks derive from molten material originating deep beneath the surface and solidifying at or near the surface (Smith & Collis 1993). Igneous rocks are further subdivided into acid, intermediate and basic groups according to alkali-silica content. Metamorphic rock forms from the recrystallization of igneous and sedimentary rocks subjected to additional heat and pressure (Smith & Collis 1993). Sedimentary rock is formed from the cementation of loose fragments of other rocks (Smith & Collis 1993). The mineralogy of the source rock strongly influences the suitability of the aggregate for a given engineering application.

### 2.2.3 Particle Shape

The particle shape of composing aggregates significantly influences the mechanical properties and constructability of pavement layers (Austroads 2008a). Particle shape is fundamental to the development of particle interlock and the subsequent fabric, packing density, modulus and shear strength. Angular, cubical particles are preferred for pavement applications. Specifications typically establish criteria for a minimum proportion of crushed particles and maximum flakiness to ensure angularity and cubical profile respectively. The proportion of crushed particles can be determined by TMR test method Q215, *Crushed Particles* (TMR 2013k). Type 1 unbound granular materials require a minimum of 70% crushed particles. The proportion of particles with variation in the least and greatest dimension of more than 60% can be determined by TMR test method Q201, *Flakiness Index* (TMR 2012b). Maximum content requirements vary for Type 1, Type 2 and Type 3 unbound granular materials and range from 35% to 40%.

### 2.2.4 Particle Size

The magnitude and quantity of the largest and smallest particle sizes composing an unbound granular material significantly impact on the long-term performance. Nominal maximum aggregate size (NMAS) can be used to classify aggregates according to particle size. NMAS is defined as the largest sieve opening size at which ≥ 10% of the particles (by mass) are retained. Typical NMAS values for unbound granular materials range from 37.5 mm to 4.75 mm. NMAS significantly influences mechanical properties and constructability. Greater NMAS values provide increased modulus, shear strength and segregation potential.

The fines ratio (Equation 1) provides an indication of the proportion of silt and clay particles to fine sand particles within the fine aggregate (< 4.75 mm) component. Fines content, greater than 10% by mass, reduces structural stability and increases moisture sensitivity. However, sufficient fines content, greater than 4% by mass, is required to reduce permeability and improve constructability. Fines ratio requirements vary for Type 1, Type 2 and Type 3 unbound granular materials and range from 0.30 to 0.65. Both NMAS and the fines ratio can be determined by TMR test method Q103A or Q103B, *Particle Size Distribution (Wet Sieving)* (Main Roads 1996a) and *Particle Size Distribution of Aggregate (Dry Sieving)* (Main Roads 1996b) respectively.

$$\text{Fines ratio} = \frac{p^{0.075}}{p^{0.425}} \qquad (1)$$

where

$p^{0.075}$ = percentage of material passing the 0.075 mm sieve opening

$p^{0.425}$ = percentage of material passing the 0.425 mm sieve opening.

In addition to the size and proportion of the largest and smallest particles, the distribution of particle sizes significantly influences the modulus, shear strength, deformation resistance, permeability and workability of the unbound granular material (Austroads 2008a). The distribution of particle sizes dictates the mass particle orientation or fabric, which has a significant impact on maximum packing density, interparticle friction, and void distribution. For pavement applications, an even (well-graded) distribution of particle sizes is preferred as it produces the maximum unit weight. Requirements for Type 1, Type 2 and Type 3 unbound granular materials vary as presented in Table 2.3. The optimal grading is determined by the nature of the source rock and the intended application. Particle size distribution can be determined by TMR test method Q103A or Q103B and is controlled by crushing, screening and blending variables during production (Austroads 2008a).

**Table 2.3: TMR granular material particle size distribution requirements**

| Sieve opening (mm) | Per cent passing (by mass) | | | | |
|---|---|---|---|---|---|
| | | Type 2 & Type 3 | | | |
| | *Type 1* | *Grading B* | *Grading C* | *Grading D* | *Grading E* |
| 75.000 | | 100 - 100 | 100 - 100 | 100 - 100 | 100 - 100 |
| 37.500 | 100 - 100 | 100 - 100 | 100 - 100 | 100 - 100 | |
| 26.500 | 85 - 100 | 85 - 100 | 100 - 100 | 100 - 100 | 85 - 100 |
| 19.000 | 75 - 100 | 55 - 90 | 80 - 100 | 100 - 100 | |
| 9.500 | 58 - 80 | 40 - 70 | 55 - 90 | 80 - 100 | 40 - 100 |
| 4.750 | 45 - 62 | 28 - 55 | 40 - 70 | 55 - 90 | |
| 2.360 | 33 - 45 | 20 - 45 | 30 - 55 | 40 - 70 | 20 - 100 |
| 0.425 | 14 - 22 | 10 - 25 | 12 - 30 | 20 - 40 | 10 - 80 |
| 0.075 | 5 - 10 | 4 - 15 | 5 - 20 | 8 - 25 | 4 - 30 |

### *2.2.5 Surface Texture*

The surface texture of aggregate particles significantly influences interparticle friction and the resulting modulus and shear strength. Other characteristics of the compacted aggregate layer influenced by surface texture include deformation resistance and constructability (Austroads 2008a). Particles with a rough surface texture are preferred in pavement applications. A standard method for measuring surface texture is not currently available. However, adequate surface texture can be ensured by avoiding the use of river gravels and establishing a minimum requirement for a proportion of crushed particles (Q215) (Austroads 2008b).

### *2.2.6 Plasticity*

The plasticity of the fine aggregate component significantly influences the modulus, shear strength, deformation resistance, permeability and constructability of the unbound granular material (Austroads 2008a). Plasticity, or sensitivity to moisture-induced behavioural changes, is a critical consideration in the selection of granular materials for road base applications. Shrink/swell potential should be minimised to ensure volumetric stability in the pavement layers. However, a small degree of plasticity is required to provide cohesion, particularly at the surface, to resist erosion provide an even, dense surface, and reduce permeability. Fine clayey-sand or clayey-filler can be incorporated to achieve the desired particle size distribution, cohesion, and permeability. Slightly plastic, well-graded products with adequate strength are optimal (Midgley 2008).

The plasticity of fine particles is typically determined by measuring the Atterberg limits. The Atterberg limits, define the behaviour transformation of granular materials relative to moisture content. However, it should be noted that Atterberg limit tests are subject to operator variability and poor repeatability (Bartley Consultants 1997). The liquid limit of a material can be determined by

TMR test method Q104A*, Liquid Limit (Cone Penetrometer)* (TMR 2010c), and maximum values range from 25 to 40. PI is the difference between the liquid and plastic limits and can be determined by TMR test method Q105, *Plastic Limit and Plasticity Index* (TMR 2010d).

Maximum PI requirements vary for Type 1, Type 2 and Type 3 unbound granular materials and range from 4 to 14. Linear shrinkage (LS) defines the propensity of the material to contract in the absence of moisture and can be determined by TMR test method Q106, *Linear Shrinkage* (TMR 2013c). Limiting values for LS vary for Type 1, Type 2 and Type 3 unbound granular materials and range from 2.5 to 7.5. Typically, either PI or LS is specified. Plasticity properties must be strictly limited and regularly monitored to ensure long-term pavement performance (Midgley 2008).

### *2.2.7 Hardness/Toughness*

Physical properties such as hardness and toughness can be assessed to determine long-term resistance to repeated loading. Hardness is defined as the ability to resist abrasion by other materials, and toughness is defined as the ability to withstand impact loadings (Austroads 2008b). Crushing resistance is an indicator of toughness and can be used to predict the resistance of an unbound granular material to abrasion and fracture during transport, compaction and in service.

The crushing resistance of coarse aggregates can be determined by measuring the 10% fines value by TMR test methods Q205A, *Ten Percent Fines Value (Dry)* (TMR 2013f) or Q205B, *Ten Percent Fines Value (Wet)* (TMR 2013g) respectively. The test involves subjecting a consolidated sample, either oven-dry or saturated surface dry after 24-hour soaking, to an increasing vertical load until a 10% (by mass) proportion of fines (4.75 mm - 0.60 mm) is generated. The wet 10% fines value represents the critical condition, and specified minimum values vary from 60 kN to 150 kN depending upon material type and mineralogy. Aggregates that break down (generate fines) during compaction should be avoided as they reduce modulus, degrade strength, and increase permeability (Midgley 2008).

### *2.2.8 Soundness*

Durability, or resistance to wear and decay, is a fundamental aggregate property (Smith & Collis 1993). Soundness is often used interchangeably with durability and defines resistance to fluctuations in climate and environment (also known as weathering). Resistance to weathering determines the performance of crushed and uncrushed rock in engineering applications. Aggregate that is initially strong can deteriorate over time while in the stockpile or in the pavement, as a result of mechanical or physiochemical deterioration. The most severe cases of unbound granular pavement failure result from the physical break down of particles as a result of weathering (Smith & Collis 1993). Particle degradation in service results in localised densification and subsequent rutting at the pavement surface (Collis & Fox 1985).

A number of standard testing methods are available to indicate the soundness of aggregates, including wet/dry strength variation, degradation factor, secondary minerals content, accelerated soundness index, ball mill value, and micro-Deval value. Resistance to mechanical and physiochemical degradation can be determined by TMR test methods Q205C, *Wet/Dry Strength Variation* (TMR 2013h), and Q208A/B, *Degradation Factor (Source Rock)/(Coarse Aggregate)* (TMR 2010k/l) respectively. Wet/dry strength variation indicates the relative concentration of clayey material and is calculated by taking the ratio of the difference in wet and dry 10% fines values relative to the dry value.

Limiting values for Type 1 and Type 2 materials vary from 30% to 45% depending upon material Type and mineralogy. Degradation factor is a measure of the settling rate of fines generated through attrition and provides an indication of the nature of the fines. Limiting values for Type 1 and Type 2 materials vary from 30 to 50 depending upon material Type and mineralogy. When blended materials are used, each source rock contribution, in addition to the blended end product, should be subjected to soundness assessment to ensure long-term durability (Austroads 2008b).

### *2.2.9 Permeability*

Permeability, or the resistance of a material to the flow of fluids, has a significant influence on the long-term performance of the pavement layer. Satisfactory long-term performance is achieved by limiting the ingress of moisture into the pavement structure (Roads Corporation Victoria 1997). The ability of gases and liquids, most commonly oxygen and water, to flow through the constructed pavement layers contributes to physiochemical degradation, disintegration and fines transport. However, sufficient permeability is required to minimise the build-up of pore-water pressure. Increasing pore-water pressure decreases the stability and effective strength of particulate materials (Bartley Consultants 1997). The permeability of an unbound granular material can be determined by Australian Standard (AS) 1289.6.7.1, *Methods of Testing Soils for Engineering Purposes - Soil Strength and Consolidation Tests - Determination of Permeability of a Soil* (Standards Australia 2013). The permeability of approximately $5.0 \times 10^{-8}$ m/sec is typical for unbound granular material utilised in pavement applications (VicRoads 2011). To prevent permeability reversal, subbase layers should be at least ten times more permeable than the overlying base (Bartley Consultants 1997).

### *2.2.10 Bearing Capacity*

The bearing capacity of an unbound granular material is critical to successful performance in pavement applications. Bearing capacity is material dependent, with large variations possible from a single source rock. The bearing capacity defines the resistance to traffic-induced loading and is commonly quantified by determining the California bearing ratio (CBR). CBR testing is commonly undertaken on saturated specimens as an indicator of limiting shear strength. The bearing capacity of an unbound granular material can be determined by TMR test method Q113A, *California Bearing Ratio (Standard Compactive Effort)* (TMR 2013d). Requirements for Type 2, Type 3 and Type 4 materials vary from 15% to 80% according to subtype.

## 2.3 Granular Material Production

Production of quality, well-graded unbound granular material requires extraction, crushing, screening, blending, wetting, and conformance testing of source rocks harvested from quarries. The configuration of the crusher(s) and screen(s) controls the particle size distribution of the end product. The common crusher types employed for the production of aggregates for pavement applications include jaw, gyratory, cone, impact, hammer mill, and vertical shaft impact crushers (Austroads 2008a). Typical unbound granular products can be produced through a single crusher run. Products conforming to tight tolerance levels often require additional processing such as screening and/or separation into discrete size fractions, prior to recombination into the desired product (Austroads 2008a). Screen variables include aperture size and shape, screen angle, vibrating speed and direction.

In addition to the distribution of particle sizes, variables in the production process also influence the constructability and durability of the end product. Some hard source rocks do not produce sufficient fines during crushing to satisfy specifications. A fine plastic material, such as imported sands and clayey fillers, are commonly added to the coarse material to produce a well-graded material with the required cohesion, workability and permeability. The nature of the fines significantly influences the in-service behaviour of the unbound granular material. Care should be observed to prevent the inclusion of weathered rock or overburden material that may degrade or disintegrate during handling, compaction and in service (Austroads 2008a). Damp mixing of the end product ensures uniform distribution of moisture and reduces segregation potential during loading, transport, and stockpiling (Kleyn 2012).

## 2.4 Sprayed Bituminous Seal

### *2.4.1 Introduction*

The purpose of the sprayed seal is to provide an even durable wearing surface that also minimises the infiltration of moisture into the underlying pavement structure. All granular materials lose strength, of varying degree, with increasing moisture content (Austroads 2008a). The seal is comprised of a thin bituminous layer upon which uniformly sized cover aggregates are embedded. The sprayed seal does not contribute to structural capacity but does significantly impact the long-term serviceability of the pavement (Bartley Consultants 1997). The sprayed seal is key to maintaining the structural capacity of unbound granular pavements. Sprayed seals are typically selected for low traffic volume roads due to the limited capacity to resist high magnitude vertical and shearing stresses. Requirements for a sprayed bituminous seal include providing a durable riding surface, all-weather accessibility, and adequate skid resistance, in addition to minimal pavement wear, maintenance, moisture infiltration and road noise (Austroads 2009a).

Bituminous sprayed seals are classified according to cover aggregate size, binder type and number of applications. Aggregates range in size from 5 mm to 20 mm measured along the greatest dimension (Austroads 2009b). Sprayed seals typically use Class 170 binder, but Class 320, multigrade and polymer modified binders have also been used. Polymer modified binder (PMB) is typically employed in applications where improved shear resistance, limited reflective cracking, increased water resistance, reduced stripping potential, or improved temperature sensitivity are desired (Austroads 2009a). Single and double application seals are most common, with double applications providing improved waterproofing, traffic noise reduction, texture and shear resistance. The design of sprayed seals is characterised by the selection of the appropriate binder application rate and the aggregate spread rate for the given base material, environment and traffic conditions.

The longevity of sprayed seals results from binder/cover aggregate and binder/base adhesion, in addition to interlocking of the cover aggregates (Austroads 2009b). The cover aggregates are pressed into the bituminous layer using a pneumatic tyre roller compactor to maximise adhesion and to ensure a densely packed configuration (Bartley Consultants 1997). The fundamental ingredient of a successful sprayed seal is a strong and stable underlying structure (Midgley 2008). The sprayed seal is bonded to the surface of the upper granular base layer. Any deficiencies in the base layer surface can be reflected through the surfacing.

Distress modes for a sprayed seal include oxidation, stripping, flushing and cracking that affects skid resistance and ride quality.

### *2.4.2 Bitumen*

A thin layer of bitumen is applied to the surface of the unbound granular pavement structure as a waterproof membrane and also to adhere the cover aggregate. The suitability of bitumen for usage in sprayed bituminous seals can be determined by MRTS17, *Bitumen* (TMR 2011b), or MRTS18, *Polymer Modified Binder* (TMR 2011c). Bitumen is refined from crude petroleum and is delivered to the project site hot (160-200 °C) to allow for application to the pavement via pressurised spray bar/wand. Requirements for bitumen vary according to classification as presented in Table 2.4.

**Table 2.4: TMR requirements for bitumen used in sprayed seals**

| Property | Class 170 | Class 320 | S0.25S | S0.7S | S0.3B |
|---|---|---|---|---|---|
| Viscosity @ 60 °C (Pa.s) | 140 - 200 | 260 - 380 | - | - | - |
| Minimum consistency @ 60 °C (Pa.s) | - | - | 250 | 700 | 300 |
| Viscosity @ 135 °C (Pa.s) | 0.25 - 0.45 | 0.4 - 0.65 | - | - | - |
| Maximum viscosity @ 165 °C (Pa.s) | - | - | 0.55 | 0.55 | 0.55 |
| Minimum flash point (°C) | 250 | 250 | 250 | 250 | 250 |
| Minimum penetration @ 25 °C (pu) | 62 | 40 | - | - | - |
| Maximum RTFO viscosity ratio (%) | 300 | 300 | - | - | - |
| Maximum insolubles in toluene (%) | 1 | 1 | - | - | - |
| Maximum stiffness @ 15°C (kPa) | - | - | 140 | 140 | 180 |

### 2.4.3 Cover Aggregate

The cover aggregate provides the traffic riding surface and is critical to the successful performance of the sprayed seal. Desired aggregates must be strong, sound, angular, and free of dust, clay, organics and other deleterious materials. The suitability of aggregate for utilisation in sprayed bituminous seals can be determined in accordance with MRTS22, *Supply of Cover Aggregate* (TMR 2010b). Cover aggregates are defined in MRTS22 according to NMAS and quality category. Typical NMAS range from 5 mm to 20 mm, with particle size distribution requirements as shown in Table 2.5 .

**Table 2.5: TMR cover aggregate particle size distribution requirements**

| Sieve opening (mm) | Per cent passing (by mass) | | | | | |
|---|---|---|---|---|---|---|
| | 20 mm | 16 mm | 14 mm | 10 mm | 7 mm | 5 mm |
| 26.500 | 100 - 100 | - | - | - | - | - |
| 19.000 | 85 - 100 | 100 - 100 | 100 - 100 | - | - | - |
| 16.000 | - | 85 - 100 | - | - | - | - |
| 13.200 | 0 - 20 | 0 - 60 | 85 - 100 | 100 - 100 | - | - |
| 9.500 | 0 - 5 | 0 - 15 | 0 - 30 | 85 - 100 | 100 - 100 | - |
| 6.700 | - | - | 0 - 5 | 0 - 30 | 85 - 100 | 100 - 100 |
| 4.750 | - | - | - | 0 - 8 | 0 - 30 | 85 - 100 |
| 2.360 | 0 - 1 | 0 - 1 | 0 - 1 | 0 - 1 | 0 - 10 | 0 - 30 |
| 1.180 | - | - | - | - | 0 - 5 | 0 - 5 |

The quality category is determined by consideration of available source material and the intended application. Material property requirements vary according to the quality category, as presented in Table 2.6. High-risk (traffic and environment) applications typically use the highest quality cover aggregates (category A).

**Table 2.6: Required material properties for TMR cover aggregates**

| Property | Aggregate quality category | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Minimum wet 10% fines value (kN) | 175 | 150 | 100 | 100 |
| Maximum wet/dry variation (%) | 35 | 35 | 40 | 40 |
| Minimum degradation factor | 45 | 40 | 40 | 35 |

| Property | Aggregate quality category | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Minimum crushed particles (%) | 80 | 80 | 80 | - |
| Maximum flakiness (%) | 30 | 35 | 35 | 35 |
| Maximum weak particles (%) | 1 | 2 | 3 | 3 |
| Maximum absorption (%) | 2 | 2 | 2 | 2 |

## 2.5 Pavement Structural Design

### *2.5.1 Introduction*

The structural components of an unbound granular pavement consist of compacted aggregate base and subbase layers. The layers are interdependent, with overlying layers distributing traffic loads and underlying layers minimising vertical displacement. The base layer is the major structural contributor to the ability of the pavement to carry the applied traffic. The subbase lies between the base and the subgrade and continues the distribution of stresses but, because it is not directly subjected to traffic loads, it can be of lower quality. The subgrade is typically compacted natural material. However, in situ stabilised or imported select fill material can also be used. Unbound granular pavement structures are typically designed with the highest quality materials closest to the surface to provide a stable running surface for traffic while protecting the underlying materials from high stresses and strains. The subgrade is generally composed of the lowest quality material and its strength is an important input to the thickness design process.

The fundamental concept of unbound granular pavement design is to provide granular material layers of sufficient thickness and quality to limit the magnitude of granular material and subgrade deformation as a result of traffic loading. Stresses and strains applied at the pavement surface are distributed across a greater area with depth, minimising the magnitude transmitted to underlying layers. The lateral distribution of load is achieved through intra- and inter- particle friction. The rate of load distribution is directly related to the properties of the granular materials used. The treatment of materials, traffic, and environment vary between different design methodologies. However, the fundamental distress mechanisms are similar (Merrill, van Dommelen & Gaspar 2006). Unbound granular pavements are typically designed to provide an acceptable level of service for 20 to 30 years. The ideal design can withstand the operational and environmental conditions throughout the designated service life at lowest WOL cost.

Design methodologies are validated by historical observations of pavement performance. The reliability of the method is reduced as input parameters are extrapolated further away from the range of the original dataset (Nunn et al. 1997). The severity of traffic loading has steadily increased as new generations of heavy vehicles are built with greater axle loads and tyre pressures. As a result, it is fairly common for conservative design inputs to be employed (Merrill, van Dommelen & Gaspar 2006). The structural design of unbound granular pavements in Australia is typically undertaken in accordance with the *Austroads Guide to Pavement Technology, Part 2: Pavement Structural Design* (Austroads 2012). The Austroads Guide provides two methods for undertaking the structural design of unbound granular pavements, including:

- mechanistic design using subgrade strains calculated from linear-elastic modelling, and
- empirical design using charts developed from historical performance observation.

### *2.5.2 Mechanistic Design*

In the mechanistic approach, linear-elastic modelling software (such as CIRCLY) is commonly used to facilitate the structural design of pavement layers. Inputs include pavement configuration, material properties, traffic, and environment. From the predicted vertical compressive strain on the top of the subgrade, the allowable traffic loading is calculated. As the predicted strains are very sensitive to the subgrade modulus, the subgrade design CBR should be carefully selected considering its variability. The principal deficiency in the mechanistic approach is that the modeling does not specifically assess permanent deformation in the unbound granular layer. The deformation resistance of the granular materials is addressed through the specifications for supply and placement, generally developed from field experience.

### *2.5.3 Empirical Design*

The required thickness of unbound granular pavement layers is most commonly determined through reference to empirical design charts. Design charts provide the minimum thickness of granular material required for a given subgrade strength (in terms of CBR) and design traffic loading (ESA). The total structural thickness may be composed of either granular base or subbase courses, with the individual layer thicknesses determined by referencing the empirical chart. Figure 8.4 in Part 2 of the *Austroads Guide to Pavement Technology* (Austroads 2012) is applicable for unbound granular pavements with sprayed bituminous seal and traffic loadings from $10^5$ to $10^8$ ESA. Approximately 550 mm thickness of pavement structure is required over a CBR 5% subgrade to successfully provide 30 years of service or approximately 5.0 x $10^7$ ESA (Roads Corporation Victoria 1997). The primary limitation of the empirical method is the inability to adjust thickness requirements based on the quality of granular materials and non-standard traffic loading.

## 2.6 Pavement Construction

### *2.6.1 Introduction*

The long-term performance of unbound granular pavements is determined by the quality of the composing aggregate, employed construction practices, and moisture management techniques, in addition to the traffic and environmental loading. Of the controllable factors, construction practice is the most easily, yet infrequently, managed aspect. The practices utilised are generally determined by the capability and familiarity of the construction crew. The availability of expertise within the construction industry, relative to unbound granular pavement, is a matter of concern (Midgley 2008). A potential lack of available expertise highlights the need for definition of best construction practice in technical guidance documentation.

### *2.6.2 Unbound Granular Layers*

The principal construction activities for establishment of unbound granular layers include platform preparation, layer formation, compaction and finishing.

*Preparation*

Thorough preparation of the underlying layer promotes satisfactory long-term performance. The ideal surface finish for the construction platform is even, dense and free of deleterious materials. A poor surface finish accelerates defects in the overlying layers. Additionally, the elevation, slope, and crown should be confirmed to ensure deficiencies are not promulgated through the pavement structure.

*Formation*

Typical unbound layer thickness ranges from 100 mm to 200 mm to maximise compactability without increasing delamination potential. The layer is usually placed using mechanical spreaders such as pavers, or spreading the end-dropped aggregate windrows or stockpiles using a grader. The optimal plant for layer formation should be selected with consideration of project size, material availability, target production rate, and geometric layout. Base and subbase courses should be placed slightly wet of optimum moisture content (OMC), with handling minimised to reduce segregation potential.

*Compaction*

Ensuring proper compaction is critical for establishing a strong, stable and durable unbound granular pavement layer. Commonly employed compaction equipment for unbound granular layers includes static and vibrating steel-wheel and pneumatic tyre rollers. Minimum compaction requirements vary according to material type and application, and typically range from 100% to 105% MDD determined using standard Proctor compactive effort. Compaction should continue until the pass of a 6.25 tonne steel-wheel roller leaves an impression depth less than 5 mm (Bartley Consultants 1997). Moisture control is critical as sufficient quantities are required to lubricate particles for achieving maximum density. However, excessive moisture trapped within the pavement can accelerate structural deterioration. The maximum allowable degree of saturation (DOS) values vary according to material type and application but generally range from 60% to 70%.

*Surface Finish*

Similar to the construction platform, the ideal surface finish for unbound granular pavement layers is even, dense and free of deleterious materials. Trimming of the compacted layer should be minimised but, where required to achieve design elevation, slope and crown, it is typically accomplished using a grader. Trimming of unbound granular material should be accomplished immediately following compaction and should be discontinued if tearing or scabbing of the surface occurs. It should be noted that trimming is not usually undertaken for pavement layers formed using a mechanical spreader. Trafficking of the constructed layer should be limited until sufficient dry back has occurred. Following formation, compaction, finishing and dry back the surface should be swept to remove dislodged particles and excessive fines.

*Key Considerations*

The principal considerations during the construction of unbound granular layers include segregation minimisation, moisture control, compaction and surface finish. Segregation significantly affects the characteristics of the finished layer and typically results from improper handling techniques. The presence of moisture within the pavement structure encourages particle realignment, swelling of expansive materials and development of positive pore-water pressure. Moisture acts as a lubricant between aggregate particles; therefore, it is required during construction for optimal workability and compaction, but reduces stability and increases the probability of differential volume change during service (Bartley Consultants 1997). The shear strength of unbound aggregate layers is realised through aggregate interlock that is maximised with compaction. Adequate compaction is also required to minimise void space, thereby reducing permeability and improving durability. A poor surface finish accelerates defects in the overlying layers. The ideal finished surface is hard, dense, impermeable, and free of loose and foreign debris (Midgley 2008).

### *2.6.3 Bituminous Sprayed Seal*

Sprayed bituminous seals are preferred to thin asphalt surfacings for unbound granular pavements due to the higher cost and fatigue cracking potential of the later (Peyton 1989). The thin bituminous surfacing is designed to resist abrasion from traffic and minimise the entry of moisture (Austroads 2009a). The application of a sprayed bituminous seal requires preparation of the basecourse surface, loading and treatment of the cover aggregate, application of binder, spreading of aggregate, compaction and trafficking (Austroads 2009b). Pretreatment of the cover aggregate should include removal of oversize particles and uniform application of bituminous precoating. The minimum degree of precoating should be in excess of 70%. The ideal application of binder produces an even film of bituminous binder. Cover aggregates should be spread and compaction of the cover aggregate should be accomplished within 30 minutes of placement using a pneumatic tyre roller to promote aggregate interlock and orient particles vertically along the thinnest dimension. The pneumatic tyre roller should have a minimum mass of 10 tonnes (Bartley Consultants 1997). The finished surface should be protected from high volume and heavy load traffic for a minimum of 12 hours after construction.

*Key Considerations*

The condition of the pavement structure at the time of initial sealing is critical to long-term performance (Midgley 2008). The basecourse surface should be reasonably dry, free of dust and other deleterious material, and tightly compacted with a mosaic appearance prior to sealing (Bartley Consultants 1997). Poor base preparation accelerates defects at the pavement surface. Premature degradation of a sprayed bituminous seal can result from binder hardening, use of soft aggregate, and/or insufficient design or construction practice (Austroads 2009b).

## 2.7 Quality Control

### *2.7.1 Introduction*

Material production and construction practices must be adequate to ensure the unbound granular pavement performs according to design assumptions (Bartley Consultants 1997). Quality assessment for unbound granular materials can be conducted on source material, supplied end product, and/or as-constructed structures (Austroads 2008b). Control of the source rock requires a significant commitment to testing, classification and inspection. When consistently applied, this approach allows for very close control of construction materials. Control of the end product requires complex specifications that address uniformity of sources and variation across size fractions, in addition to blended and recycled materials (Austroads 2008b). Testing of as-constructed structures is generally limited to minimise disturbance and associated accelerated distress development.

Ensuring materials meet specification limits is critical to achieving satisfactory performance and delivering a cost-effective pavement (Kleyn 2012). Granular layers are never homogeneous due to disparities in the distribution of particle sizes and moisture, in addition to variable compactive effort. High standards of construction and monitoring practice can minimise these variations (Bartley Consultants 1997). The optimal quality control program includes regular monitoring of material properties such as mineralogy, particle shape, size and surface texture, plasticity, hardness/toughness, soundness, permeability and bearing capacity; and construction elements such as segregation, compaction, DOS, evenness, horizontal deviation and deflection. A description of, and typical limits related to, the material properties listed above are provided in Section 2.2.

### *2.7.2 Segregation*

Segregation is defined by a lack of homogeneity in the spatial distribution of aggregate particle sizes. Aggregate segregation produces sections of the pavement layer that are too coarse, resulting in high air void content and rough surface texture; and too fine, exhibiting reduced shear strength and stability. Segregation results from improper mixture proportioning, stockpiling, loading and unloading, in addition to layer formation practices. The occurrence of segregation is typically identified visually, but can be quantified by determining the particle size distribution of irregular material in accordance with TMR test method Q103A (Main Roads 1996a).

### *2.7.3 Compaction*

Compaction defines the process by which air voids are reduced and aggregate interlock is improved through application of repetitive passes of static and dynamic compaction equipment. The degree of compaction is commonly quantified through measurement of relative dry density (RDD). RDD is the ratio of in situ dry density to MDD for a specific unbound granular material. Standard practice is to reference either relative compacted density or solid relative density.

Relative compacted density is typically determined in Queensland according to TMR test method Q142A, *Dry Density: Moisture Relationship (Standard Compaction)* (TMR 2010g). In this method, the mass of material filling a fixed volume is determined by compacting in thin lifts using a compactive effort of 596 kJ/m$^3$. Relative compacted density can also be determined in accordance with TMR test method Q142B, *Dry Density: Moisture Relationship (Modified Compaction)* (TMR 2010h). This method is similar to Q142A, except that the compaction is accomplished using a compactive effort of 2703 kJ/m$^3$. The solid relative density can be determined in accordance with TMR test method Q109, *Apparent Particle Density of Soil* (Main Roads 1996c). In this method, the theoretical maximum particle density is determined by measuring the mass of both coarse and fine aggregates relative to the mass of an equivalent volume of water.

The influence of density on performance-related properties such as modulus, shear strength, deformation resistance and permeability is substantial. For this reason, minimum RDD is clearly specified and regularly monitored to ensure satisfactory performance. Typical requirements for RDD include 102% of relative compacted density determined using standard effort (Q142A) for Type 1, and 100% for Type 2, Type 3 and Type 4 base and subbase courses. It is common practice for in-situ density to be routinely checked using a nuclear density gauge calibrated using the sand replacement method.

### 2.7.4 Evenness

The evenness or roughness of the final constructed pavement surface is a critical measure influencing both functional (ride quality) and structural (deformation) performance. Excessive roughness produces discomfort to users, increased vehicle wear, and accelerates structural deterioration of the pavement structure by imparting dynamic shearing loads. Evenness is also an indicator of construction quality. Roughness is commonly determined in 100 m to 500 m sections according to TMR test methods Q708A/B/C/D, *Road Roughness – Surface Evenness (Using a NAASRA Roughness Meter/a Two Laser Profilometer/Static Level and Staff/the ARRB Walking Profiler)* (TMR 2011d/e/f/g). Typical requirements include a maximum 60 counts per kilometre.

### 2.7.5 Horizontal Deviation

The shape of the final constructed pavement surface is another critical measure significantly affecting both functional (safety) and structural (deformation) performance. Humps and sags in the lateral profile undermine laminar run-off of precipitation, promoting accumulation that can increase potential for aquaplaning and moisture intrusion into the pavement structure. Results of significant horizontal surface deviation include user discomfort, increased vehicle wear and accelerated deterioration of the pavement. Horizontal deviation is also an indicator of construction quality. Horizontal deviation can be determined in accordance with TMR test method Q712, *Three Metre Straightedge* (TMR 2013l), and maximum allowable values range from 5.0 mm for Type 1 to 8.0 mm for all other material types.

### 2.7.6 Deflection

Deflection of the road surface under load is a qualitative assessment of the structural capacity of the as-constructed pavement. Surface deflection is generally determined through visual assessment of vertical movement under a loaded water cart. A minimum gross vehicle load of 20 tonnes is generally required, with zero visible deflection permitted.

## 2.8 Performance

### 2.8.1 Introduction

Key performance requirements for road pavements include the ability to sustain design traffic without excessive deformation, resist cracking, provide an adequate construction platform, and deliver a safe and comfortable ride. The primary factors driving unbound granular pavement performance include traffic and environmental loading, moisture conditions, confinement, material properties, and the condition of the bituminous seal (Bartley Consultants 1997). The intrinsic (hardness, friction, contamination, source), manufacturing (shape, maximum size, size distribution, texture, fractured faces, fines quality) and construction (density, moisture content, orientation) properties of the aggregate, in addition to the imposed boundary stresses, significantly influence performance (Austroads 2008a). The long-term performance of pavements is dependent upon the use of satisfactory design, material selection, construction and maintenance practices. ‘Failure of any one of these aspects will severely compromise the longevity of the pavement and lead to premature distress and failures’ (Organisation for Economic Co-operation & Development 2005).

Newly constructed or rehabilitated unbound granular pavements undergo an initial ‘settling’ period, during which construction and traffic loads induce particle rotation and relocation until a dense, stable fabric is achieved (Bartley Consultants 1997). Some practitioners are of the view that if unbound granular pavement achieve such a stable state, they perform indefinitely given traffic, environment, and material properties do not change over time (Bartley Consultants 1997). Reliability defines the probability that the pavement will provide the required level of service throughout the design traffic loading (Austroads 2012). Typical reliability factors for pavement infrastructure range from 80% to 95%, with the appropriate level determined by the application and operational constraints. The primary risk for unbound granular pavements is that rutting will reach a condition requiring intervention before reaching the design traffic loading (Arampamoorthy & Patrick 2010).

Pavement distress occurs according to two modes, functional and structural distress. Functional distress indicates that the pavement can no longer achieve its primary function without discomfort to users and/or damage to plant. Structural distress is defined by collapse of the system or one of the components, resulting in a lack of capability to safely sustain traffic loading. The root causes of both functional and structural pavement distress are related to traffic loading, environment, climate and/or durability. Human factors such as improper design, construction and maintenance practices can also exacerbate failure modes. Functional and structural failures are indicated by the development of distresses. The terminal condition for pavements occurs when the severity of distresses progresses to the extent that removal and replacement of the structure is required (Organisation for Economic Co-operation & Development 2005).

### *2.8.2 Functional Distress*

Functional distress refers to the development of distresses that reduce or inhibit the capability of a pavement structure to fulfill the functional requirements. Functional requirements vary between road agencies but, as a minimum, include providing a reasonably safe and comfortable riding surface. The principal functional distresses reducing the serviceability of unbound granular pavements include roughness, flushing, stripping and cracking. Roughness or evenness refers to the general rideability of the pavement. Roughness is caused by surface irregularities along the longitudinal profile of the pavement and can significantly impact user comfort and vehicle operating costs. Flushing is the build-up of a film of bituminous material at the pavement surface that creates a shiny, glass-like surface that becomes sticky when hot. The depression of cover aggregate into the underlying base is the most common cause and results in reduced skid resistance. Stripping is the removal of sealing aggregate from the pavement surface, leaving behind the bituminous binder. Stripping generally occurs when the bituminous material becomes brittle or has insufficient bonding with the aggregate. Consequences include reduced skid resistance and increased the potential for generation of airborne debris. Cracking can be expressed as transverse, longitudinal or block, and is the occurrence of linear separation of the surfacing. Cracking reduces ride quality and allows moisture to infiltrate the pavement structure, accelerating structural distress development.

### 2.8.3 Structural Distress

Diminished capacity to reliably support user traffic is the definition of structural failure for road infrastructure. The principal structural distresses reducing the serviceability of unbound granular pavements are related to irregular surface deformation. Deformation of the pavement surface results from either shear of the upper layers or excessive repeated displacement of the foundation. Shoving includes the plastic movement of pavement layers as a result of traffic loading. Shoving is caused by the combination of heavy vehicle acceleration, braking and turning with an unstable subsurface structure. Rutting is the occurrence of surface depressions in the area of the pavement subjected to traffic loading (wheelpaths). Consolidation or shear movement within any pavement layer can produce surface rutting, but repeated subgrade deflection is the most common source. Shoving and rutting manifest as depressions on the pavement surface that decrease ride quality and increase aquaplaning potential.

### 2.8.4 Modelling

Creagh, Wijeyakulasuriya & Williams (2006) developed a risk assessment model for the performance risks associated with unbound granular pavements in Queensland. Fault tree analysis (FTA) was used to model the interactions between performance variables such as traffic, material properties, environment, and climate; in addition to construction and maintenance practices; and pavement failure modes, including permanent deformation, cracking, shear, and loss of skid resistance. The developed distress model was calibrated using historical pavement performance data. The authors observed that unbound granular pavements in Queensland have a significant risk of permanent deformation and potholing, low risk of loss of skid resistance, and negligible risk of cracking (Creagh, Wijeyakulasuriya & Williams 2006).

Schlotjes et al. (2013) developed a computational methodology for predicting the distress modes of unbound granular road pavements in order to prioritise mitigation strategies and make the most effective use of available maintenance funding. The researchers found that the prediction of pavement distress is difficult due to complex interactions between composing materials, traffic, environment, and climate, in addition to inherent variability (Schlotjes et al. 2013). FTA and support vector machines (SVM) were used to determine the probability of early failure mode development. Long-term pavement performance sections (5628) in New Zealand were used to validate the models using historic performance and maintenance data. Factors considered included traffic, pavement composition, strength, environment, surface condition, and subgrade moisture sensitivity. The principal distress modes were determined to be permanent deformation, cracking and shear. 97% of the investigated pavement structures were observed to have a probability of premature distress less than 0.2 and 79% less than 0.1 (Schlotjes et al. 2013). Of the 2% of sections identified as failing, 1% were the result of permanent deformation, 9% were the result of cracking, and 90% of the premature distress were the result of shear-related distress modes.

## 2.9 Maintenance

Unbound granular pavements deteriorate with the repeated application of traffic and environmental loads. Regular condition monitoring can indicate when the rate of deterioration accelerates and maintenance/rehabilitation intervention is required to re-establish the serviceability and prevent significant structural deterioration (Merrill, van Dommelen & Gaspar 2006). The service life can be extended by intermediate maintenance activities, including crack sealing and patching (Organisation for Economic Co-operation & Development 2005). Effective management requires balancing the serviceability of the asset against economic investment (Organisation for Economic Co-operation & Development 2005). Quantifying the benefit of maintenance activities requires developing reliable and repeatable methods for monitoring the condition of pavements, forecasting deterioration rates, and assessing the impact on users (Brillet et al. 2003).

# 3 HIGH-STANDARD GRANULAR (HSG) BASE

## 3.1 Introduction

Naturally occurring granular material is a fundamental pavement construction material (Austroads 2008a). Unbound granular pavements have been provisioned for significant proportions (≈ 70%) of the Australian road transport network. However, underperformance in Queensland (Creagh, Wijeyakulasuriya & Williams 2006) has limited unbound granular pavements to rural applications with light-to-moderate (< 5 x $10^6$ ESA) traffic volumes. HSG base provides improved bearing capacity and resilience as compared to standard granular material, allowing for extended use of the economical unbound granular pavement configuration (Kleyn 2012). Heavy-duty unbound granular pavements can be provisioned at approximately 60% the construction cost of concrete or deep strength asphalt pavements (Roads Corporation Victoria 1997).

High-standard basecourse is a premium crushed aggregate product that provides improved permeability, durability, stiffness and shear strength as compared to standard granular material (Kleyn 2012). The distribution of particles sizes for HSG material is tightly controlled and a low plasticity index (PI) range of 2 to 6 is desired (Roads Corporation Victoria 1997). According to Part 2 of the Austroads Guide to Pavement Technology (2012), high-standard base is:

- sourced from sound and durable igneous or metamorphic rock
- manufactured in a highly processed and controlled manner to tight tolerances
- specified similarly to normal standard material, but with an emphasis on the type and quantity of fines, permeability, modulus and performance under repeated loading
- constructed in a highly controlled manner to tight tolerances.

Similar to standard granular material, the long-term performance of unbound granular pavements incorporating HSG base is significantly influenced by the properties of the composing material, structural design and construction practices, in addition to observed maintenance and rehabilitation techniques (Kleyn 2012). Material properties, construction practice and quality control testing must be adequate to ensure that the HSG base performs according to design assumptions (Bartley Consultants 1997). HSG base layers can, for the most part, be designed, constructed and managed in accordance with best practice for standard unbound granular materials. However, the principal difference between standard and HSG base is the level of control over the source, end product and in situ material properties.

## 3.2 Applications

Heavy-duty unbound granular pavements can provide significant cost savings as compared to asphalt and/or concrete pavements, particularly where differential soil movement is anticipated (Hazell & Perry 2009). Pavement layers incorporating HSG base are designed and constructed using similar methods as for standard unbound granular material. HSG base can be employed in pavement applications where unbound granular pavement would typically be specified, but a greater level of reliability is required. However, to balance the increased costs of improved production, material property and construction control, the technology is most efficiently employed in SG(HD) applications. SG(HD) unbound granular pavements are typically provisioned in heavy traffic volume (> 7 x $10^7$ ESA) or high-load intensity applications (Midgley 2008). HSG is ideally utilised in moderate to heavy traffic rural and light traffic urban applications. Accelerated testing in the 1980s concluded that properly constructed HSG base could be used in pavements with a bearing capacity up to 5 x $10^7$ ESA (Kleyn 2012). The application of 2 x $10^7$ ESA loads of accelerated loading produced only minimal surface deformation for a heavy-duty unbound granular pavement (Roads Corporation Victoria 1997).

The current Victorian criteria for heavy-duty unbound granular pavements were developed as a result of widespread accelerated (12 months) distress development along rural motorways in the early 1970s. The utilised basecourse materials were ill-suited to the application, as clean, hard aggregates typically used in urban environments were selected for pavements designed and constructed according to rural highway standards (Jameson 2000). A large research effort was undertaken and a number of modifications were incorporated to the heavy-duty unbound pavement delivery system. As a result of systematically monitoring long-term performance, VicRoads (Roads Corporation Victoria 1997) has observed heavy-duty unbound granular pavements regularly exceed design life expectations. Additionally, the relative low cost of granular pavements has allowed for the establishment of the rural motorway system in Victoria (Jameson 2000).

## 3.3 Material Requirements

### *3.3.1 Specifications*

HSG material has been employed successfully throughout Australia and internationally, but the approaches do vary. High density, low permeability and moderate plasticity are critical to the satisfactory performance of HSG materials (Jameson 2000). Control of material properties is typically accomplished through specification of effective conformance testing methods, limits and frequencies. Typical specified properties for HSG material include mineralogy, particle size distribution, hardness, soundness, particle shape, plasticity, clay type and quantity, permeability and modulus (Austroads 2012). Material requirements for HSG base employed in the previous Queensland HSG trial (Main Roads 2002), Victoria (VicRoads 2011) and South Africa (Committee of Land Transport Officials 1998) are presented in Table 3.1. When selecting or specifying HSG material, other factors to be considered include the intended function, design assumptions, and production method, in addition to available quality control and assurance testing methods.

**Table 3.1: Comparison of HSG base material property requirements**

| Property | Gatton Bypass duplication | VicRoads | COLTO |
|---|---|---|---|
| | G1.1 | Class 1 | G1 |
| Minimum wet 10% fines value (kN) | 130 | - | 125 |
| Maximum aggregate crushing value (%) | - | - | 24 |
| Maximum wet/dry variation (%) | 40 | - | - |
| Maximum ball mill value | 30 | 30 | - |
| Minimum crushed particles (%) | 70 | 60 | 100 |
| Maximum flakiness index (%) | 35 | 35 | 35 |
| Maximum liquid limit | 25 | 30 | 25 |
| Plasticity index | 3 - 7 | 2 - 6 | 0 - 5 |
| Linear shrinkage | 1.5 - 3.5 | - | 0 - 2 |
| Weighted plasticity index | 80 - 150 | - | - |
| Weighted linear shrinkage | 40 - 85 | - | - |
| Minimum unsoaked CBR (%) | 80 | - | - |

### *3.3.2 Mineralogy*

The nature of the source rock has a significant influence on the long-term performance of the HSG material. Igneous and metamorphic rocks are preferred due to greater strength and improved durability. Aggregate should be sourced from unweathered rock without inclusions to correct the particle size distribution (Kleyn 2012).

### 3.3.3 Particle Size Distribution

Careful selection and monitoring of the particle size distribution is critical for consistently achieving adequate compacted density. The particle size distribution providing theoretical maximum density can be determined using Equation 2, where a smaller adjustment coefficient produces finer gradations and larger values coarser blends.

$$P = 100\left(\frac{d}{D}\right)^{n} \tag{2}$$

where

P = percentage (by mass) of particles passing the designated sieve

d = opening size of the designated sieve

D = maximum aggregate size

n = adjustment coefficient.

The distribution of particle sizes for HSG materials should be bound by maximum density curves constructed with n values of 0.3 and 0.5 for the fine and coarse boundaries respectively (Kleyn 2012). Particle size distribution requirements for HSG base employed in Queensland, Victoria and South Africa are presented in Table 3.2.

**Table 3.2: Comparison of HSG base particle size distribution requirements**

| Sieve opening (mm) | Per cent passing (by mass) | | | |
|---|---|---|---|---|
| | Gatton Bypass duplication | VicRoads | | COLTO |
| | G1.1 | Class 1 & 2 (LA ≤ 25) | Class 1 & 2 (LA > 25) | G1, G2 & G3 |
| 37.5 | 100 - 100 | - | - | 100 - 100 |
| 26.5 | - | 100 - 100 | 100 - 100 | 84 - 94 |
| 19 | 80 - 100 | 95 - 100 | 95 - 100 | 71 - 84 |
| 13.2 | - | 78 - 92 | 78 - 92 | 59 - 75 |
| 9.5 | 55 - 90 | 63 - 83 | 63 - 83 | - |
| 4.75 | 40 - 70 | 44 - 64 | 44 - 64 | 36 - 53 |
| 2.36 | 30 - 55 | 30 - 48 | 29 - 48 | - |
| 2 | - | - | - | 23 - 40 |
| 0.425 | 18 - 30 | 14 - 22 | 13 - 21 | 11 - 24 |
| 0.075 | 8 - 20 | 7 - 11 | 5 - 9 | 4 - 12 |

Successful applications have been constructed using both 37.5 mm and 26.5 mm NMAS HSG materials (Kleyn 2012). However, 26.5 mm NMAS material is preferred due to improved efficiency in spreading, compacting, and achieving an even finish with reduced segregation potential (Midgley 2008). The fine (< 0.425 mm) component of the HSG material should be slightly (2% to 3%) higher than the maximum density curve to facilitate optimal aggregate interlock (Kleyn 2012). However, the fines (< 0.075 mm) content should be limited to 10% to maximise stability (Bartley Consultants 1997).

### *3.3.4 Hardness*

Sufficient aggregate hardness is required to resist break down during construction and in service. Hardness can be quantified through measurement of resistance to crushing. For HSG materials, the 10% fines value (wet) should not be less than 130 kN (Bartley Consultants 1997).

### *3.3.5 Soundness*

Weathered or unsound materials should not be included in HSG materials to withstand high compaction forces applied during construction and variable moisture conditions in service (Kleyn 2012). The soundness of HSG material is commonly assessed using wet/dry strength variation or ball mill laboratory testing, and values should not exceed 40% and 30% respectively.

### *3.3.6 Particle Shape*

Aggregate interlock is critical to HSG material modulus and shear strength. Specification of the minimum proportion of crushed and maximum proportion of flaky particles is commonly utilised to promote aggregate interlock. At least 70% of the coarse component (> 4.75 mm) of the HSG base aggregate should have two or more broken faces (Bartley Consultants 1997). The proportion of flaky particles should not exceed 35%.

### *3.3.7 Plasticity*

The plasticity properties of HSG material influence the permeability, constructability and volume stability of the constructed pavement layer. Liquid limit, PI and LS are typically measured to quantify the plasticity of the material. The liquid limit of HSG material should not exceed 25. Specified PI and LS values vary, and range from 0.0 to 7.0 and 0.0 to 3.5 respectively.

### *3.3.8 Clay Type and Quantity*

Control of the fines (< 0.075 mm) component of the HSG material is critical due to the significant impact on workability, cohesion and permeability (Hazell & Perry 2009). Fine material content is typically limited to ensure sufficient permeability and stability are achieved. However, a proportion of fines are required to promote cohesion and inhibit segregation. Non-reactive clays are preferred.

### *3.3.9 Permeability*

The permeability of the granular pavement material is a key property that is designed for and measured in both the Victoria (Roads Corporation Victoria 1997) and New South Wales (Hazell & Perry 2009) implementation of HSG. Minimum and maximum limits on permeability are typically applied to HSG material to establish a moisture barrier that is not susceptible to positive pore-water pressure development.

### *3.3.10 Modulus*

HSG materials provide higher modulus compared to standard granular materials as a result of the rigid particles, low air void volume and high degree of aggregate interlock.

## 3.4 Material Production

The high quality of HSG material results from careful planning and execution of production practice. HSG material is produced in a systematic, tightly controlled manner from igneous or metamorphic source rock. Unlike standard granular material, HSG materials are carefully blended using metered conveyor belts to limit variation in particle size distribution and segregation potential of the end product. The high quality of HSG is ensured through rigorous on site control and quality assurance testing. Quality control is typically accomplished through lot testing of stockpiled material (Austroads 2012).

## 3.5 Structural Design

The HSG base is the primary load-bearing layer for the SG(HD) unbound granular pavement. The structural thickness of HSG base layers typically ranges from 100 to 300 mm as determined by traffic, environment, pavement composition, and subgrade bearing capacity constraints. Layer thickness of 100 mm to 175 mm was observed to be optimal for HSG material (Hazell & Perry 2009).

The structural design of unbound granular pavements incorporating HSG base is commonly accomplished using linear-elastic pavement design software such as CIRCLY . Representative material properties include elastic modulus of 300 MPa to 700 MPa, degree of anisotropy of 2.0, and Poisson’s ratio of 0.35 (Austroads 2012).

## 3.6 Construction

When properly constructed, HSG base provides a dense impermeable structural layer, with increased durability, strength and stiffness. Greater in situ density is a key characteristic of HSG material. This is achieved through a well-graded particle size distribution and careful attention to construction practices. These characteristics have a profound effect on the long-term performance of the pavement (Austroads 2008a). HSG base allows for the reliable implementation of unbound granular pavements in heavy traffic rural applications.

Proper construction of unbound HSG base is a rigorous process requiring strict adherence to specifications to ensure long-term performance (Austroads 2012). The principal construction activities of layer formation, compaction, finishing, and quality control testing should be accomplished by best practice for unbound granular materials.

### *3.6.1 Layer Formation*

HSG material should be spread and compacted in uniform layers with final compacted thickness between 100 mm and 150 mm. Due to the high production rate of mechanical spreading equipment, sufficient stockpiles of granular material should be established prior to initiating the paving operation (Roads Corporation Victoria 1997). Minimising segregation is critical and uncompacted layer thickness should not be less than twice the maximum particle size, or greater than four times the maximum particle size up to 250 mm (Bartley Consultants 1997). The moisture content during placement should be within 85% to 100% of OMC for optimal workability.

### *3.6.2 Compaction*

Ideal compaction equipment includes a vibrating steel-wheel roller of minimum 3.2 tonne mass and vibrating frequency of 37 Hz, and a pneumatic tyre roller of minimum 7.0 tonne mass (Bartley Consultants 1997). Compaction should begin on the low side of the alignment and work towards the high side. Compaction should be continued until the HSG base reaches a stable condition without visible weave or creep under loading. Excessive rolling and reworking should be avoided, as it increases potential for aggregate break down and subsequent rutting of the surface (Midgley 2008). Pavement compaction is ideally assessed according to characteristic RDD values (Roads Corporation Victoria 1997).

### *3.6.3 Finishing*

Straightedge deviation should not exceed 7.0 mm, and vertical geometric tolerances should be limited to +0 mm to +15 mm (Bartley Consultants 1997). The compacted material should be protected from traffic for approximately 12 hours to prevent damage to the surface (Kleyn 2012). The upper basecourse layer is typically allowed to dry back to 70% of OMC prior to application of the bituminous seal coat (Roads Corporation Victoria 1997). TMR (MRTS05 specifies the dry-back moisture level in terms of DOS (60% for major highways and 65% for other roads with Type 1 and

Type 2 basecourse)) and ARRB (APRG TN13 specifies a DOS of 70% or 60% in the case of very moisture sensitive materials). Drying back improves the performance of the bituminous surfacing by allowing satisfactory penetration of the binder into the surface. Consequently, the pavement material remains drier in the long term, assuring a stronger and stiffer pavement without premature failures. Ball Penetration results are a measure of pavement hardness indicating the likely embedment of sealing aggregate into the pavement surface causing the seal to flush. Any pavement with a ball penetration value greater 4 mm should not be sealed and should be allowed to further dry-back until a satisfactory result is obtained.

#### *3.6.4 Quality Control*

The construction of HSG basecourse should be accomplished to high standards of density, DOS, thickness, shape and evenness (Austroads 2012). 'Acceptance is [ideally] based on assessment of individual test results and of each day's overall production' (Peyton 1989). Frequent control testing is essential to achieving a high-quality product.

*Relative Density*

The high unit weight and degree of aggregate interlock in HSG material has a significant impact on pavement performance. As described in Section 2, the most commonly used method of assessing the adequacy of the field compaction is to calculate RDD, which is the ratio of in situ dry density to laboratory MDD. The minimum required RDD for HSG base is 100% of relative compacted density determined using modified effort (Austroads 2012). Compaction acceptance is typically determined by comparing the characteristic RDD value, based on multiple tests within each lot, to the specification criteria (Peyton 1989).

The method of determining MDD is one of the principal differences in the application of HSG materials, both nationally and internationally. The specification developed for the Gatton Bypass duplication required 102% of relative compaction determined using standard Proctor compactive effort (Main Roads 2002). MRTS05 specifies the RDD for each lot to be represented by the characteristic value of the relative dry density of the individual samples taken from the lot. The characteristic value is calculated by equation; Characteristic Value = (Mean RDD – kS), where S is the standard deviation of the test results and k is taken from the Variable Acceptance Sampling Plan - 90/10 scheme, in accordance with *ARRB Special Report 30: The selection of Statistical Compliance Schemes for Construction Quality Control*. Calculation steps are stated in Clause 12 of *MRTS01 Introduction to Technical Specifications.*

VicRoads (2011) requirements align with Austroads (2012), e.g. 100% of relative compaction determined using modified Proctor compactive effort, which is a higher level than specified for the Gatton Bypass. VicRoads also specifies RDD to be represented by the characteristic value and is calculated by equation; Characteristic Value = (Mean RDD – 0.92S). The minimum RDD requirement for HSG materials in South Africa is 88% of apparent particle density (COLTO 1998). This approach of specifying MDD in terms of specific gravity or solid relative density, as opposed to relative compacted density, is in agreement with the recommendations of Kleyn (2012) that solid relative density is more appropriate, as HSG base should approximate the solid density of the intact parent rock.

*Degree of Saturation (DOS)*

Moisture must be tightly controlled during construction; overlying layers should not be constructed until the underlying layer has reached (dried out to) an appropriate moisture content.

MRTS05 specifies the DOS for each lot to be represented by the characteristic value of the degree of saturation of the individual samples taken from the lot. The characteristic value shall be calculated as stated in Clause 12 of *MRTS01 Introduction to Technical Specifications.*

TMR (QDMR 1996): An Accelerated Loading Facility (ALF) trial at Beerburrum, Queensland indicated that by drying back a pavement moisture content from 75% OMC to 70% OMC (equivalent to 85% DOS for the material type used), resulted in about a fourfold increase in pavement life under accelerated loading. This difference may not be as pronounced at lower moisture contents, but it demonstrates the importance of allowing pavements to dry back to maximise the service life.

# 4 CENTENARY MOTORWAY DUPLICATION

## 4.1 Introduction

Stage 2 of the Darra to Springfield Transport Corridor project included a $475 million integrated road and rail development between Brisbane's Richlands and Springfield suburbs (Queensland Government 2012). The project was accomplished through the TrackStar Alliance partnership between the Queensland government and local contractors. The road component included duplication of 5.5 km of the Centenary Motorway in addition to construction of three bridges, a central median and upgrade of two existing on-ramps. The rail component included 9.5 km of dual-track passenger line, two new stations at Springfield and Springfield Central, an integrated bus interchange at Springfield Central, and seven rail bridges. The objective of the project was to improve transport connectivity in the south-western suburbs through sustainable development that reduces roadway congestion and improves safety (Queensland Government 2012).

The Centenary Motorway is an interregional route carrying a large proportion of heavy vehicles between the outskirts of urban areas in southern Queensland and northern New South Wales (TrackStar Alliance 2012). The scope of works for the duplication project included provision of a new separated two-lane traffic alignment (northbound) between Springfield Parkway and the Logan Motorway interchange (Johnson Road). The existing two-lane alignment accommodates the southbound traffic.

The HSG base and seal trial included approximately 4.65 km of the northbound alignment between chainages 585 and 5235. The trial pavement consisted of a double application bituminous sprayed seal, HSG base and Type 2.3 subbase constructed atop of the existing subgrade.

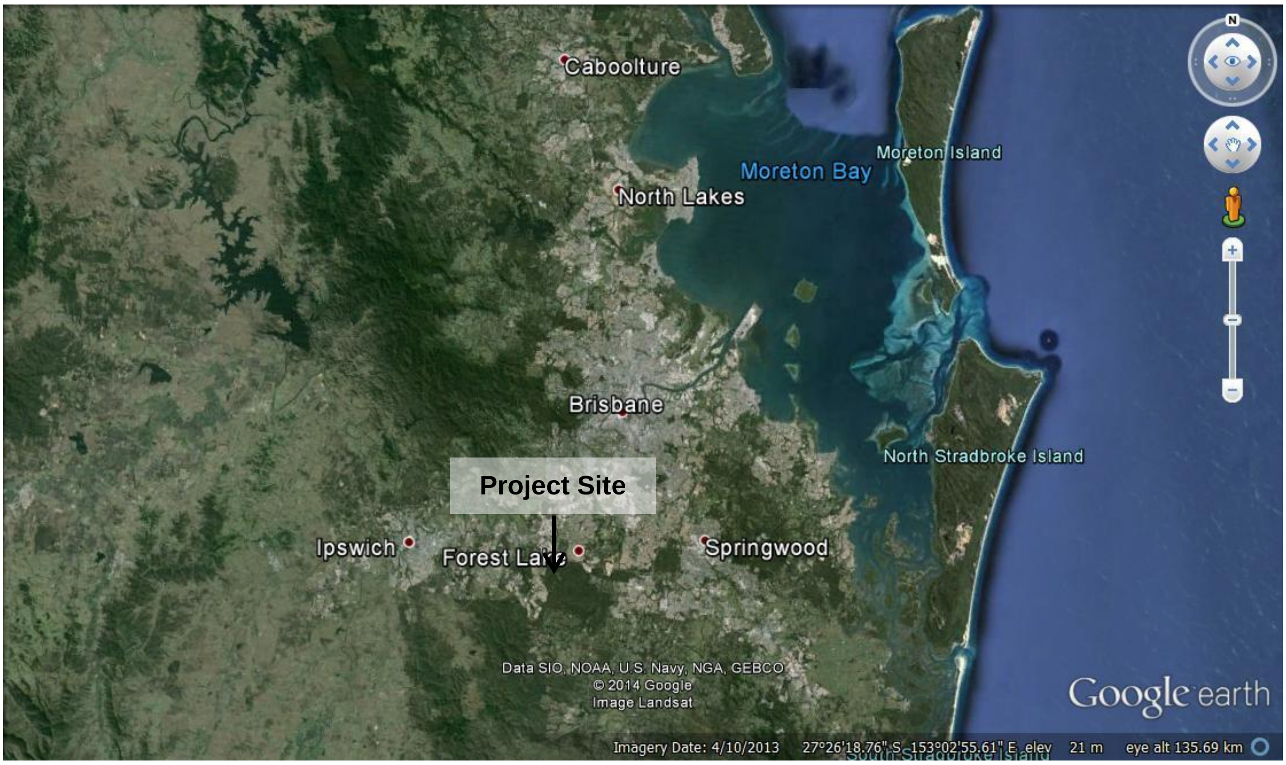
The pavement works for the new alignment were initiated in June 2013 and completed in October 2013. Practical completion of the Stage 2 Darra to Springfield Transport Corridor project was achieved in April 2014.

## 4.2 Site Conditions

### *4.2.1 Location*

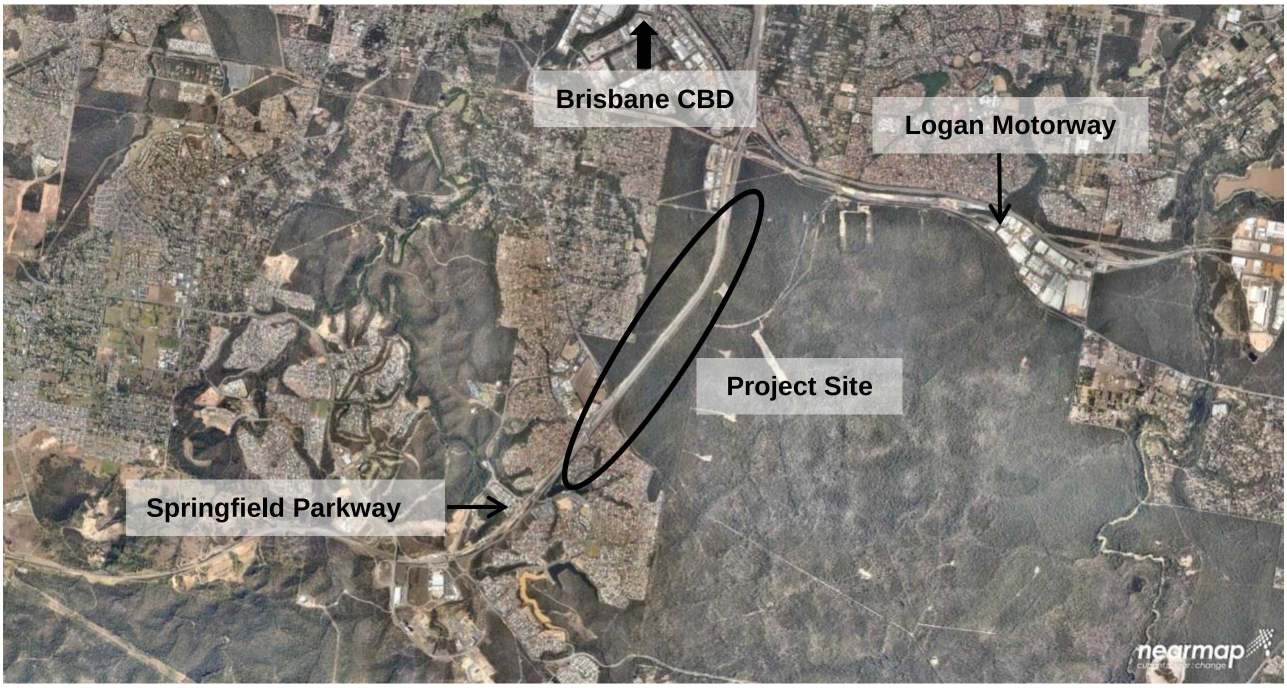
The project is located along the outer Brisbane suburbs, 25 km south-west of the central business district (CBD). The Springfield and Springfield Lakes suburbs have recently experienced extensive residential and commercial development. This development has increased demand on the already significantly loaded Centenary Motorway. The northbound duplication runs from Springfield Parkway to the Logan Motorway interchange. The new alignment serves as dual northbound lanes, with the existing alignment serving dual lanes of southbound traffic. The location of the project relative to the Brisbane CBD is shown in Figure 4.1. The project site relative to the Logan Motorway and Springfield Parkway is also presented in Figure 4.2 .

**Figure 4.1: Location of project site**




Source: Google Maps (2013), 'Queensland', map data, Google, California, USA.

**Figure 4.2: Immediate vicinity of project site, including Logan Motorway and Springfield Parkway (Nearmap 2014)**




Source: Nearmap (2015), 'Queensland', map data, Nearmap, Sydney, NSW.

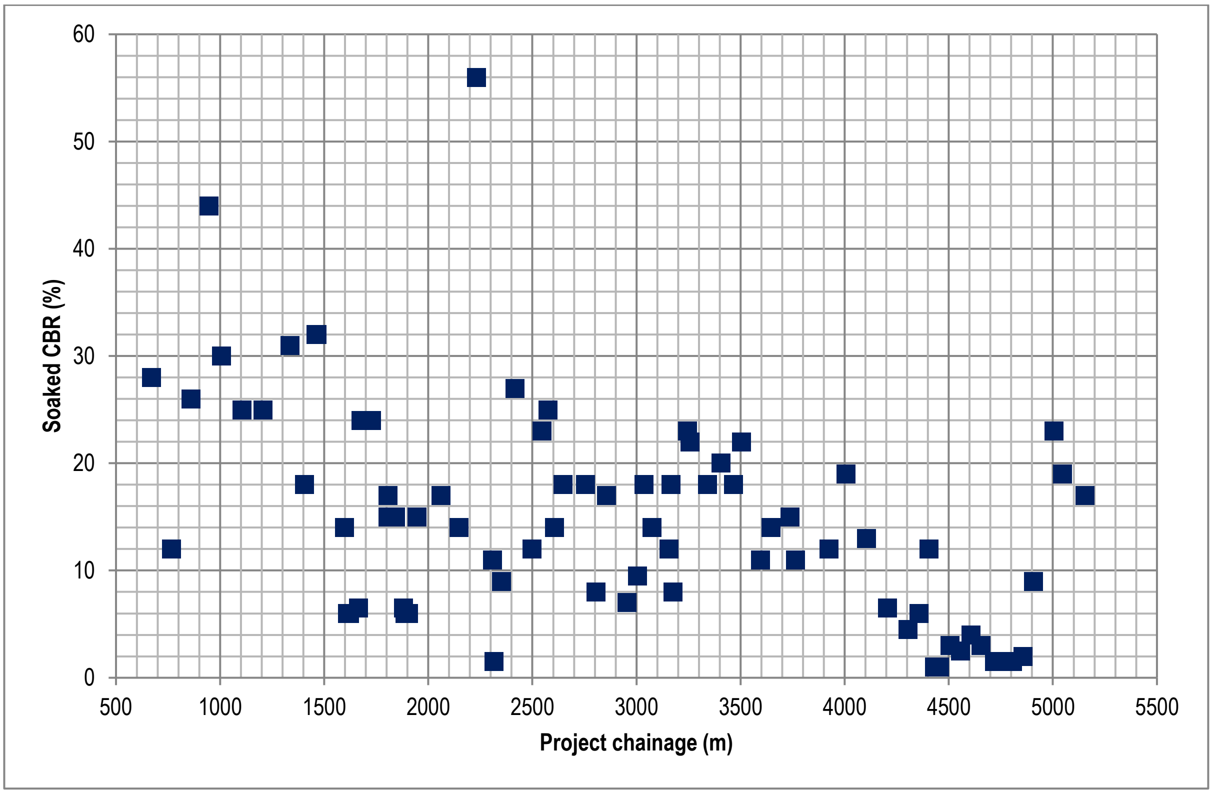
### *4.2.2 Climate*

The trial site is located in south-east Queensland at a relative elevation of 40 m above sea level. The local climate is characterised by moderate to high temperatures, with infrequent high intensity/low duration rainfall events. The mean maximum air temperature is 27.3 °C, and the mean minimum is 13.9 °C; with the maximum temperature typically occurring in January and the minimum typically occurring in July (Bureau of Meteorology 2014). The precipitation patterns are summer dominant, with mean annual rainfall ranging from 800 mm to 1200 mm. The mean maximum monthly precipitation is 123 mm and the mean minimum is 31 mm, with the wettest period occurring in January and the driest occurring in August (Bureau of Meteorology 2014).

### *4.2.3 Subgrade Conditions*

The trial site is located in the wet/non-reactive environmental zone. The classification refers to the high mean annual rainfall and the generally moisture-stable natural soils. Characterisation of subgrade conditions was accomplished through laboratory determination of soaked CBR (Q113A) using remoulded specimen. The engineering properties of the natural foundation materials vary along the trial site, as presented in Figure 4.3. Potentially unsuitable (1% < CBR ≤ 3%) subgrades were identified between project chainages 760 to 840, 1460 to 2080, 2760 to 3060, and 4760 to 4960 (TrackStar Alliance 2012).

**Figure 4.3: Variation in foundation support conditions**




### *4.2.4 Design Traffic Loading*

Estimation of future traffic volumes was accomplished with reference to 2010 TMR gazettal and anti-gazettal AADT counts for the Centenary Motorway. The counts indicated an AADT of 23 076 vehicles and approximately 7% heavy vehicles (TrackStar Alliance 2012). Additionally, a 4% heavy vehicle growth rate was assumed, the minimum allowable according to Clause 7.5 of the TMR *Pavement Design Supplement* (TMR 2013a). A design life of 10 years was adopted for the Centenary Motorway duplication project (TrackStar Alliance 2012). The final design traffic volume for the 10-year service life was 1.0 x $10^7$ ESA or an average 2315 ESA per day in the year of opening (TrackStar Alliance 2012).

## 4.3 Design

### *4.3.1 Geometric*

The typical cross-section for the Centenary Motorway duplication includes two 3.5 m wide traffic lanes, 2.0 m wide sealed outer-edge shoulders, 1.0 m wide inner-edge sealed shoulders, and 1.0 m to 1.5 m wide unsealed verge (TrackStar Alliance 2012).

The design speed adopted for the alignment was 110 km/h, with an operational posted speed of 80 km/h.

Provision for a 1-in-100 year average recurrence interval flood event was adopted in the drainage design for the roadworks (TrackStar Alliance 2012). The intrusion of water into the pavement cannot be prevented, but can be minimised by the provision of adequate drainage systems and high-quality surface seals (Bartley Consultants 1997). In flood-prone areas, potential for subsurface drains to introduce moisture into the pavement system during flooding events has to be considered (Hazell & Perry 2009). Pavement drawings indicated subsoil drains were provided at the interface between SG(HD) pavement and existing pavements. In other locations, table drains have been provided.

### *4.3.2 Pavement*

A SG(HD) unbound granular pavement incorporating HSG base was provisioned to minimise the initial capital investment compared to other pavement alternatives (TrackStar Alliance 2012). The structural design included a double/double 14/7 mm sprayed bituminous seal, HSG base, in addition to Type 2.3 upper and lower subbase. The pavement cross-section is presented in Figure 4.4. It should be noted that the HSG base layer was placed in two 110 mm lifts and the upper layer is not depicted in Figure 4.4.

Figure 4.4: Pavement cross-section including lower HSG base, upper subbase, lower subbase and natural subgrade

The structural design was accomplished using the mechanistic method (TMR 2013a). Design inputs for the HSG base included elastic modulus of 500 MPa for the top sublayer, degree of anisotropy of 2.0, and Poisson's ratio of 0.35.

Design layer thicknesses included 220 mm HSG base, 150 mm Type 2.3 upper subbase, and variable thickness Type 2.3 lower subbase. The thickness of the lower subbase was determined by the design subgrade bearing capacity including 0 mm, 100 mm or 140 mm for CBR values of 10%, 7% and 5% respectively (TrackStar Alliance 2012). The adopted design is congruent with the typical Victorian heavy-duty unbound granular pavement consisting of a double/double sprayed bituminous seal overlying 200 mm HSG base, 200 mm crushed rock subbase and 150 mm select fill atop the natural foundation (Jameson 2000).

The variation in the strength of the natural subgrade is shown in Figure 4.3. Based on the geometric alignment and nominated subgrade treatments (refer Table 4.4), different trial pavement design cross-sections are illustrated in Figure 4.5. A table presenting the different layer thicknesses is presented in Table 4.1.

Between Ch. 4405 – 4880 m, the natural subgrade was excavated and replaced by with 500 – 1000mm of select fill.

**Figure 4.5: Trial pavement design cross-section depicting variable lower subbase thickness**

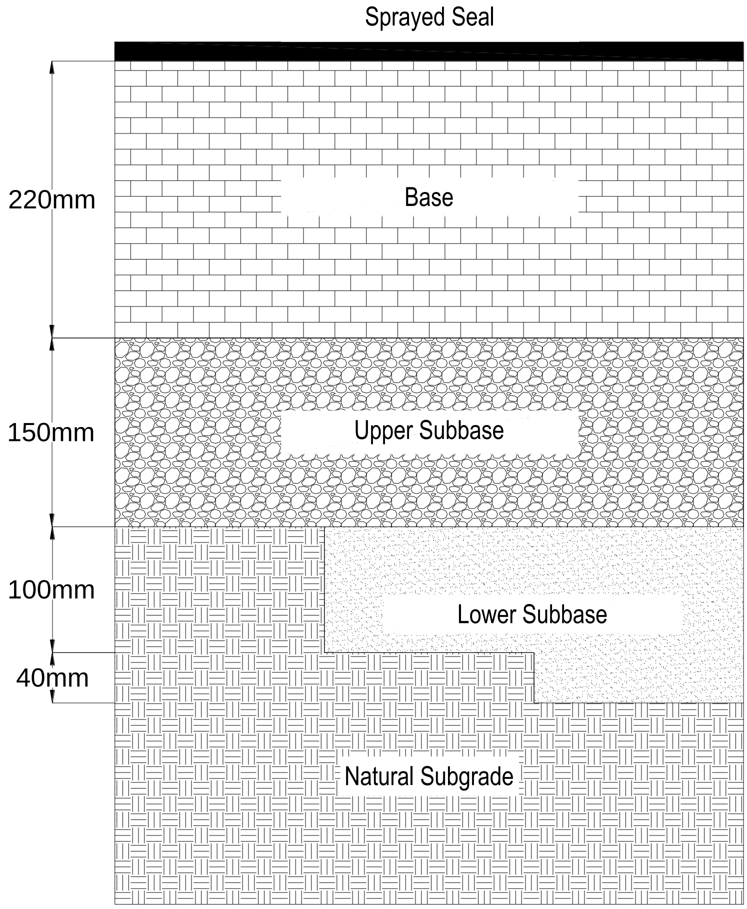


Table 4.1: Summary of design pavement configuration

| Section | Start chainage (m) | End chainage (m) | Base thickness (mm) | Upper subbase thickness (mm) | Lower subbase thickness (mm) | Design subgrade strength (% CBR) |
|---|---|---|---|---|---|---|
| 1 | 575 | 1465 | 220 | 150 | - | 10 |
| 2 | 1465 | 1608 | 220 | 150 | - | 10 |
| 3 | 1608 | 1692 | 220 | 150 | 140 | 5 |
| 4 | 1692 | 1855 | 220 | 150 | - | 10 |
| 5 | 1855 | 1995 | 220 | 150 | 140 | 5 |
| 6 | 1995 | 2307 | 220 | 150 | - | 10 |
| 7 | 2307 | 2905 | 220 | 150 | - | 10 |
| 8 | 2905 | 3005 | 220 | 150 | - | 10 |
| 9 | 3005 | 4155 | 220 | 150 | - | 10 |
| 10 | 4155 | 4405 | 220 | 150 | 140 | 5 |
| 11 | 4405 | 4580 | 220 | 150 | - | 10 |
| 12 | 4580 | 4680 | 220 | 150 | 140 | 10 |
| 13 | 4680 | 4880 | 220 | 150 | - | 10 |
| 14 | 4880 | 4955 | 220 | 150 | 100 | 7 |
| 15 | 4955 | 4975 | 220 | 150 | - | 10 |
| 16 | 4975 | 5155 | 220 | 150 | - | 10 |

### *4.3.3 Bituminous Seal*

The sprayed seal design was carried out in accordance with the Austroads (2006) sprayed seal design method. The design selected for the Centenary Motorway duplication included a double application PMB seal overlying a SG(HD) unbound granular pavement. Double application seals provide a robust, heavy-duty surfacing (Austroads 2009a). The initial seal design included:

- prime: 0.90 L/m$^2$ proprietary emulsion
- 1$^{st}$ coat: 0.90 L/m$^2$ S0.3B & 110 m$^2$/m$^3$ 14 mm cover aggregate (slow lane)
  1.00 L/m$^2$ S0.3B & 110 m$^2$/m$^3$ 14 mm cover aggregate (fast lane)
- 2$^{nd}$ coat: 0.70 L/m$^2$ S0.3B & 230 m$^2$/m$^3$ 7 mm cover aggregate (slow lane)
  0.75 L/m$^2$ S0.3B & 230 m$^2$/m$^3$ 7 mm cover aggregate (fast lane).

## 4.4 Risk Mitigation

The road transport network represents the single largest asset of the Queensland government, requiring continuous investment for operation and maintenance (Creagh, Wijeyakulasuriya & Williams 2006). Premature pavement distress necessitates reallocation of scarce funds and delay of critical maintenance works. In the case of the Gatton Bypass duplication (Section 1.2), use of nonconforming material and insufficient design and construction practices contributed to rapid distress after only six months in service. Prevention of premature distress requires careful site and material characterisation and rigorous monitoring of construction properties to ensure the constructed pavement conforms to the design assumptions.

Minimising risk of premature pavement distress can be accomplished by identifying and developing mitigation strategies for likely distress modes. A risk management workshop for the Centenary Motorway duplication project was held in March 2013 and included representatives from TMR, the TrackStar Alliance, independent technical experts and the quarry selected to produce the HSG base material. The objective of the workshop was to identify and rate risks associated with the paving and sealing works. Identified risks were assigned a priority, and mitigation strategies were developed for the risks considered high priority.

Identified high priority risks included:

- in-pavement particle size distribution not meeting specifications
- construction delay as a result of allowing granular materials to dry back
- potential delamination as a result of placing the HSG base in two 110 mm layers
- trapping moisture in the structure at joints between new and existing pavements due to differential permeability
- construction delay as a result of extended compliance testing
- stripping of the sprayed seal due to cold-weather construction conditions.

Developed mitigation strategies included:

- inclusion of the provision for both stockpile and in situ compliance testing
- addition of repeat-load triaxial testing to determine maximum allowable DOS
- requirement for use of aggregate paver and maximum delay of three days between formation of upper and lower base layers
- delay of sealing operations until September 2013
- limiting traffic speed to 60 km/h for first two weeks following opening; 80 km/h thereafter.

## 4.5 Specification and Supply of HSG Material

The specification for the HSG base was based on MRTS05 (TMR 2011a), which was amended and superseded where applicable with project specific Annexure MRTS05.1 (TrackStar Alliance 2013). The TrackStar Alliance specification was developed to minimise risk of premature distress and increase reliability of the SG(HD) unbound granular structure. The principle deviations from MRTS05 included:

- more stringent limits on material properties (refer to Table 4.2)
- requisite use of paver
- increased relative density requirements (refer to Section 4.5.3)
- increased frequency of compliance testing
- development of construction method statement (CMS).

The CMS was required to document the equipment and procedures proposed to place, compact and finish the HSG base layers to achieve a tight, uniform surface that was free of loose, segregated and contaminated materials.

### *4.5.1 Material Quality Requirements*

The TrackStar Alliance specification for the HSG base was based upon MRTS05 (TMR 2011a) and modified specifically for the Centenary Motorway duplication project. Procedural amendments included requirements for both stockpile and in situ compliance testing. Testing amendments included the addition of repeated load triaxial testing, fine aggregate component degradation factor, and secondary minerals content. The property limits for the HSG material were modified from TMR Type 1.1 material to include an increased minimum 10% fines (wet) value, reduced degradation factor, addition of a plasticity index lower limit, and reduced construction tolerance for end product particle size distribution. The properties of the trial base material are presented in Table 4.2 alongside established HSG material requirements.

### Table 4.2: Comparison of TrackStar Alliance material properties to other HSG base materials

| Property | TrackStar specification | Gatton Bypass duplication | VicRoads | COLTO |
|---|---|---|---|---|
| | Base | G1.1 | Class 1 | G1 |
| Minimum wet 10% fines value (kN) | 140 | 130 | - | 125 |
| Maximum wet/dry variation (%) | 35 | 40 | - | - |
| Maximum ball mill value | - | 30 | 30 | - |
| Minimum degradation factor | 60[a] | - | - | - |
| Minimum crushed particles (%) | 70 | 70 | 60 | 100 |
| Maximum flakiness index (%) | 35 | 35 | 35 | 35 |
| Maximum aggregate crushing value (%) | - | - | - | 24 |
| Maximum liquid limit | 25 | 25 | 30 | 25 |
| Plasticity index | 2 - 6 | 3 - 7 | 2 - 6 | 0 - 5 |
| Linear shrinkage | - | 1.5 - 3.5 | - | 0 - 2 |
| Weighted plasticity index | 0 - 150 | 80 - 150 | - | - |
| Weighted linear shrinkage | - | 40 - 85 | - | - |
| Maximum swell (%) | 0.5 | - | - | - |
| Minimum unsoaked CBR (%) | - | 80 | - | - |
| Maximum degree of saturation (%) | 65 | 65 | - | - |
| Minimum moisture content (%OMC) | - | - | 85 | 100 |
| Minimum relative standard compaction (%) | 102 | 102 | - | - |
| Minimum relative modified compaction (%) | - | - | 100 | - |
| Minimum relative density (%) | - | - | - | 88[b] |

[a] Degradation factor limit for fine (< 4.75 mm) component only.

[b] Apparent relative density.

### 4.5.2 Crushed Rock Production

The production of the HSG base material was similar to the standard practice pursued in the generation of TMR Type 2.1 aggregate, but with tighter controls on particle size distribution and increased control testing frequency.

The material was blasted from a metamorphic greywacke rock face and subjected to the primary jaw, in addition to secondary and tertiary cone crushing. The crushed material was separated into discrete particle sizes using a series of screens prior to stockpiling. The aggregate was processed (crushed, screened) dry with moisture added prior to stockpiling.

Stockpiles were constructed using articulating and telescoping conveyor belts to minimise drop height and segregation potential. The stockpile of blended HSG product was generated by sampling the discrete size stockpiles in appropriate proportions using a front-end loader. This process is a key deviation from established best practice where stockpiles of the graded end product are generated using metered conveyor belts provide precise control of proportioning. The end product was collected from five different stockpile faces and blended with water in a pugmill mixer prior to transport.

Blending of the HSG material and water in the pugmill was not specified, but was undertaken to maximise moisture distribution and minimise segregation potential. The particle size distribution limits of the trial base material are presented in Table 4.3 alongside established HSG material requirements.

**Table 4.3: Comparison of TrackStar Alliance particle size distribution to other HSG base materials**

| Sieve opening (mm) | Per cent passing (by mass) | | | |
|---|---|---|---|---|
| | TrackStar specification | Gatton Bypass duplication | VicRoads | COLTO |
| | Base | G1.1 | Class 1 (LA ≤ 25) | G1 |
| 37.5 | - | 100 - 100 | - | 100 - 100 |
| 26.5 | 100 - 100 | - | 100 - 100 | 84 - 94 |
| 19.0 | 95 - 100 | 80 - 100 | 95 - 100 | 71 - 84 |
| 13.2 | 78 - 92 | - | 78 - 92 | 59 - 75 |
| 9.5 | 63 - 83 | 55 - 90 | 63 - 83 | - |
| 4.75 | 44 - 64 | 40 - 70 | 44 - 64 | 36 - 53 |
| 2.36 | 30 - 49 | 30 - 55 | 30 - 48 | - |
| 2.0 | - | - | - | 23 - 40 |
| 0.425 | 14 - 23 | 18 - 30 | 14 - 22 | 11 - 24 |
| 0.075 | 6 - 12 | 8 - 20 | 7 - 11 | 4 - 12 |

### 4.5.3 Resilient modulus

Repeated-load triaxial testing was undertaken on the HSG material prior to construction to quantify moisture sensitivity and determine the maximum allowable DOS. The TrackStar Alliance base material was sampled and tested in February 2013. The MDD of the material was 2.156 t/m$^3$, determined using standard Proctor compactive effort, and the OMC was 6.8%. Seven repeated-load triaxial specimens were tested covering three RDD levels (104%, 103% and 102% MDD) and three DOS levels (60%, 65% and 70%).

Testing was executed in accordance with TMR test method Q137, *Permanent Deformation and Resilient Modulus of Granular Unbound Materials* (TMR 2013e). A vertical stress of 750 kPa was applied cyclically to an undrained 150 mm diameter cylindrical specimen with a constant confining pressure of 125 kPa for 100 000 loading cycles. The load, vertical displacement and pore-water pressure of the specimen were continually monitored and used to calculate resilient modulus and permanent strain.

The resilient modulus and permanent strain results are presented in Figure 4.6 and Figure 4.7 respectively.

Note that these modulus specimens were tested at moisture contents wetter than those at the time of sealing (Section 4.7.3). This may have contributed to the low modulus and high permanent strains.

Figure 4.6: Resilient modulus results from repeated-load triaxial testing

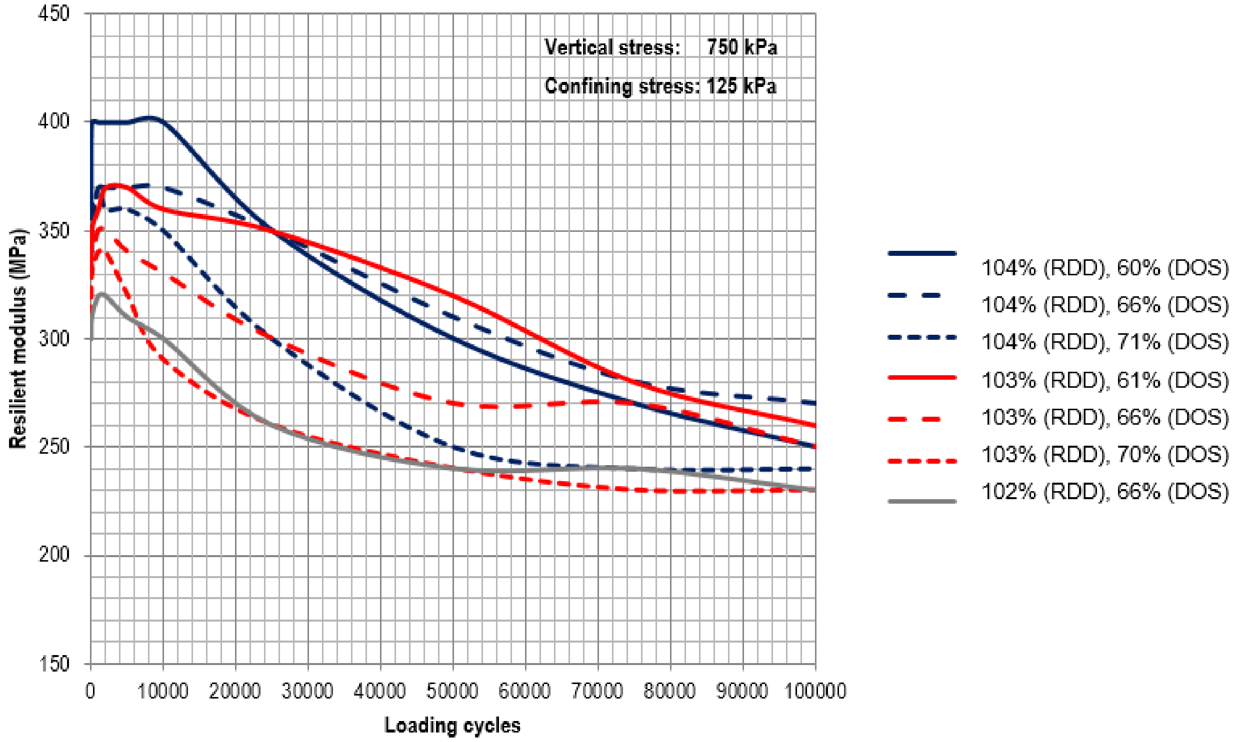
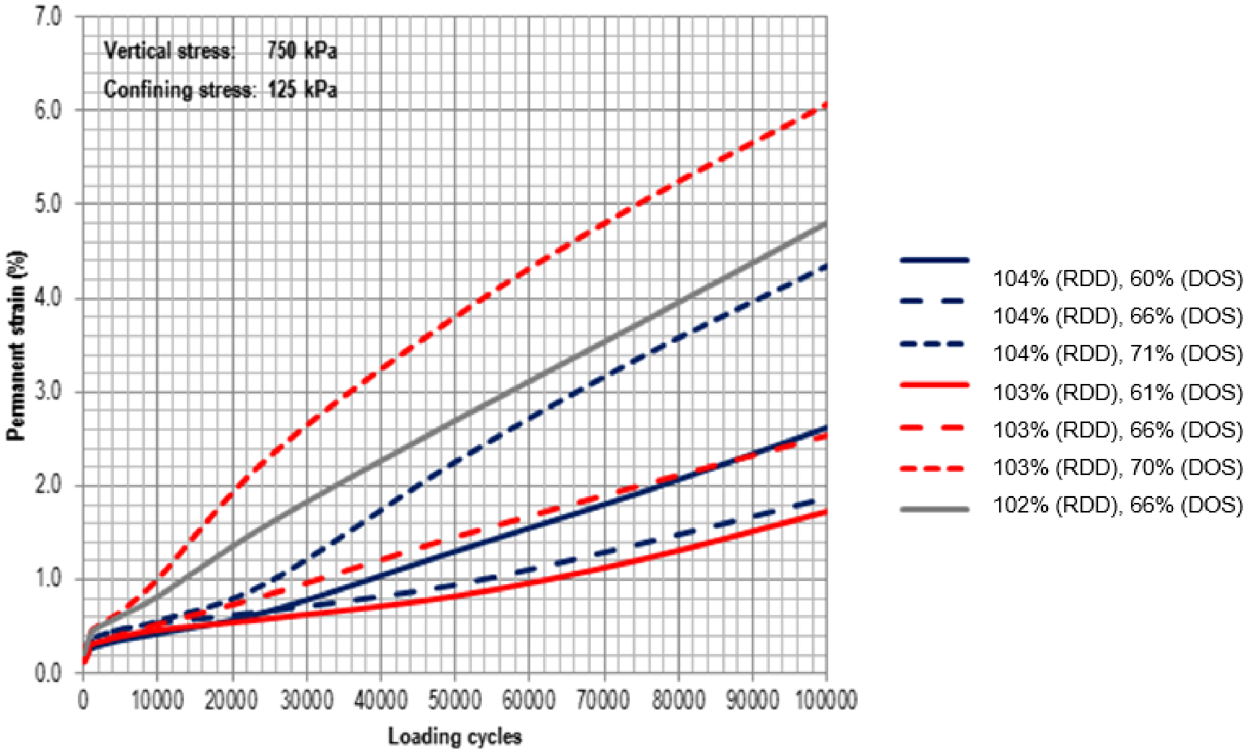


Figure 4.7: Permanent strain results from repeated-load triaxial testing




## 4.6 Supporting Layers

Establishing structurally and volumetrically stable layers to support the HSG is critical to long-term pavement performance. Pavements incorporating the highest quality base materials will rapidly deteriorate if the underlying layers are not sufficiently designed and constructed. Layers underlying the HSG base on the trial site include upper subbase, lower subbase (where applicable), and subgrade/select fill materials.

### *4.6.1 Subgrade/Select Fill*

As presented in Figure 4.3, the natural foundation of the trial site is highly variable. The bearing capacity measured during preliminary site characterisation varied from 1.0% to 56% CBR, with a mean CBR value of approximately 15%. The treatments undertaken to provide a stable construction platform varied according to the bearing capacity and swell potential of the natural materials, as presented in Table 4.4 .

Table 4.4: Summary of subgrade treatment methods

| Treatment | Description | Bearing capacity (% CBR) | Swell (%) | Project chainage (m) |
|---|---|---|---|---|
| A | Scarify and compact | ≥ 10.0 | - | - |
| B | Scarify, compact and provision lower subbase | 5.0 - 10.0 | - | 1605 - 1705<br>1855 - 1995<br>4155 - 4405<br>4880 - 4955 |
| C | Excavate 150 mm and replace with select fill | 3.0 - 5.0 | - | 2905 - 3005 |
| D | Excavate 500 mm, replace with select fill and provision lower subbase | ≤ 3.0 | < 5.0 | 4580 - 4680 |
| E | Excavate 1000 mm and replace with select fill | ≤ 3.0 | > 5.0 | 4405 - 4580<br>4680 - 4880 |

Preparation of the foundation included clearing and grubbing, stripping of topsoil, and replacement of unsuitable material as required. Unsuitable materials are natural soils with bearing capacity less than 3.0% CBR, weighted PI greater than 4000, or PI greater than 50. Requirements for fill material are provided in MRTS04, *General Earthworks* (TMR 2014b) and generally include weighted PI < 1200, PI ≥ 7%, and 15 to 30% (by mass) of the material passing the 0.075 mm sieve opening. Following topsoil stripping and/or replacement of unsuitable material, the construction platform was scarified to a depth of 150 mm and compacted to a minimum RDD of 97% relative compacted density, determined using standard effort.

### 4.6.2 Subbase

The upper and lower subbase were composed of TMR Type 2.3 unbound granular material with particle size distribution conforming to Grading C. Material property and particle size distribution requirements are presented in Table 2.1 and Table 2.3 respectively. Additional material requirements included a minimum soaked CBR > 45%. The crushed rock was sourced from the same metamorphic greywacke quarry as the HSG base material. The subbase layers were placed in single lifts with a maximum thickness of 150 mm. The minimum specified compaction was 100% of standard Proctor MDD.

## 4.7 Construction of HSG Base

### 4.7.1 Base placement

The base was constructed in two uniform 110 mm layers. MRTS05 (TMR 2011a) allows compacted layer thicknesses between 75 mm and 250 mm. The target lift thickness of 110 mm was selected to ensure optimal moisture conditions and compactive efforts during compaction.

HSG material delivered to the project site was discharged from haul trucks into a series of small (approximately 1.5 m high) stockpiles, as shown in Figure 4.8. This material was either transferred to the paver using a front-end loader (Figure 4.9) or pushed out using the motor grader to form the HSG layer. The paver was the primary method of basecourse layer formation. The motor grader was mainly utilised in limited access, crossfall transition or construction staging areas. The formation of the base layer using both a paver and a motor grader is shown in Figure 4.10 and Figure 4.11 respectively.

Stockpiles that were not immediately incorporated into the production of the base layer received intermittent applications of water to maintain the optimal moisture condition. Modification of the moisture content of HSG material at the project site should be conducted using a pulvimixer to ensure even distribution and thorough mixing is achieved (Hazell & Perry 2009). The HSG material was spread and compacted dry of the OMC. The in situ moisture content typically ranged from 50% to 100% of OMC. Delays in HSG material delivery resulted in an intermittent paving operation and significant downtime for the mechanical spreader. Adequate time should be allowed for delivered material to be stockpiled and tested prior to incorporation into the works (Hazell & Perry 2009).

Figure 4.8: HSG base material being delivered and formed into stockpiles

Figure 4.9: Front-end loader filling aggregate hopper of paver


Figure 4.10: Forming of upper HSG base layer using paver

**Figure 4.11: Forming of upper HSG base layer using motor grader**

### 4.7.2 Compaction

Each formed base layer was subjected to primary compaction using four passes of a 15 tonne vibrating smooth drum steel roller. Heavy vibration was applied during the initial pass, with light vibration applied on passes two through four. Secondary compaction was accomplished using two passes of a 20 tonne pneumatic tyred roller. Additional passes of the steel-wheel roller in static mode were applied to achieve an even final surface. Compaction of the formed base using both steel-wheel and pneumatic tyred rollers is shown in Figure 4.12. The minimum RDD required for the HSG base was 102% of standard Proctor MDD.

Figure 4.12: Compaction equipment used on the project, including vibrating smooth drum (left) and pneumatic tyred (right) rollers

### 4.7.3 Conformance Testing

*Material Properties*

The utilisation of characterisation testing at regular intervals allowed for monitoring and control of product quality. One of the principal differences between HSG base and traditional unbound granular material is the increased frequency and reduced tolerance in material characterisation testing. The conformance testing requirements were outlined in the TrackStar Alliance specification for the HSG base and included a 10% fines (wet) value (Q205B), wet/dry strength variation (Q205C), fine component degradation factor (Q208B), crushed particles (Q215), flakiness index (Q201), particle size distribution (Q103A), plasticity limits (Q105), and fines ratio. The conformance of material lots was assessed relative to the characteristic value in accordance with MRTS01, *Introduction to Technical Specifications* (TMR 2014a). Calculation of the characteristic value allows for consideration of the statistical variance in individual property measurements. When less than ten measurements are collected for assessment of a lot, the characteristic value can be calculated according to Equation 3.

$$CV = \frac{1}{n}\sum_{i=1}^{n} x_i \pm \left[0.828\sqrt{\sum_{i=1}^{n}\frac{\left(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i\right)^2}{n-1}}\right] \quad (3)$$

where

CV = characteristic value

n = number of measurements

$x_i$ = individual measurement

0.828 = k-factor for ten tests, taken from 90/10 Scheme of Variable Acceptance Sampling Plan (for unknown variability). Here the k-factor, in accordance with MRTS01, has been fixed to 0.828 for any number of tests less than or equal to 10 ($n \leq 10$)

Material conformance was determined by comparing the minimum and maximum limit characteristic values to the lower and upper specification limits respectively. During construction of the trial pavement, specimens were recovered from both stockpile and in-service pavement (HSG base) prior to compaction. The relationship between stockpile and pavement properties was developed using a minimum of ten separate samples. The project administrator reviewed the relationship and supporting data before allowing conformance testing from the stockpile only. However, infrequent check testing of in situ properties was conducted throughout the project to ensure compliance. The material property conformance testing results for both the stockpile and pavement HSG base material are presented in Table 4.5.

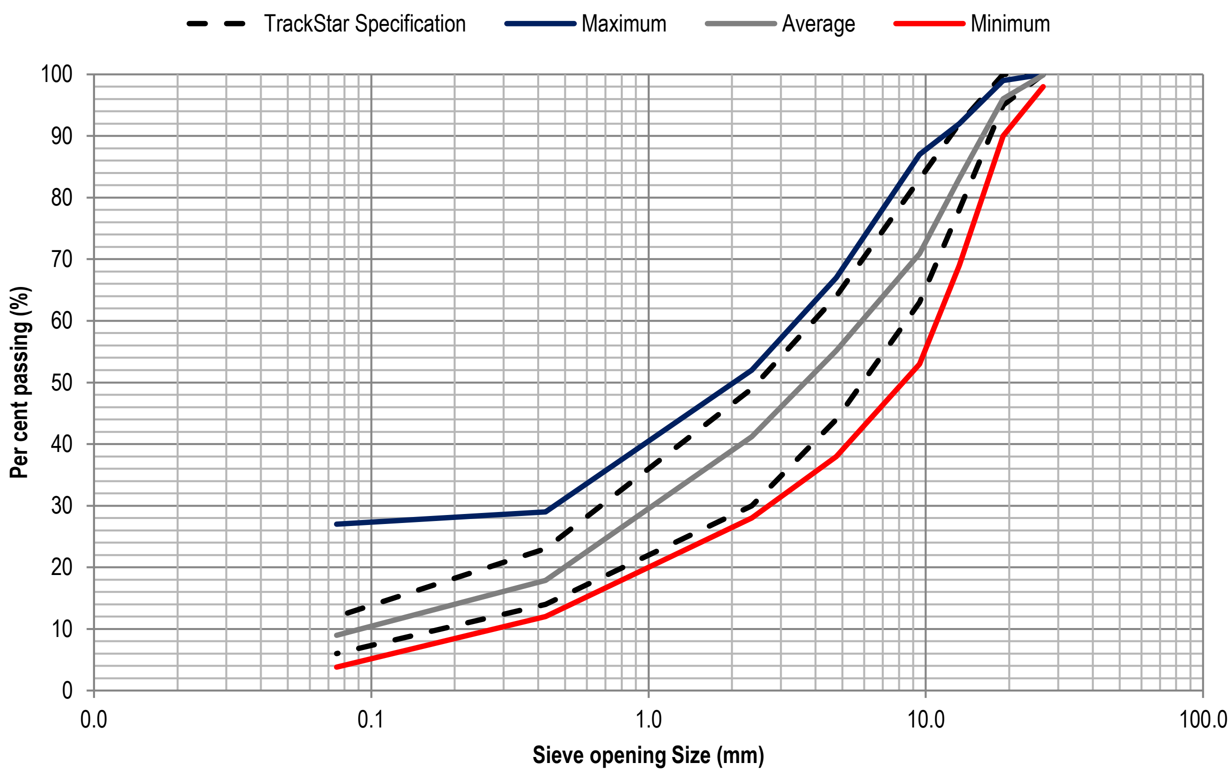
**Table 4.5: Material properties of stockpile and in-pavement HSG material**

| Property | Specification limits | | Stockpile | | | Pavement | | |
|---|---|---|---|---|---|---|---|---|
| | Upper | Lower | Mean | $\sigma^2$ | Nonconforming | Mean | $\sigma^2$ | Nonconforming |
| Wet strength (kN) | - | 140 | 163 | 3.95 | 0% | - | - | - |
| Dry strength (kN) | - | - | 221 | 13.84 | - | - | - | - |
| Wet / dry strength variation (%) | 35 | - | 26 | 4.00 | 5% | - | - | - |
| Degradation factor | - | 45 | 54 | 3.24 | 0% | - | - | - |
| Crushed particles (%) | - | 70 | 100 | 0.00 | 0% | - | - | - |
| Flakiness index (%) | 35 | - | 21 | 2.99 | 0% | - | - | - |
| Liquid limit (%) | 25 | - | 19 | 0.31 | 0% | 18 | 0.34 | 0% |
| Plastic limit (%) | - | - | 14 | 0.44 | - | 14 | 0.61 | - |
| Plasticity index (%) | 6 | 2 | 5 | 0.40 | 0% | 4 | 0.60 | 0% |
| Linear shrinkage (%) | - | - | 3 | 0.30 | - | 2 | 0.52 | - |
| Weighted plasticity index | 150 | - | 90 | 7.75 | 0% | 74 | 13.46 | 0% |
| Weighted linear shrinkage | - | - | 47 | 5.69 | - | 33 | 10.74 | - |
| Fines Ratio | 0.55 | 0.30 | 0.49 | 0.02 | 1% | 0.50 | 0.05 | 6% |

The material properties of the majority of lots delivered to the project were found to be conforming. A single lot was found to have nonconforming wet/dry strength variation (38%); and eight lots were observed to have nonconforming fines ratios, seven of which were in excess of the limit (too fine). The combined average, maximum, and minimum particle size distribution testing results for the

HSG base materials obtained from both stockpiles and the formed pavement are presented in Figure 4.13.

**Figure 4.13: Particle size distribution conformance summary for HSG material**




The individual particle size distribution measurements were highly variable, with some values considerably outside of project specification limits. Given the HSG material was mixed on the quarry floor (Section 4.5.2 ) rather than being metered on conveyor belts, the variability in gradation presented in Figure 4.13 is not unexpected. The particle size distribution conformance testing results for both the stockpile and pavement HSG base material is presented in Table 4.6.

**Table 4.6: Particle size distribution of stockpile and in-pavement HSG material**

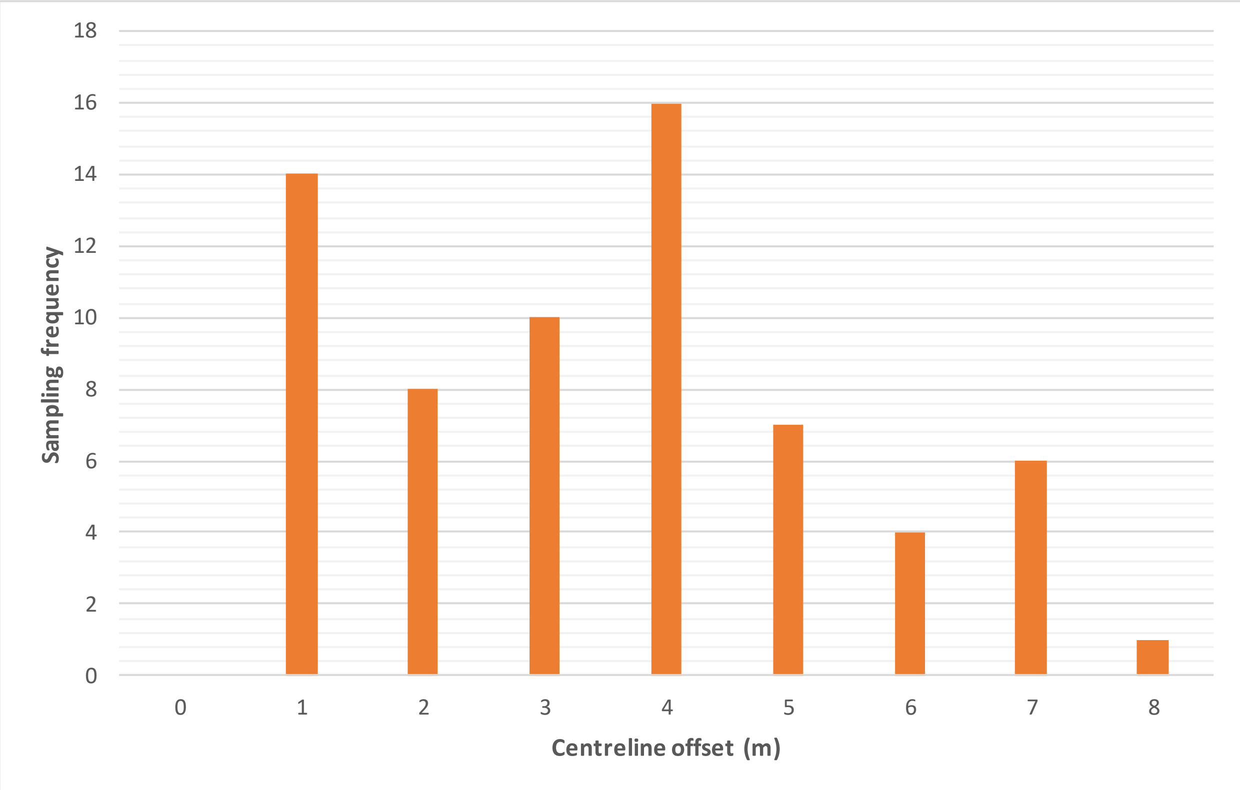
| Property | Specification limits | | Stockpile | | | Pavement | | |
|---|---|---|---|---|---|---|---|---|
| | Upper | Lower | Mean | $\sigma^2$ | Nonconforming | Mean | $\sigma^2$ | Nonconforming |
| % passing 26.5 mm | 100 | 100 | 100 | 0.24 | 8% | 100 | 0.42 | 26% |
| % passing 19.0 mm | 100 | 95 | 97 | 1.00 | 8% | 96 | 1.76 | 52% |
| % passing 13.2 mm | 92 | 78 | 85 | 2.28 | 8% | 82 | 4.01 | 17% |
| % passing 9.50 mm | 83 | 63 | 73 | 3.27 | 0% | 70 | 4.56 | 11% |
| % passing 4.75 mm | 64 | 44 | 57 | 2.73 | 0% | 54 | 4.48 | 7% |
| % passing 2.36 mm | 49 | 30 | 43 | 2.00 | 0% | 40 | 4.02 | 2% |
| % passing 0.425 mm | 23 | 14 | 18 | 1.04 | 0% | 18 | 2.58 | 11% |
| % passing 0.075 mm | 12 | 6 | 9 | 0.51 | 0% | 9 | 2.20 | 11% |

The particle size distribution of the majority of stockpile HSG material was found to be conforming, with only two lots exhibiting excessive coarse material retained on the 26.5 mm, 19.0 mm and/or 13.2 mm sieve.

However, a significant portion (70%) of HSG base lots sampled from the formed pavement layer were found to have nonconforming distribution of particle sizes. The primary cause of non-conformance was an excess of 26.5 mm, 19.0 mm and 13.2 mm nominal size coarse aggregate.

Investigation of sampling locations revealed that 44% of pavement specimens were collected between 0.0 m and 1.0 m, or 3.0 m and 4.0 m from the alignment centreline. The distribution of sampling locations is presented in Figure 4.14. Collection of samples from the edges of the formed pavement layer limits disturbance to areas of the pavement subjected to direct traffic loading (wheelpath), but is non-representative as coarser materials tend to accumulate at the extents of the stockpile, hopper and/or formation due to increased potential energy. It should be noted that the nonconforming lots were evenly distributed between pavement sections formed using the paver and motor grader, which indicates potential sample collection shortfalls or alternatively material segregation in both construction processes. Recovering representative samples from the formed pavement requires careful attention to excavation and collection of all particles. Often the smallest particle sizes can be left behind, skewing subsequent gradation results.

Figure 4.14: Distribution of gradation sampling locations relative to alignment centreline




With respect to the HSG base, the enhancements to MRTS05 included:

- conformance testing of both stockpile and in-pavement material
- tightening of the grading pilot boundary limits
- inclusion of a plasticity index minimum limit of 2.0
- 25% maximum secondary minerals content (basic igneous only)
- 94 minimum accelerated soundness index (basic igneous only)

- acceptance of imported sands and fillers subject to administrator approval, with:
  - 60 minimum degradation factor
  - 15% (by mass) maximum proportion
- requirement for submission of HSG base material mix design for administrator approval.

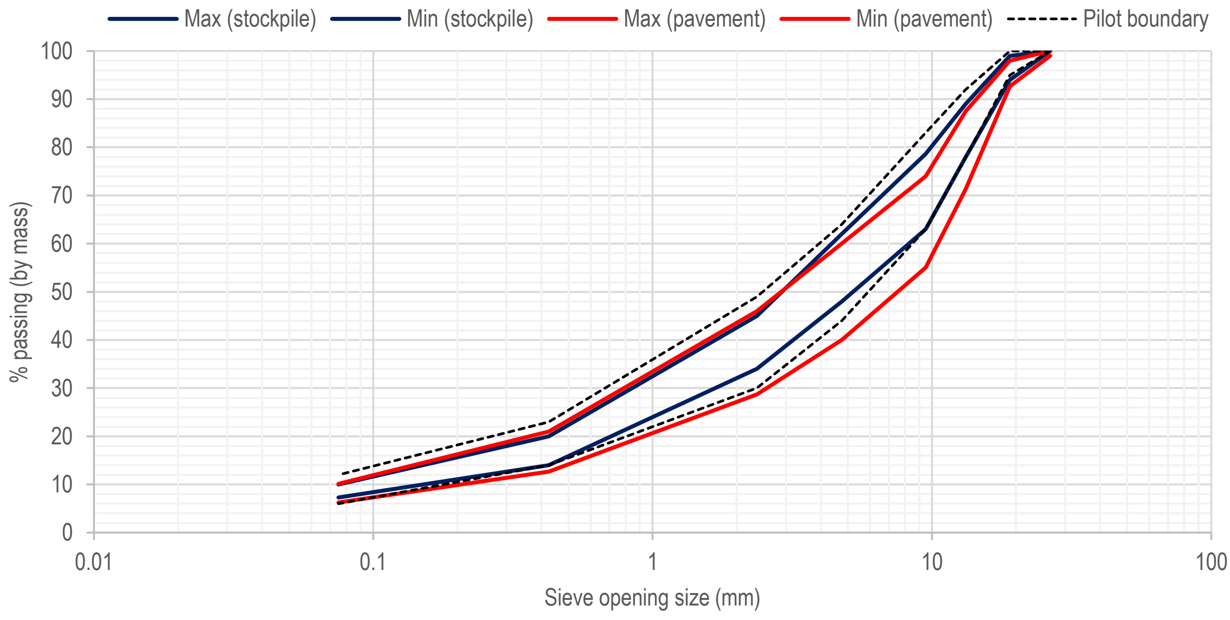
Limited audit material characterisation testing conducted by the ARRB Group confirmed that the product met the project specification requirements for the properties tested. Review of the material property conformance testing results showed a small proportion of sampled materials exhibited nonconforming wet/dry strength variation (5%) and fines content (4%). A significant (≈ 27%) number of samples were observed to have nonconforming particle size distribution. As discussed in Section 4.7.3, potential errors in sampling technique may have influenced the results. However, segregation of pavement material may also contribute to the apparent non-conformance. The variability observed in material properties, in particular particle size distribution, would not be expected for an HSG base material, as consistency is fundamental to increased reliability.

*Stockpile vs. In-pavement Particle Size Distribution*

A key component of the project was the enhanced protocol for compliance testing from both stockpile and the formed uncompacted pavement. Coarse aggregate property samples were collected from the stockpile in accordance with MRTS05 (TMR 2011a). Particle size distribution, Atterberg limits and fines ratio samples were collected from both the stockpile and the formed pavement layer. The contractor was required to demonstrate a relationship between stockpile and in-pavement material properties to the satisfaction of the administrator before compliance testing could be returned to stockpile-only standard practice.

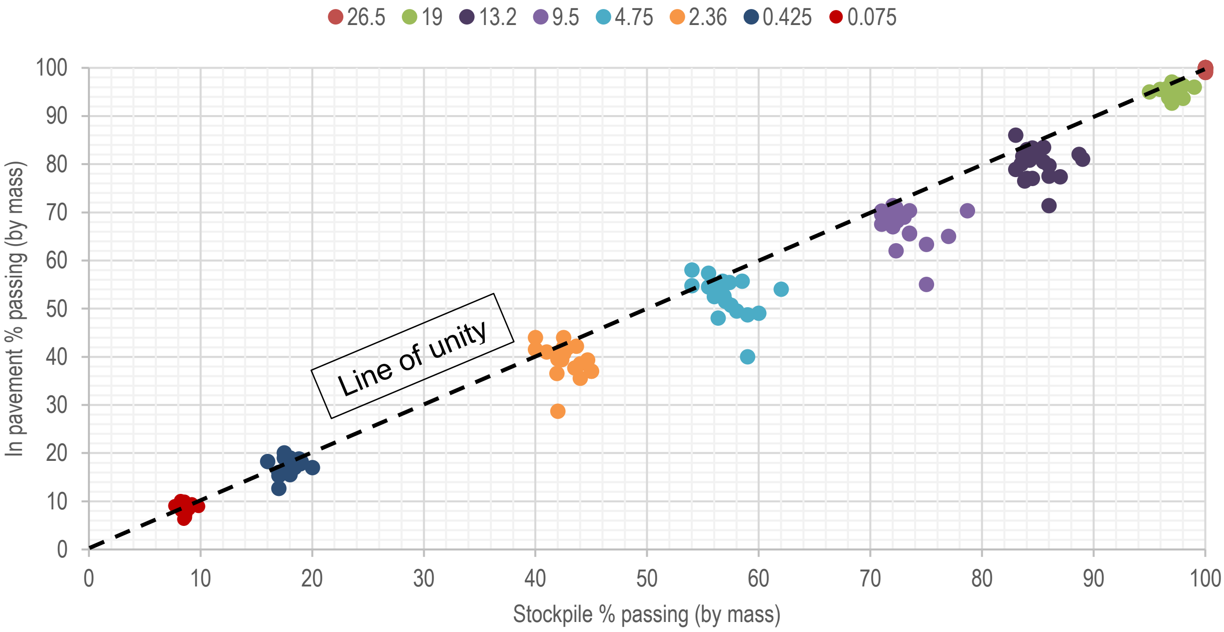
As outlined in Section 4.7.3, a significant difference was observed in the distribution of particle sizes between samples collected from stockpile and the formed uncompacted pavement. The relative difference for the HSG materials supplied to the project is presented in Figure 4.15.

**Figure 4.15: Comparison of stockpile and pavement PSD results**



The most significant variation is observed in the relative proportion of the samples passing the 13.2 mm, 9.5 mm, 4.75 mm and 2.36 mm sieve opening sizes. Reference to the mean particle size distribution for all HSG materials supplied to the project would indicate that the in-pavement samples were coarser than those obtained from stockpile. The relationship between the percentage passing the project specification (Annexure MRTS05.01) control sieves of stockpile and in-pavement samples on a per-lot basis is presented in Figure 4.16.

**Figure 4.16: Relationship between pavement and stockpile PSD results**




As can be observed in Figure 4.16, the largest and smallest particle sizes, including 26.5 mm, 19.0 mm, 0.425 mm and 0.075 mm, are present in uniform proportions. However, a greater proportion of the intermediate size particles from 13.2 mm to 2.36 mm are present in the pavement samples. The ratio and absolute difference of the percentage of particles passing the project specification control sieves for pavement and stockpile samples are presented in Table 4.7.

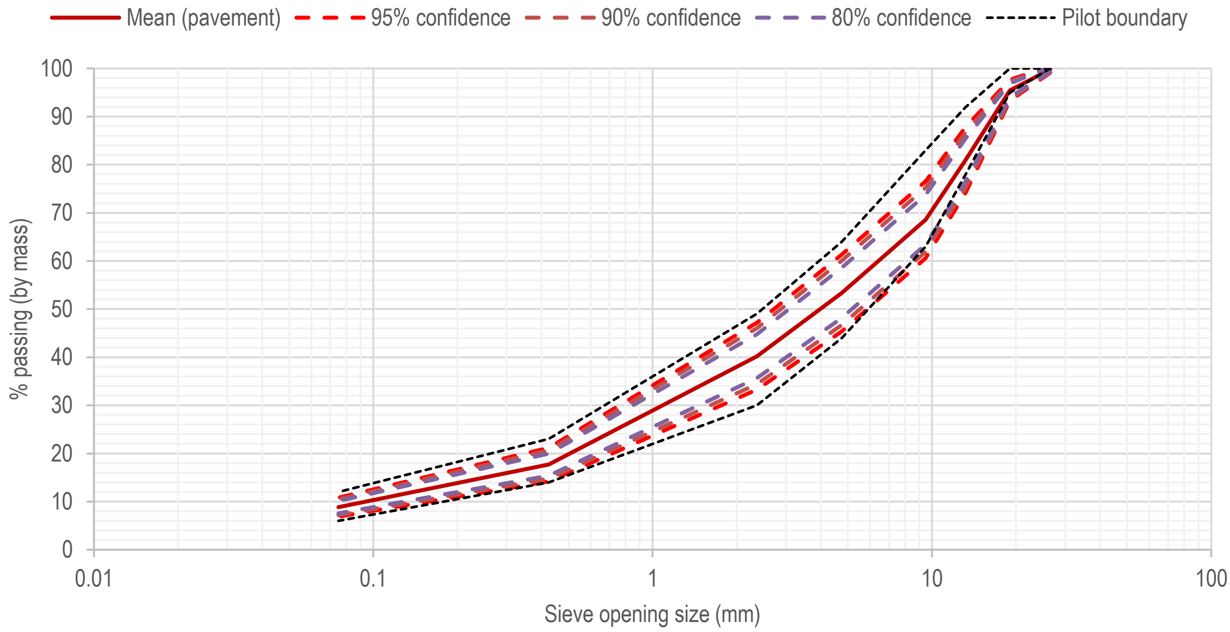
**Table 4.7: Comparison of % passing results for pavement and stockpile samples**

| Sieve opening size (mm) | % passing ratio | | % passing difference | |
|---|---|---|---|---|
| | Average | Range | Average | Range |
| 26.5 | 1.00 | 0.99 - 1.00 | ± 1 | -1 - 0 |
| 19.0 | 0.99 | 0.96 - 1.02 | ± 3 | -4 - 2 |
| 13.2 | 0.96 | 0.83 - 1.08 | ± 10 | -15 - 6 |
| 9.5 | 0.95 | 0.73 - 1.16 | ± 15 | -20 - 10 |
| 4.75 | 0.95 | 0.68 - 1.25 | ± 16 | -19 - 12 |
| 2.36 | 0.96 | 0.68 - 1.24 | ± 11 | -13 - 9 |
| 0.425 | 1.00 | 0.75 - 1.31 | ± 5 | -5 - 5 |
| 0.075 | 1.02 | 0.74 - 1.27 | ± 2 | -2 - 2 |

While some variation can be observed for all of the particle sizes, the 26.5 mm, 19.0 mm, 0.425 mm and 0.075 mm size fractions are generally present in equivalent proportions (100%), where only 95% of the relative pavement sample proportions pass the intermediate sieve sizes from 13.2 mm to 2.36 mm as compared to the stockpile samples. The variance should not be considered as an abundance of small gravel and coarse sand particles being present in the pavement samples, but a lack of large gravel, fine sand, silt and clay particles. The deviations may be the result of procedural and logistical deficiencies in the collection of in situ samples, as discussed in Section 4.7.3.

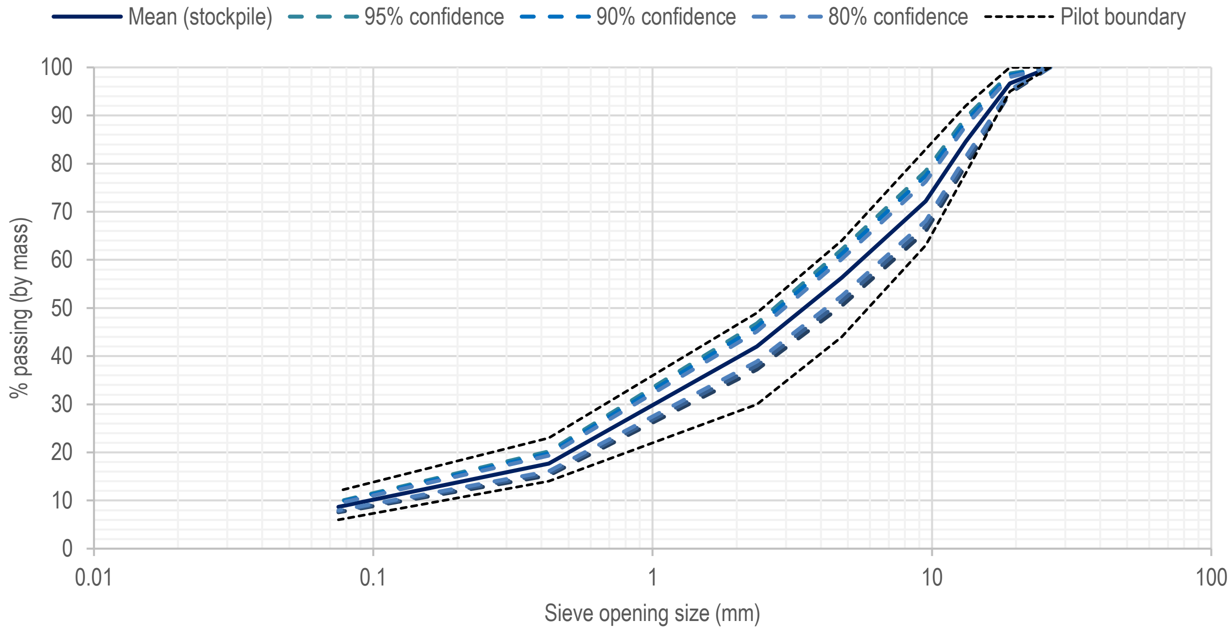
Due to the level of attention and care required to obtain representative specimen, it may be difficult to reliably determine the distribution of particles sizes for materials sampled from the formed pavement. The average particle size distribution of HSG material sampled from the pavement on the Centenary Motorway duplication project is presented in Figure 4.17. At confidence levels as low as 80%, it is not possible to conclude that the material conformed to the project specification requirements. The apparent non-conformance is to due excess coarse (26.5 mm - 9.5 mm) material content.

**Figure 4.17: Confidence intervals for HSG material sampled in situ**




However, when examining the average particle size distribution of material sampled from stockpile, presented in Figure 4.18, it is possible to accept the delivered product as fully conforming at a 95% confidence level.

**Figure 4.18: Confidence intervals for HSG material sample from stockpile**



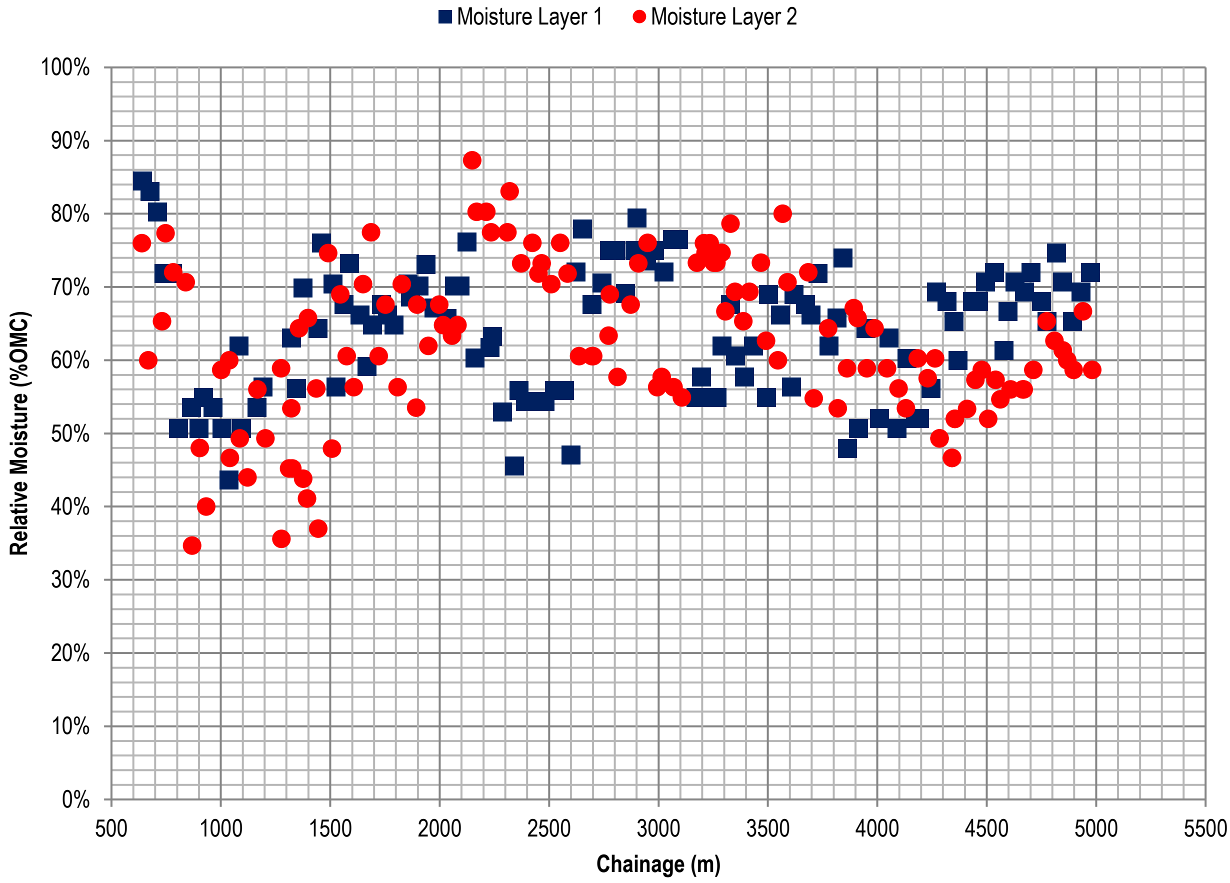

*Density and Moisture Results*

The RDD and relative moisture of compacted pavement sections were determined using a nuclear density gauge in accordance with TMR test method Q141A, *Compacted Density of Soils and Crushed Rock (Nuclear Gauge)* (TMR 2010e). Calibration of the nuclear density gauge was conducted prior to the assessment of each lot in accordance with Q141B, *Compacted Density of Soils and Crushed Rock (Sand Replacement)* (TMR 2010f), and Q102A, *Standard Moisture Content (Oven Drying)* (TMR 2013b).

The reference MDD and OMC determined according to standard compactive effort (Q142A, TMR 2010g) were measured for each 1000 tonnes of HSG material delivered to the project site. A minimum of four randomly distributed measurements were collected for each lot following compaction.

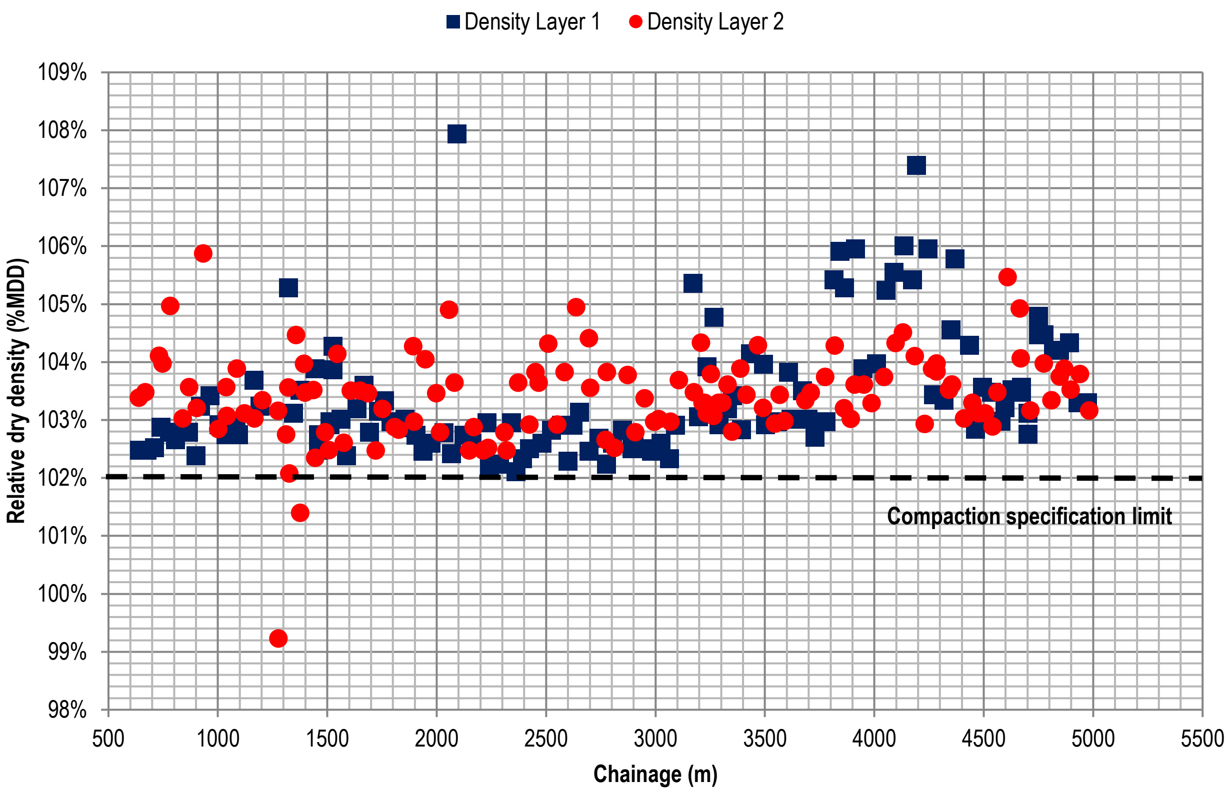
The in situ moisture content was measured to represent the full depth of the HSG base layer in accordance with Test Method Q141A and Test Method Q102A as specified in Clause 10.1.3 of MRTS05 (TMR 2011a) as presented in Figure 4.19.

Figure 4.19: Relative moisture content measured following compaction




Relative moisture values ranged from 33% to 86% of OMC. It should be noted that the relative moisture values were determined using the nuclear density gauge following compaction. Almost all of the sampled lots were found to be conforming. The measured RDD values for each 110 mm thick HSG base layer are presented in Figure 4.20.

Figure 4.20: Relative density measured following compaction




Measured RDD values ranged from 99% to 108% of MDD, with a mean of approximately 103%. In comparison, VicRoads (2011) requires a minimum 100% characteristic relative dry density determined according to modified Proctor compactive effort. It is noted that there are no reliable conversion of MDDs determined between standard and modified compaction energy.

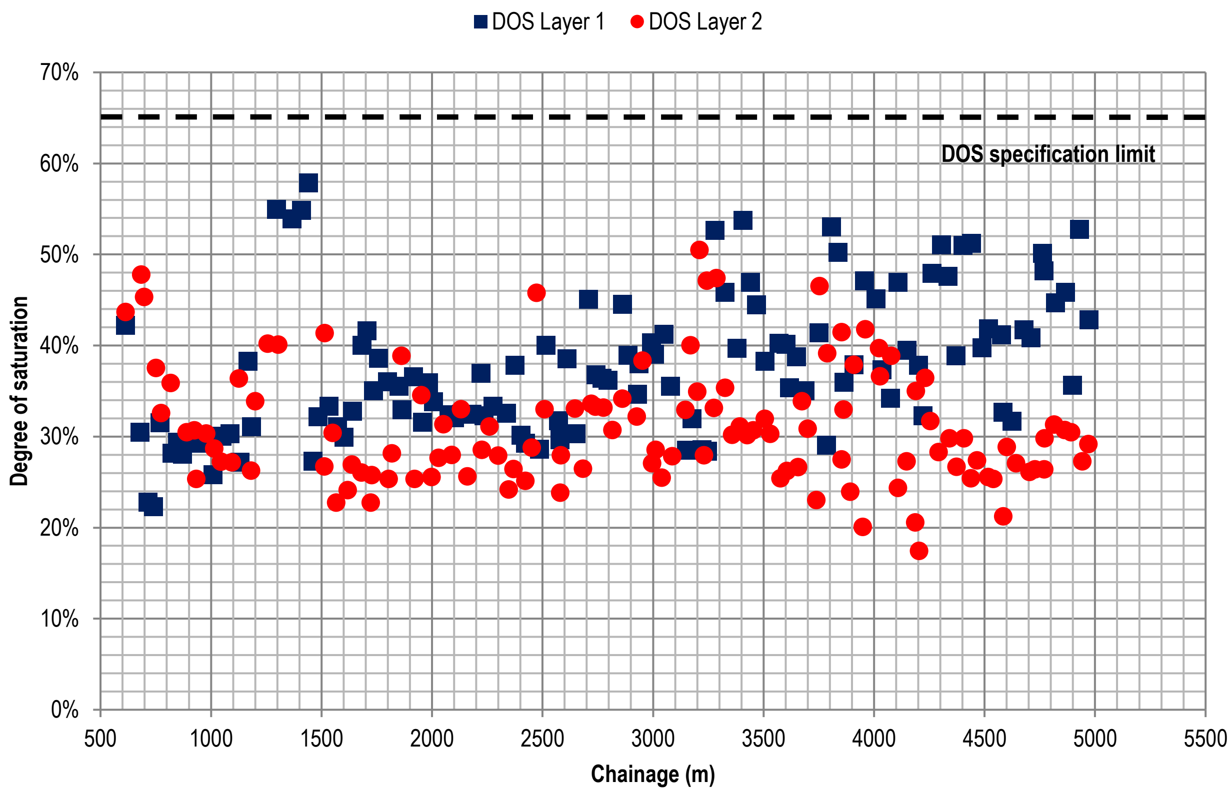
Apparent particle density measurements ranged from 79% to 86%, with a mean of approximately 83% of MDD determined according to solid relative density. COLTO (1998) requires a minimum 88% of solid relative density. All of the constructed trial HSG base would be considered nonconforming according to the South African standard.

*Dry-back to Target Degree of Saturation*

Following compaction, the HSG base layers were allowed to dry back prior to placement of the overlying layer/surfacing. The degree of saturation for each lot was measured and the characteristic value was calculated using Equation 3 as stated in Clause 12 of MRTS01. This test was performed in accordance with Test Method Q146 within a period of six hours prior to the placement of the next pavement layer or the surfacing.

As discussed in Section 4.5.3, repeated-load triaxial testing was undertaken to determine the maximum allowable DOS before sealing. The adopted minimum requirement included moisture content of approximately 5.6%, corresponding to a maximum DOS of 65%. Prior to sealing, the in situ dry density and moisture content were measured using a nuclear gauge. The reference specific gravity for measurement of DOS was determined in accordance with TMR test method Q146 for each 1000 tonnes of HSG material delivered to the project site. A minimum of four randomly distributed nuclear gauge measurements were collected for each lot, at a maximum six hours before sealing. The measured DOS values for each 110 mm thick HSG layer are presented in Figure 4.21.

Figure 4.21: Degree of saturation (DOS) measured prior to sealing




Measured DOS values ranged from 17% to 58%, with a mean of approximately 35%. All of the sampled lots conformed to the DOS specification requirement.

Note that modulus results (Section 4.5.3) were measured at 60%, 65% and 70% DOS substantially wetter than the field values at sealing.

## 4.8 Application of Sprayed Seal

### *4.8.1 Preparation of HSG Base*

Following dry back of the upper HSG base layer, all loose material, including lenses of pavement material, was removed from the surface and swept with a road broom, in accordance with Clause 10.1 of MRTS11. A mechanical broom was utilised to remove excess fines and loose surface aggregate, as shown in Figure 4.22.

Figure 4.22: Removal of surface debris before application of prime coat

#### 4.8.2 Prime

The proprietary emulsion prime was applied to the prepared HSG base after sufficient dry back and loose material removal were completed. Both manual application with the hand sprayer and automated application using a bitumen spray truck were utilised. Typically, use of the hand sprayer was limited to irregular or limited access areas. The purpose of the bituminous prime was to maximise bonding between the HSG base and the PMB sprayed seal. Application of the emulsion prime coat is shown in Figure 4.23.

Figure 4.23: Application of prime coat to prepared HSG base


### 4.8.3 Sprayed Seal

Prior to the initial seal (after priming) of the HSG base layer, Ball Penetration testing was carried out in accordance with the requirements of MRTS11, Table 6.2.

The PMB seal was applied to the HSG base surface once curing of the prime was completed. The seal consisted of a double/double 14/7 mm S0.3B PMB design. The initial seal application was applied to the cured prime surface, followed by spreading of the 14 mm cover aggregate. Immediately following rolling of the 14 mm cover aggregate using a pneumatic tyre roller, an additional application of PMB was applied, followed by spreading and rolling of the 7 mm cover aggregate using the pneumatic tyre roller. Spraying of the initial PMB seal is shown in Figure 4.24. Application and rolling of the 14 mm cover aggregate is presented in Figure 4.25 and Figure 4.26 respectively.

Figure 4.24: Application of initial PMB seal


Figure 4.25: Spreading of 14 mm sealing aggregate

Figure 4.26: Rolling of the 14 mm sealing aggregate


### 4.8.4 Conformance Testing

*Cover aggregate*

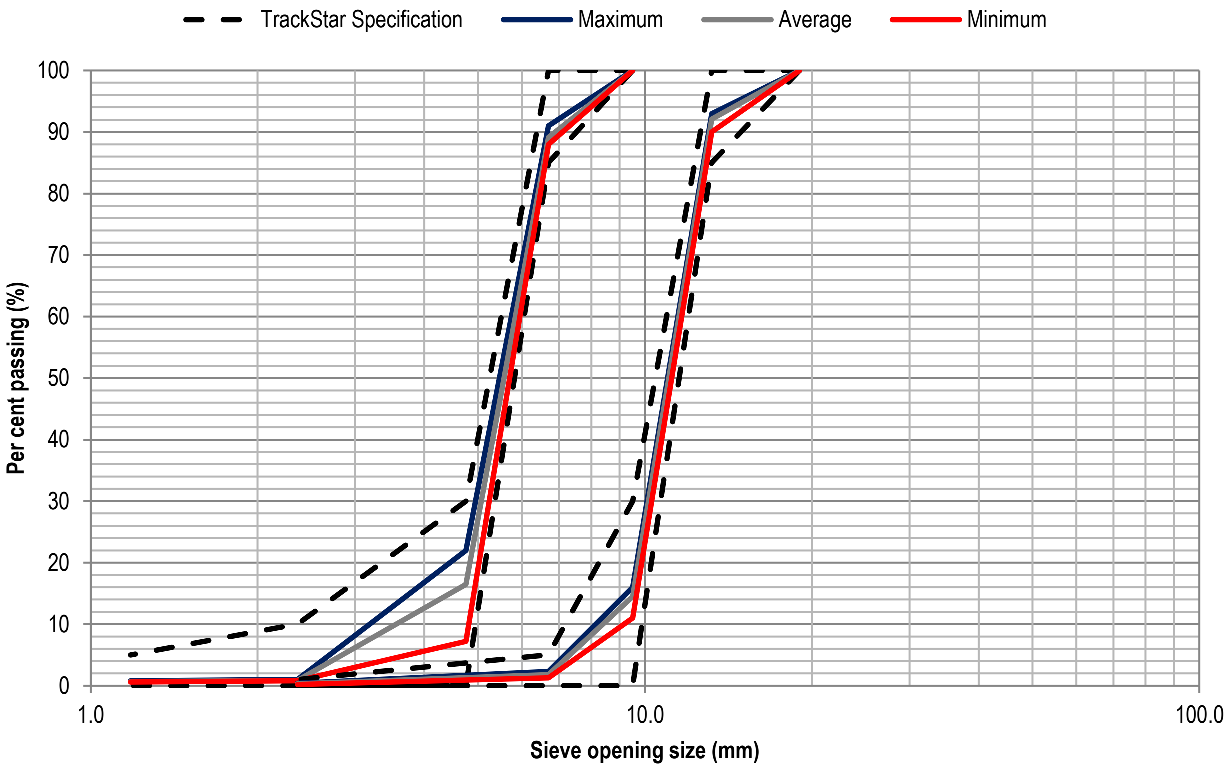
Conformance testing requirements for the 14 mm and 7 mm cover aggregate included a 10% fines (wet) value (Q205B), wet/dry strength variation (Q205C), weak particles (Q217), crushed particles (Q215), flakiness index (Q201), degradation factor (Q208B), absorption (Q226), stripping value (Q212A), degree of precoating (Q216) and average least dimension (ALD) (Q202). Samples were collected from stockpiles on site, and the associated testing results are presented in Table 4.8.

Table 4.8: Material properties of stockpiled 14 mm and 7 mm cover aggregates

| Property | Specification limits | | 14 mm stone | | | 7 mm stone | | |
|---|---|---|---|---|---|---|---|---|
| | Upper | Lower | Mean | σ | Nonconforming | Mean | σ | Nonconforming |
| Wet 10% fines value (kN) | - | 175 | - | - | - | - | - | - |
| Wet / dry strength variation (%) | 35 | - | - | - | - | - | - | - |
| Weak particles (%) | 1 | - | 0 | 0.00 | 0% | - | - | - |
| Crushed particles (%) | - | 80 | - | - | - | - | - | - |
| Flakiness index | 30 | - | 13 | 2.20 | 0% | 18 | 5.20 | 0% |
| Degradation factor | - | 45 | - | - | - | - | - | - |
| Absorption (%) | 2 | - | - | - | - | - | - | - |
| Stripping value | 10 | - | 3 | 2.30 | 0% | - | - | - |
| Degree of precoating (%) | - | 70 | 99 | 0.40 | 0% | - | - | - |
| Average least dimension (mm) | - | - | 8.3 | 0.20 | - | 4.4 | 0.10 | - |

The conformance testing results available for review included only per cent weak particles, flakiness index, stripping value, degree of precoating and ALD. ALD values were not specified, but the measure is critical to the seal design as it provides an indication of particle cubicity and available binder volume. Measured values were 8.3 mm and 4.4 mm for the 14 mm and 7 mm cover aggregates respectively. For the material properties reviewed, none of the sampled lots of either 14 mm or 7 mm cover aggregates were found to be nonconforming. In addition to the other material properties, conformance of the particle size distribution of the cover aggregates was regularly assessed during construction. The mean, maximum and minimum values are presented in Figure 4.27. The particle size distribution of both the 14 mm and 7 mm cover aggregates were highly uniform and no lots were found to be nonconforming.

Figure 4.27: Particle size distribution conformance summary for 14 mm and 7 mm cover aggregates




*Binder Application and Aggregate Spread Rates*

Monitoring of the binder application and aggregate spread rates during construction provides an indication of the quality with which the seal has been constructed. Minor variation between design and actual values is expected, but consistency in material usage is desired. The average binder application and cover aggregate spread rates for discrete lots along the alignment are presented in Table 4.9 and Table 4.10 respectively.

**Table 4.9: Mean S0.3B PMB binder application rates for trial pavement**

| Project chainage (m) | Base coat (14 mm) | | Surface coat (7 mm) | |
|---|---|---|---|---|
| | Slow lane (l/m$^2$) | Fast lane (l/m$^2$) | Slow lane (l/m$^2$) | Fast lane (l/m$^2$) |
| 605 - 815 | 0.92 | 1.01 | 0.72 | 0.76 |
| 815 - 3110 | 0.91 | 1.01 | 0.71 | 0.76 |
| 1205 - 1505 | 0.89 | 1.01 | 0.69 | 0.74 |
| 3135 - 3805 | 0.91 | 1.01 | 0.71 | 0.75 |
| 3805 - 4035 | 0.92 | 1.01 | 0.71 | 0.76 |
| 4035 - 4875 | 0.90 | 1.01 | 0.71 | 0.75 |
| 4875 - 4995 | 0.94 | 1.01 | 0.71 | 0.76 |
| 4995 - 5330 | 0.92 | 1.05 | 0.71 | 0.73 |

**Table 4.10: Mean cover aggregate spread rates for trial pavement**

| Project chainage (m) | Base coat (14 mm) | | Surface coat (7 mm) | |
|---|---|---|---|---|
| | Slow lane (m$^2$/m$^3$) | Fast lane (m$^2$/m$^3$) | Slow lane (m$^2$/m$^3$) | Fast lane (m$^2$/m$^3$) |
| 605 - 815 | 108 | 110 | 225 | 227 |
| 815 - 3110 | 108 | 108 | 223 | 228 |
| 1205 - 1505 | 112 | 106 | 241 | 220 |
| 3135 - 3805 | 108 | 108 | 223 | 227 |
| 3805 - 4035 | 108 | 110 | 228 | 227 |
| 4035 - 4875 | 109 | 109 | 227 | 230 |
| 4875 - 4995 | 108 | 110 | 228 | 227 |
| 4995 - 5330 | 108 | 105 | 217 | 227 |

The average binder application rates for the base seal were approximately 0.91 L/m$^2$ and 1.02 L/m$^2$ for the slow and fast lane respectively. The average cover aggregate spread rate for the base seal was approximately 108 m$^2$/m$^3$. The design values for the base seal included binder application rates of 0.90 L/m$^2$ and 1.00 L/m$^2$, for the slow and fast lane respectively, and cover aggregate spread rate of 110 m$^2$/m$^3$. The average binder application rates for the surface seal were approximately 0.71 L/m$^2$ and 0.75 L/m$^2$ for the slow and fast lane respectively. The average cover aggregate spread rate for the surface seal was approximately 226 m$^2$/m$^3$. The design values for the surface seal included binder application rates of 0.70 L/m$^2$ and 0.75 L/m$^2$, for the slow and fast lane respectively, and cover aggregate spread rate of 230 m$^2$/m$^3$. The consistency of the values presented in Table 4.9 and Table 4.10, and the close agreement of design and actual values, are indicative of a sprayed bituminous seal constructed to a high standard.

# 5 MATERIAL AUDIT TESTING

## 5.1 Introduction

Increasing traffic loads, use of nonstandard materials, lack of expertise, material variability, and complexity of particulate behaviour have contributed to the rise in the underperformance of unbound granular pavements in Queensland (Creagh, Wijeyakulasuriya & Williams 2006). As a result, one of the objectives of this investigation was to establish the 'as-constructed' properties of the pavement and to monitor changes in both surface condition and structural capacity on an annual basis. The monitoring program included independent verification of HSG base and sealing cover aggregate material properties (Section 5), surface condition assessment using a network survey vehicle (NSV) (Section 6), and non-destructive structural evaluation using a falling weight deflectometer (FWD) (Section 7).

## 5.2 HSG Base

One of the most concerning findings of the Gatton Bypass duplication investigation (O'May 2007) was the discrepancy between the pavement material properties and the project specification requirements. Confirmation of the Centenary Motorway duplication project HSG base material properties was undertaken as part of the baseline performance assessment. One sample was recovered from the production quarry (single stockpile) and two additional samples were recovered on site from 5 to 6 randomly selected stockpiles on two separate days of construction. The results of the classification testing are described in Section 5.2.1 and deformation resistance testing using the large-scale wheel tracker and repeat-load triaxial test are given in Section 5.2.2 and Section 5.2.3 respectively.

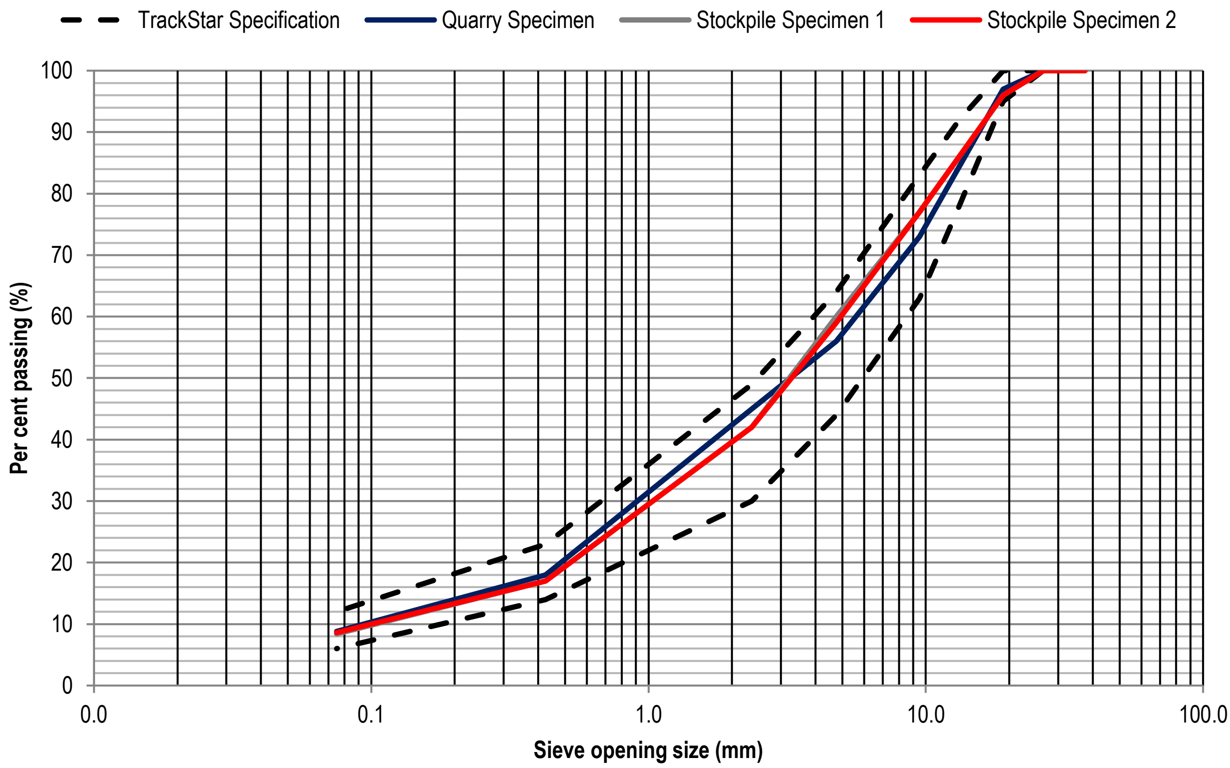
### *5.2.1 Characterisation Testing*

The confirmation testing program included particle size distribution, 10% fines (wet) value, wet/dry strength variation, degradation factor, crushed particles, flakiness index, Atterberg limits, linear shrinkage, weighted plasticity index, weighted linear shrinkage and fines ratio. Specimens were recovered by ARRB Group staff and delivered to TMR Material Services – Brisbane for characterisation testing in accordance with the standard test methods outlined in the project specification. The results from material characterisation testing are presented in Table 5.1 and from particle size distribution testing in Figure 5.1.

**Table 5.1: HSG base material property confirmation testing summary**

| Property | Specification limits | | Quarry | Stockpile | |
|---|---|---|---|---|---|
| | Upper | Lower | Specimen 1 | Specimen 1 | Specimen 2 |
| Wet strength (kN) | - | 140 | 179 | - | - |
| Dry strength (kN) | - | - | 227 | - | - |
| Wet / dry strength variation (%) | 35 | - | 21 | - | - |
| Degradation factor | - | 45 | 52 | 43 | 47 |
| Crushed particles (%) | - | 70 | 100 | 100 | 100 |
| Flakiness index (%) | 35 | - | 20 | 29 | 30 |
| Liquid limit (%) | 25 | - | 19 | 19 | 19 |
| Plastic limit (%) | - | - | 15 | 16 | 15 |
| Plasticity index (%) | 6 | 2 | 4 | 3 | 4 |
| Linear shrinkage (%) | - | - | 3 | 3 | 3 |
| Weighted plasticity index | 150 | - | 70 | 59 | 61 |
| Weighted linear shrinkage | - | - | 62 | 55 | 54 |
| Fines Ratio | 0.55 | 0.30 | 0.48 | 0.49 | 0.51 |

**Figure 5.1: HSG base particle size distribution confirmation testing summary**



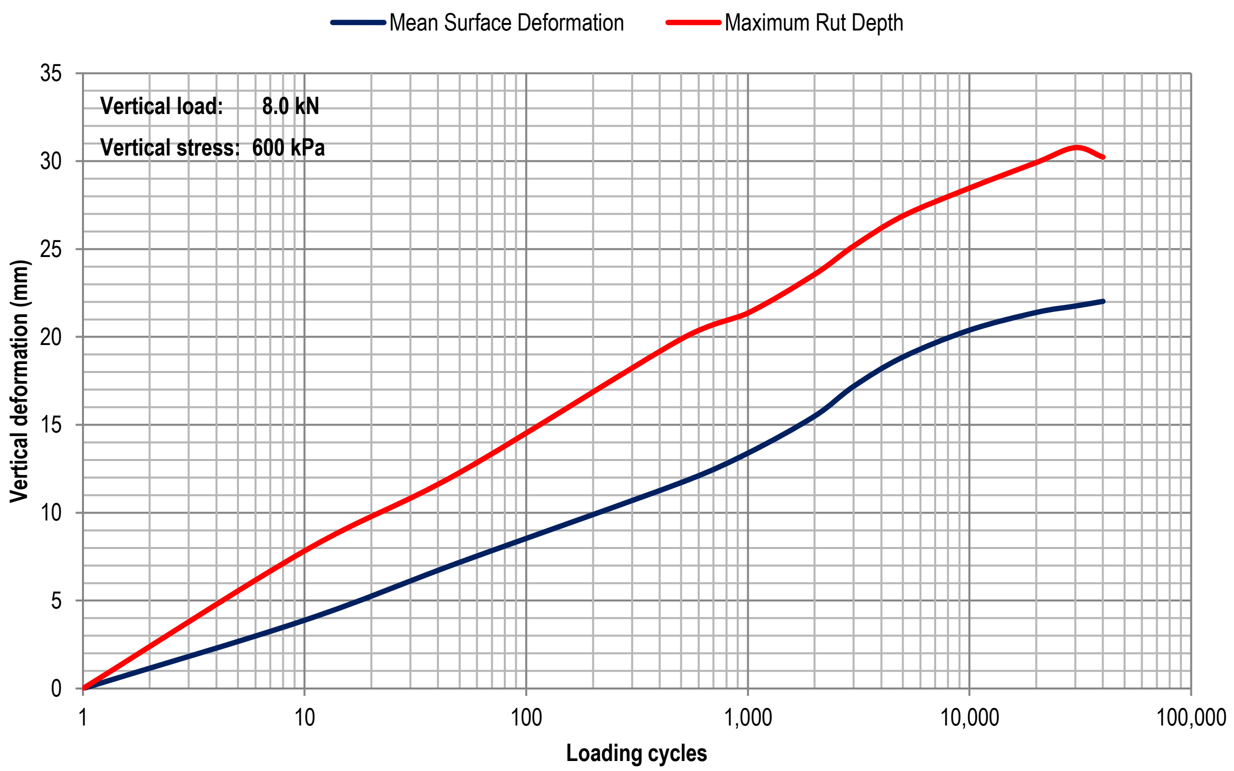

With the exception of the degradation factor for stockpile Specimen 1 (43), the properties of both the quarry and stockpile specimens were found to conform to the project specification. Some variation between the quarry and stockpile particle size distribution specimens can be observed, but all of the results fall within the middle third of the grading pilot boundary limits for the HSG base. The stockpile specimen collection sites were separated by approximately 1.0 km and collection times were separated by five days. The level of consistency can also be observed between specimens collected at the quarry site and those obtained from stockpiles on site. The consistency level of the testing results supports the suggestion in Section 4.7.3 that the significant number (≈ 70%) of nonconforming in-pavement particle size distribution testing results may be the result of improper sampling techniques.

### *5.2.2 Wheel-tracking*

Evaluation of the rutting potential of the HSG base material was investigated by observing the performance under laboratory simulative traffic loading. Testing was accomplished in accordance with the provisional test method presented in Austroads (2013) report, *Development of a Wheel-tracking Test for Rut Resistance Characterisation of Unbound Granular Materials*. The testing consisted of applying a vertical load of 8.0 kN via a pneumatic tyre (600 kPa) to the surface of a compacted HSG material slab with dimensions of 700 mm length, 500 mm width and 300 mm depth. The pneumatic tyre is loaded and advanced across the surface of the confined slab. Upon reaching the end, the load is removed and the wheel returned to the starting position. This process is repeated until 30 000 loading cycles have been applied. Laser profilometers continually monitor the displacement of the surface to determine the vertical surface deformation and maximum rut depth.

The base material sample was obtained from the production quarry (Quarry Specimen 1) during construction of the trial pavement. The target testing conditions were a dry density of 2.198 t/m$^3$ (RDD = 99%) and moisture content of 5.6% (DOS = 66%). However, due to moisture migration during testing, actual testing conditions were an average dry density of 2.17 t/m$^3$ (RDD = 98%) and an average moisture content of 4.5% (DOS = 49%). A summary of the surface deformation and rut depth observed during the wheel-tracking test are presented in Figure 5.2 .

**Figure 5.2: Wheel-tracking summary results**




A broadly applicable correlation between wheel tracking results and in-service performance has not yet been developed. However, performance in the wheel-tracking test is indicative of the deformation potential of granular materials. The results indicate that the material may be susceptible to permanent deformation at test conditions (RDD = 98%, DOS = 49%). The HSG base was constructed to a higher RDD standard (Figure 4.20) and the moisture contents at the time of sealing (Figure 4.21) were considerably lower than the testing conditions. Hence, the constructed HSG base should be more rut resistant than indicated from these wheel-tracking results. It should be noted that the actual moisture content of the specimen varied during testing.

### *5.2.3 Repeat-load Triaxial*

The results of the repeat-load triaxial testing described in Section 4.5.3 were reviewed further to validate the results of the wheel-tracking test. The HSG base material was prepared to three RDD levels (104%, 103% and 102%) and three DOS levels (60%, 65% and 70%). The initial moduli values ranged from 320 MPa to 400 MPa. These results are low compared to the expected minimum value of 500 MPa for HSG (Austroads 2012). Additionally, the significant decrease in resilient modulus and increase in permanent strain with loading cycles indicates that the HSG base material is unstable and potentially susceptible to permanent deformation. The poor performance of the material is likely due to the high moisture content.

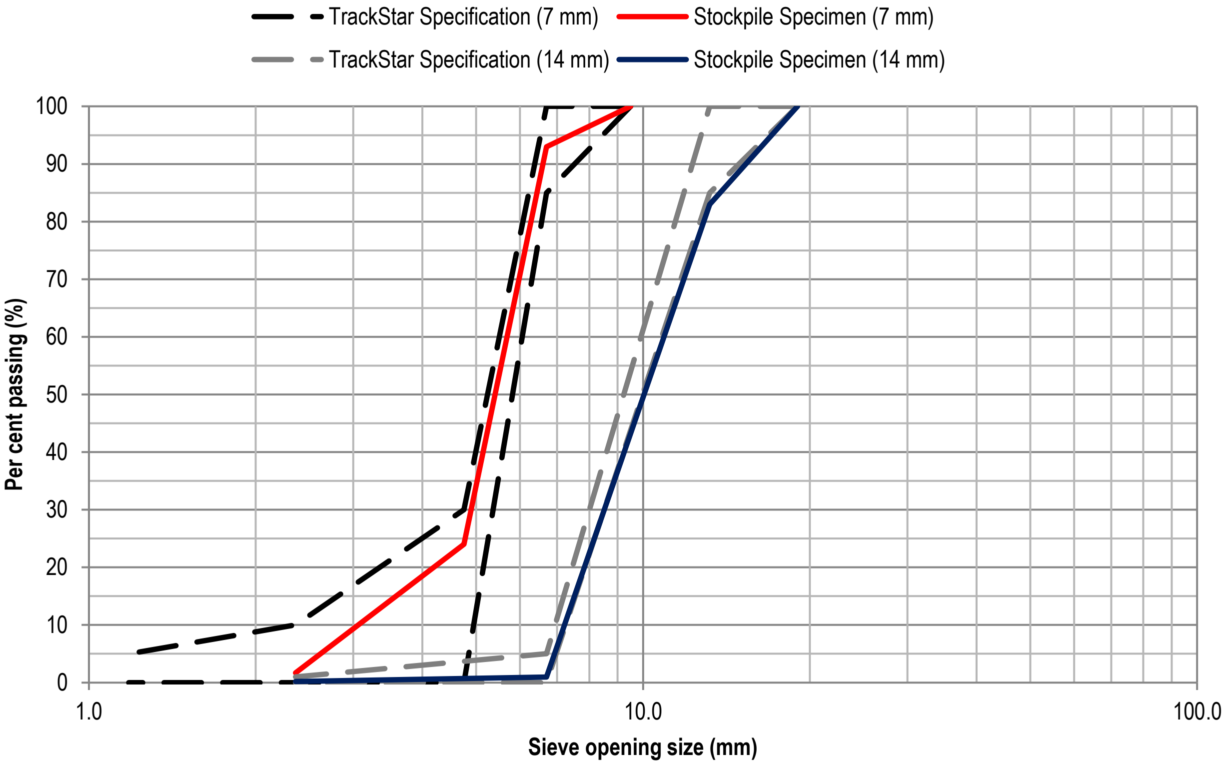
## 5.3 Cover Aggregate

Confirmation of the material properties of the sprayed seal cover aggregate was also undertaken as part of the baseline performance assessment. Specimens were recovered on site from randomly selected stockpiles. The confirmation testing program included particle size distribution, flakiness index, degree of precoating and ALD. Specimens were recovered by ARRB Group staff and delivered to TMR Material Services – Brisbane for characterisation testing in accordance with the standard test methods outlined in the project specification. The results from material characterisation testing are presented in Table 5.2, and the results from the particle size distribution testing are shown in Figure 5.3.

**Table 5.2: Cover aggregate material property confirmation testing summary**

| Property | Specification limits | | Stockpile | |
|---|---|---|---|---|
| | Upper | Lower | 7mm Specimen | 14 mm Specimen |
| Wet 10% fines value (kN) | - | 175 | - | - |
| Wet / dry strength variation (%) | 35 | - | - | - |
| Weak particles (%) | 1 | - | - | - |
| Crushed particles (%) | - | 80 | - | - |
| Flakiness index | 30 | - | 17 | 17 |
| Degradation factor | - | 45 | - | - |
| Absorption (%) | 2 | - | - | - |
| Stripping value | 10 | - | - | - |
| Degree of precoating (%) | - | 70 | 90 | 99 |
| Average least dimension (mm) | - | - | 4.2 | 8.8 |

**Figure 5.3: Cover aggregate particle size distribution confirmation testing summary**




For the material properties investigated, both the 7 mm and 14 mm cover aggregate samples conformed to the project specification. The average ALD of 4.2 mm and 8.8 mm are very similar to the 4.4 mm and 8.3 mm measured during construction as a part of conformance testing. Additionally, the particle size distribution of the 7 mm cover aggregate conformed to MRTS11. However, the 14 mm specimen is nonconforming, with excess coarse material (83%) retained on the 13.2 mm opening size sieve.

# 6 PAVEMENT SURFACE CONDITION

## 6.1 Introduction

Assessment of the pavement surface condition was undertaken using an ARRB Group network survey vehicle (NSV) as shown in Figure 6.1. The NSV is built around the Hawkeye 2000 platform and employs an array of laser profilometers, accelerometers and cameras to assess the condition of the pavement surface. Features of the Hawkeye 2000 system include digital laser profilometery, automatic crack detection, transverse profile and deformation measurement, digital video capture, and GPS tracking. A principal advantage of utilising a NSV for the surface condition assessment is the ability to collect detailed data at traffic speeds with minimal impact to the road user.

Pavement surface condition were assessed using the NSV in October 2013, October 2014, October 2015 and October 2016.

Pavement characteristics determined using the system include roughness, longitudinal and transverse profile, rutting, faulting and macrotexture, in addition to accurate distance mapping and the production of data shape files.

**Figure 6.1: Measurement of rutting, roughness, texture and cracking**


## 6.2 Assessment Methodology

### *6.2.1 Roughness*

Measurement of surface roughness was carried out in accordance with Austroads test method AG:AM/T001, *Pavement Roughness Measurement with an Inertial Laser Profilometer* (Austroads 2011b). Roughness determined according to the Austroads (2011b) method is based upon the quarter-car model presented as International Roughness Index (IRI) and indicates suspension displacement accumulation in m/km. For this investigation, the displacement accumulation in both the left and right wheelpaths was reported in 25 m segments for each traffic lane. Lane IRI is the average of the IRI values obtained 0.75 m either side of the profiler centre and is the measure applied in this study. An alternative measure of roughness, NAASRA roughness counts, was determined at the time of testing from the Lane IRI using Equation 4. Note that TMR has since revised this equation, however for consistency in the report the new equation has not been adopted.

$$NAASRA = 33.67(IRI\ ) - 1.95 \tag{4}$$

where

*NAASRA* = NAASRA roughness in counts per kilometre

*IRI* = Lane IRI in metres per kilometre based on the quarter-car model.

### *6.2.2 Rutting*

Measurement of surface rutting was carried out in accordance with Austroads test method AG:AM/T009, *Pavement Rutting Measurement with a Multi-laser Profilometer* (Austroads 2011d). Rutting is determined in the Austroads (2011d) method through measurement of the transverse pavement surface profile using a vehicle-mounted multi-laser profilometer with complimentary displacement transducer. The lasers measure the distance between a fixed horizontal datum and the pavement surface, and report the maximum rut in each wheelpath in addition to the lane maximum in millimetres. For this investigation, the wheelpath and lane maximum vertical deviation values were reported by 25 m segments for each lane.

### *6.2.3 Cracking*

Assessment of cracking can be determined from manual review of digital video captured during NSV runs, or through the employment of automated crack detection software using the Hawkeye 2000 system. The manual review method was utilised during this assessment. The cracking type, including longitudinal, transverse and block, amount (length/area), severity and location, is noted through forward and backward pass review of digital video data.

### *6.2.4 Texture*

The measurement of surface macrotexture for the constructed pavement was carried out in accordance with Austroads test method AG:AM/T013, *Pavement Surface Texture Measurement with a Laser Profilometer* (Austroads 2011e). The macrotexture of the pavement surface was determined according to the Austroads (2011e) method using a vehicle-mounted laser profilometer and a complimentary displacement transducer. The sensor measured texture depth (SMTD) is a continuous measure of the surface profile divided laterally into 300 mm segments composed of 40 samples with 7 mm spacing. The SMTD is the root mean square of the residuals between the 40 measurements and a second-order polynomial representing the pavement surface (Austroads 2011e). The calculation of SMTD is as shown in Equation 5.

$$SMTD = \sqrt{\frac{\sum_{i=1}^{40}(y_i - y_e)^2}{40}} \tag{5}$$

where

*SMTD* = sensor measured texture depth

$y_i$ = sensor measurement i of 40

$y_e$ = second-order polynomial prediction of i.

For this investigation, the mean SMTD measured within a 25 m segment of both the left and right wheelpaths was determined for each lane. An alternative measure of surface texture determined according to the traditional sand patch texture depth (SPTD) method correlates well with SMTD and can be calculated as shown in Equation 6.

$$SPTD = 1.926(SMTD) + 0.039 \quad (6)$$

where

*SPTD* = equivalent sand patch texture depth

*SMTD* = sensor measured texture depth.

## 6.3 Post Construction Assessment (2013)

The post construction surface condition assessment was conducted in October 2013, prior to opening to traffic. The as-constructed pavement surface was generally found to be highly variable, both longitudinally and transversely. A summary of the surface condition assessment is provided in Table 6.1. The mean and standard deviation (σ) were determined by referencing the 25 m values for each lane along the approximately 4.65 km-long trial section. The proportion of the constructed pavement not conforming to specification criteria was determined using the results reported every 25 m and should not be interpreted as contract conformance based on individual lots (100-500 m). The σ of the 25 m values was in excess of 35% of the mean roughness and 25% of the mean rutting measurements. Additionally, both roughness and rutting were observed to vary between the slow and fast lanes. Variation between lanes is expected for multiple lane in-service pavements. However, the surface condition assessment was conducted prior to opening to traffic. As expected, no cracking was observed in the pavement surface. The surface texture was generally consistent along the alignment.

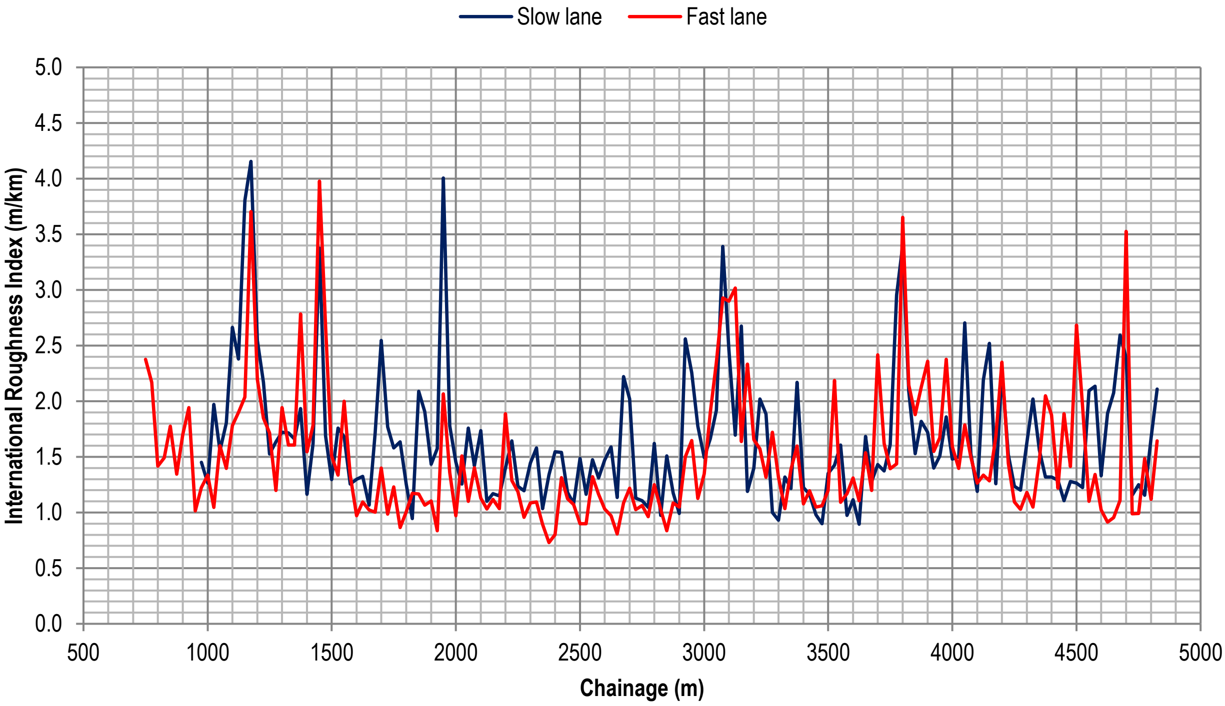
**Table 6.1: Post construction surface condition assessment summary**

| Property | Slow lane | | Fast lane | |
|---|---|---|---|---|
| | Mean | σ | Mean | σ |
| IRI roughness (m/km) | 1.66 | 0.60 | 1.50 | 0.59 |
| Rutting (mm) | 3.7 | 0.8 | 4.6 | 1.5 |
| Cracking (m) | 0 | - | 0 | - |
| SMTD (mm) | 0.91 | 0.08 | 0.94 | 0.07 |

### 6.3.1 Roughness

The measurement of roughness was accomplished using a vehicle-mounted laser profilometer with a complimentary accelerometer and distance transducer. The roughness of the trial pavement surface was determined by averaging the results of two independent surveying runs with the NSV. The results of the roughness assessment are presented in Figure 6.2 and include IRI roughness measurements in 25 m intervals.

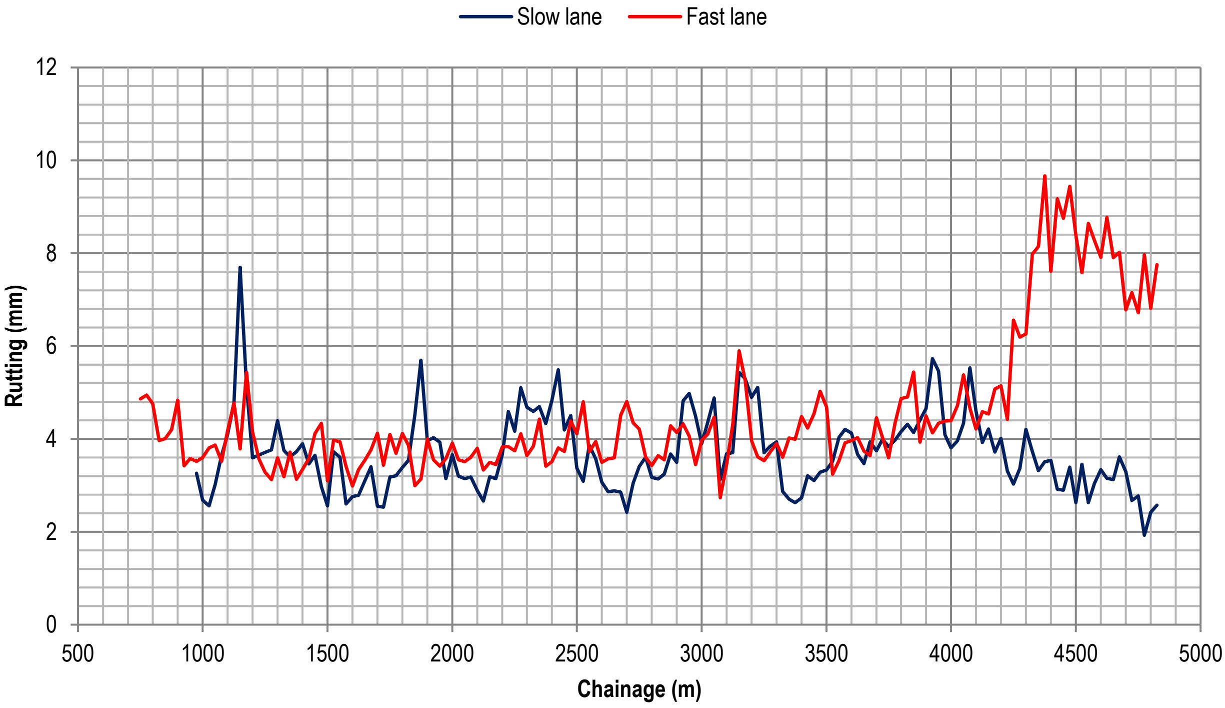
Figure 6.2: Summary results from post-construction roughness assessment




### 6.3.2 *Rutting*

Rutting along with both roughness and surface texture was measured using the ARRB Group NSV laser profilometer. As the assessment was conducted post construction and the alignment had not yet been opened to traffic, traffic-induced rutting would not have yet taken place. However, the measurement of deviation from a horizontal datum does provide a baseline for future assessment and also an indication of lateral uniformity of the constructed structure. The rutting results were determined by averaging the lane maximum of two independent survey runs and are presented in Figure 6.3 in 25 m intervals.

**Figure 6.3: Summary results from post construction rutting assessment**




A number of measurements between project chainage 4300 and 4800, and exclusively in the fast lane, exhibited rutting in excess of 7 mm. Further investigation of the results revealed that the extreme values were reproduced in both survey runs and are isolated in the outer side of the fast lane, adjacent to a drainage feature. Subgrade replacement with Class A select fill to depths of 500 mm and 1000 mm was conducted for the pavement sections between project chainages 4405 m and 4880 m due to low in situ foundation support (< 3% CBR). The isolation of high values to the fast lane adjacent to the edge drain suggests either consolidation as a result of increased moisture content or permanent deformation of pavement layers under construction traffic. The source of the lateral surface deviation is best confirmed through structural evaluation (FWD) and will be discussed further in Section 7.

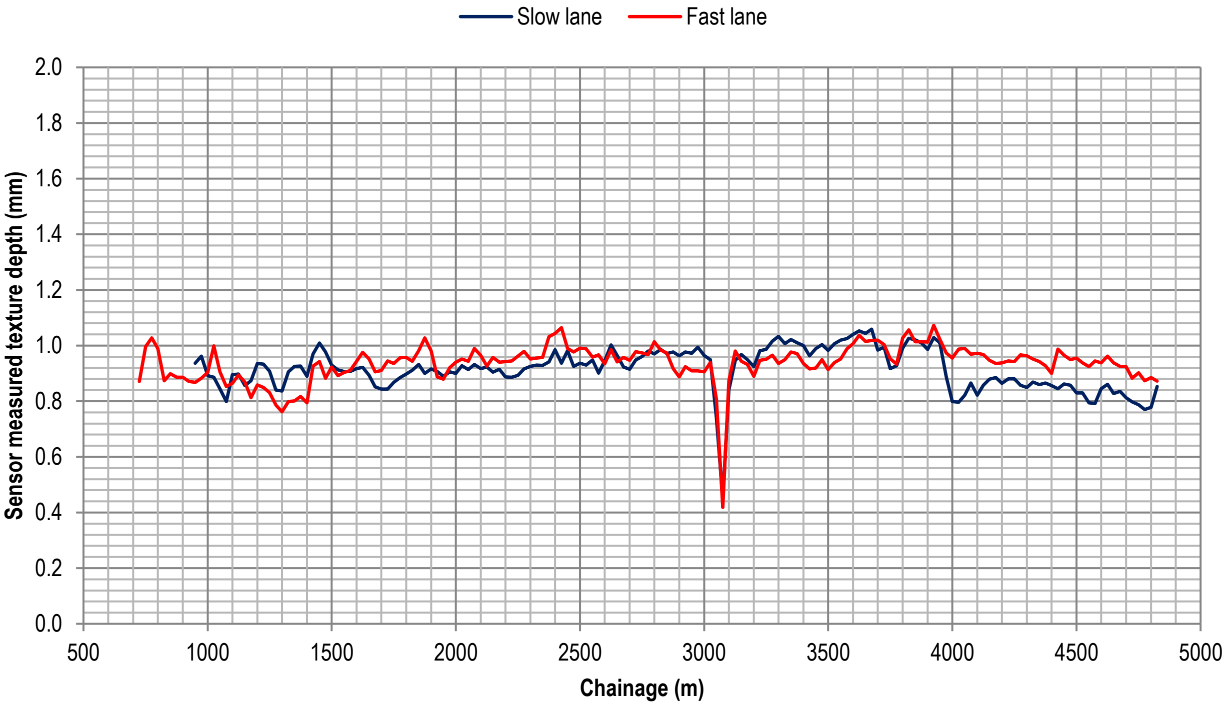
### *6.3.3 Cracking*

No evidence of cracking was observed during the post-construction surface condition assessment. The occurrence of cracking will continue to be monitored in future assessments.

### *6.3.4 Texture*

Where the seal is the final surfacing or shall be opened to public traffic, surface texture shall be tested in accordance with clause 16.2 of MRTS11. The surface texture results were obtained by averaging the measurements from two independent NSV survey runs, and are presented in Figure 6.4. The texture is presented in terms of SMTD.

Figure 6.4: Summary results from post construction texture assessment

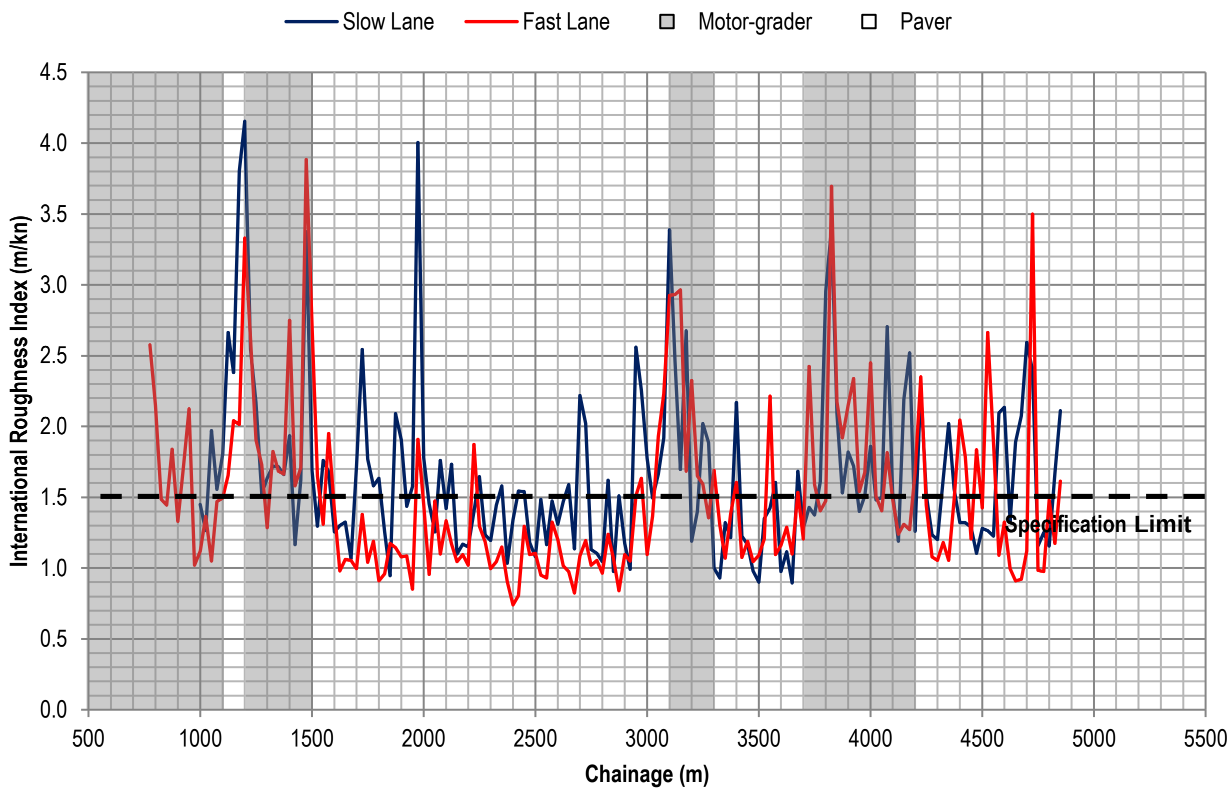



A minimum requirement for surface macrotexture does not currently exist in Queensland. Austroads (2011a) recommends a minimum mean texture depth of 0.6 mm for highways with travelling speeds greater than 80 km/h. All of the measured road sections exceed the Austroads (2011a) recommended limit. It is generally accepted that better texture depth provides reduced road noise and improved surface moisture transport. Greater texture depth values provide lower social impact and increased user safety, and should be monitored if not explicitly required for compliance. The measured surface texture is generally consistent both longitudinally and transversely. However, deviation between the slow and fast lane can be observed between project chainages 3950 and 4800.

### 6.3.5 Measured roughness and layer formation method

The cracking, surface texture and surface deflection values were consistent across the project alignment. However, substantial variability was observed in roughness measurements, in addition to a significant number (≈ 40%) of measurements in excess of the specification limit of 50 NAASRA counts (IRI ≈ 1.5). Roughness values presented in IRI relative to project chainage are presented in Figure 6.5. The method of base layer formation, either by motor grader or paver, is also shown in Figure 6.5. Areas of high roughness correlate well with transition zones between different construction areas. Due to site access limitations, the project was constructed in discrete sections. It is often difficult to attain compaction and maintain grade in abutting sections. Additionally, issues with HSG material availability resulted in frequent start/stop operation of the mechanical spreader. It is proposed that the discontinuous construction operation contributed to the significant level of roughness non-conformance.

Figure 6.5: Relationship between measured roughness and layer formation method




The impact of construction practices on the quality of the final product is also illustrated by excessive rutting measurements for the fast lane between project chainages 4300 m and 4800 m. Additional densification of the pavement layers after construction is the suspected cause for the rutting measurements in excess of 6.0 mm. Proper compaction and moisture control techniques limit the consolidation of pavement layers under subsequent traffic.

## 6.4 12-month Assessment (2014)

The 12-month surface condition assessment was conducted in October 2014, one year after opening of the trial pavement to traffic. The methods and procedures for the assessment were identical to those observed for the post construction assessment. A summary of the surface condition assessment is provided in Table 6.2. The pavement condition had not changed significantly over the preceding 12-month period. The mean roughness and rutting values increased slightly, with significant variability both longitudinally and transversely. Similar to the post construction assessment, no cracking was observed in the pavement surface. The mean SMTD was observed to increase by approximately 6%.

Table 6.2: 12-month surface condition assessment summary

| Property | Slow lane | | Fast lane | |
|---|---|---|---|---|
| | Mean | σ | Mean | σ |
| IRI roughness (m/km) | 1.69 | 0.63 | 1.55 | 0.66 |
| Rutting (mm) | 3.7 | 0.8 | 4.7 | 1.8 |
| Cracking (m) | 0 | - | 0 | - |
| SMTD (mm) | 0.99 | 0.08 | 0.98 | 0.07 |

### *6.4.1 Roughness*

The measured IRI values collected during the post-construction (2013) and 12-month (2014) surface condition assessment are very similar, as shown in Figure 6.6 and Figure 6.7 for the slow and fast lanes respectively. Minor progression in the mean roughness can be observed as both the slow and fast lane values, presented in red, collected during the 12-month assessment plot slightly above the post construction values, presented in blue. The majority of the trial pavement could be categorised as having excellent condition (IRI < 1.8) with isolated areas categorised as mediocre (3.3 < IRI < 6.0). The high level of repeatability of the NSV can also be observed as the general trends are replicated between the surveys.

**Figure 6.6: Summary results from 12-month roughness assessment of the slow lane**

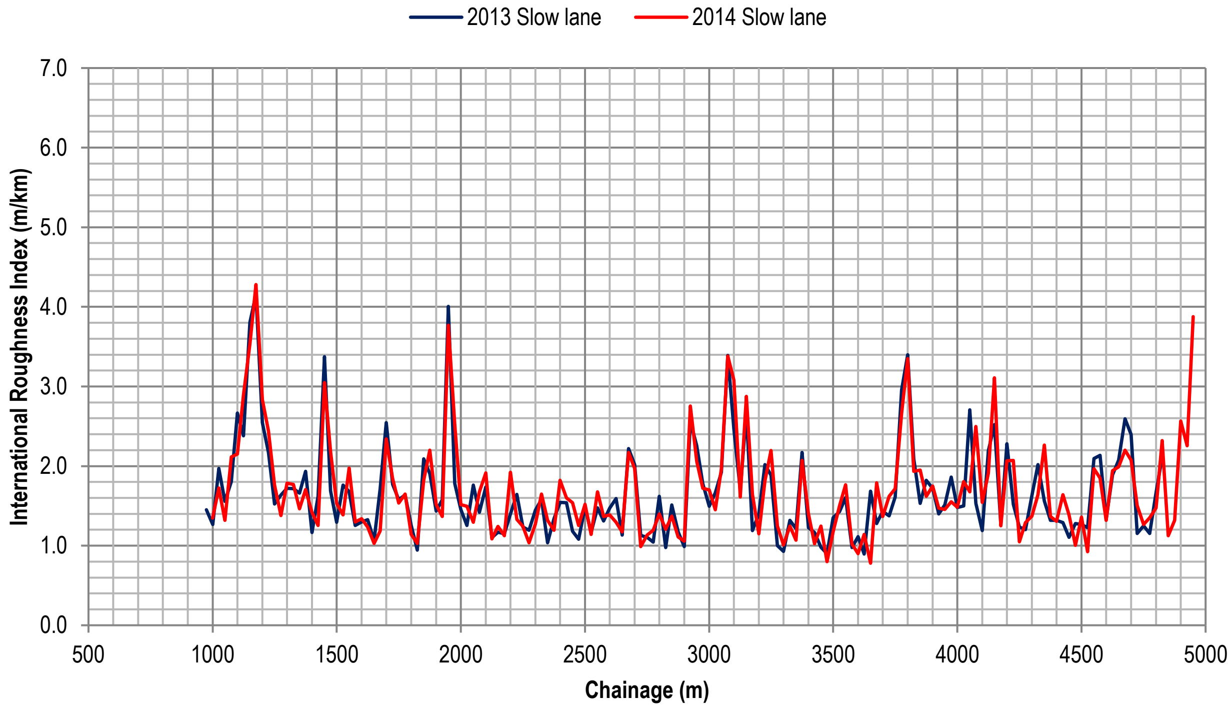
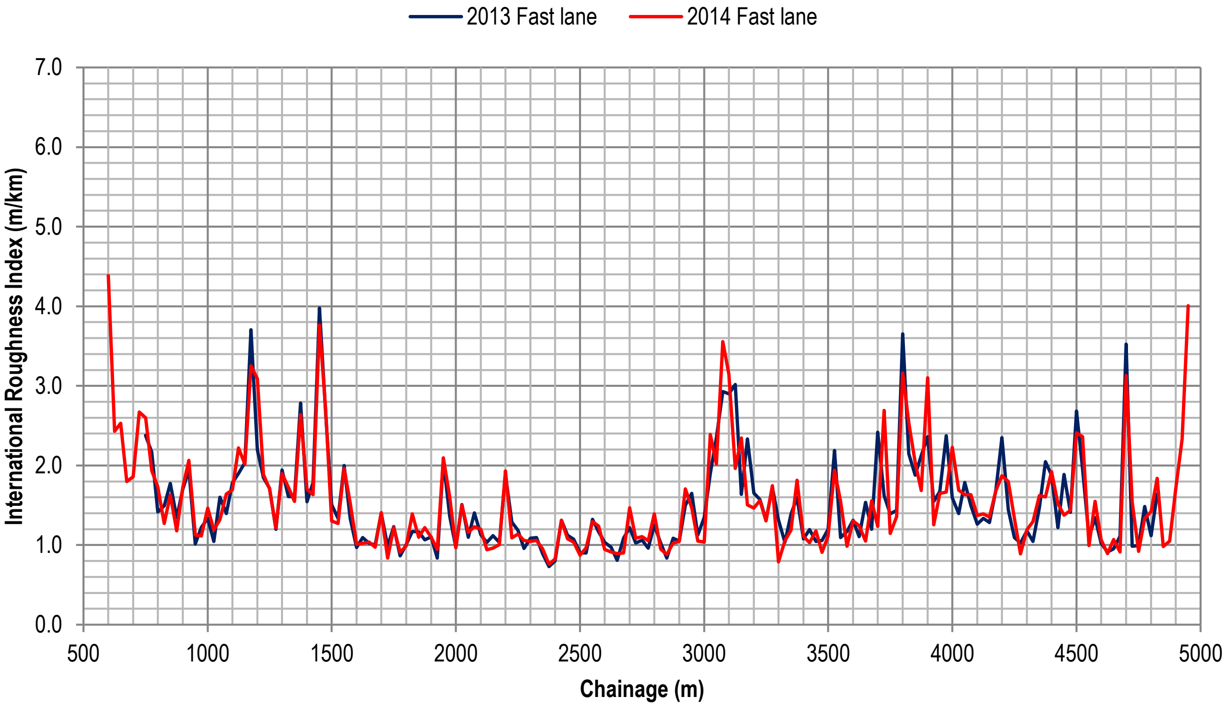


**Figure 6.7: Summary results from 12-month roughness assessment of the fast lane**




### 6.4.2 *Rutting*

The measured rutting values collected during the post-construction and 12-month surface condition assessment are very similar as shown in Figure 6.8 and Figure 6.9 for the slow and fast lanes respectively. No progression in the mean rutting was observed with the exception of between project chainages 4300 m and 4950 m. Despite the excessive rutting values measured between these chainages 4300 m and 4950 m, the remainder of the trial pavement could still be categorised as having excellent condition (rutting < 10 mm).

Figure 6.8: Summary results from 12-month rutting assessment of the slow lane

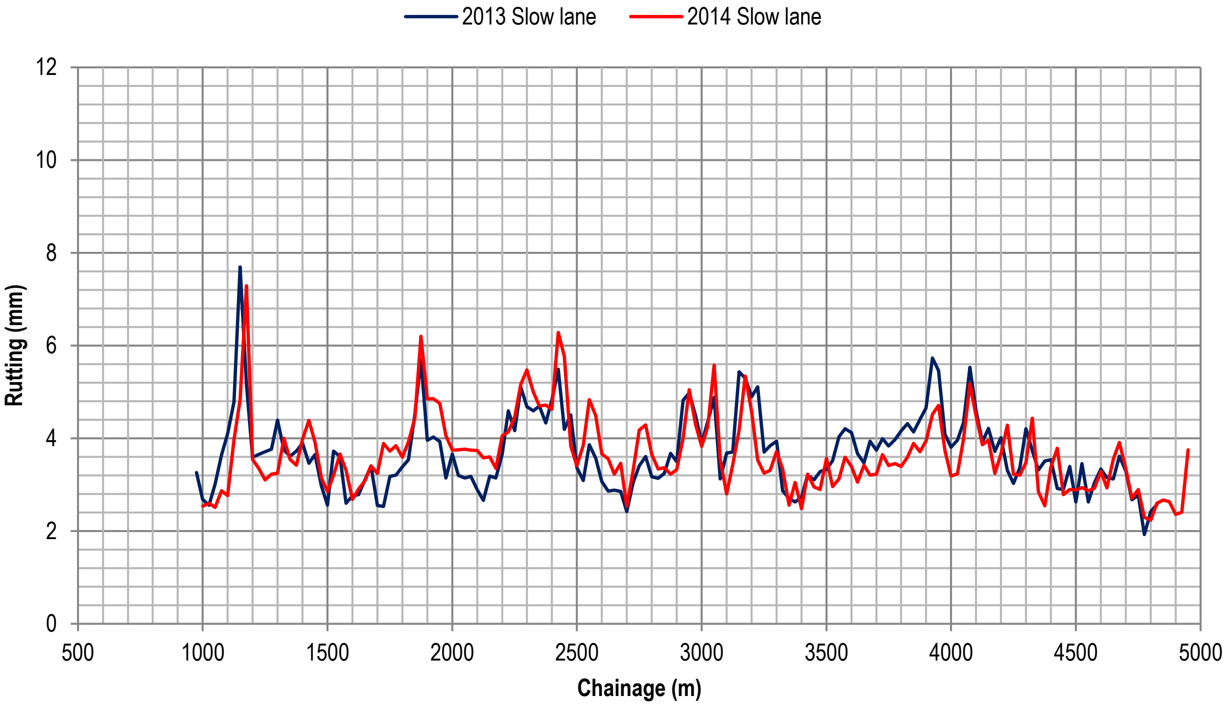
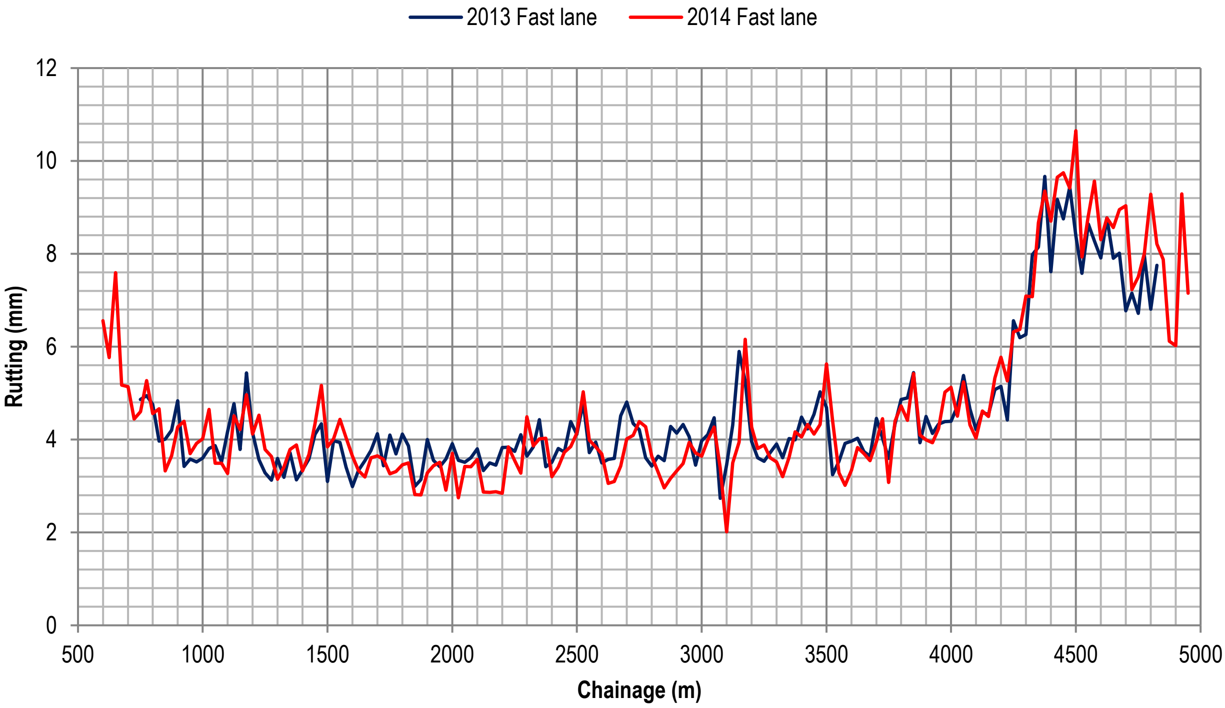



Figure 6.9: Summary results from 12-month rutting assessment of the fast lane




The excessive rutting measurements collected during the post-construction assessment between project chainages 4300 m and 4950 m have been replicated in the 12-month surface condition assessment. The mean rutting values over this section of the alignment have also increased by approximately 1.0 mm. Following the post construction assessment, the cause of the deformation was postulated to be the combination of moisture-sensitive foundation soils and moisture availability (excess compaction water) or excessive trafficking during construction. While the root cause has not yet been identified, the isolated rutting progression indicates insufficient structural capacity. The deterioration should be closely monitored and a forensic evaluation undertaken to assist in the development of rehabilitation strategies if the mean values exceed 15 mm.

### *6.4.3 Cracking*

No evidence of cracking was observed during the 12-month surface condition assessment. The occurrence of cracking will continue to be monitored in future assessments.

### *6.4.4 Texture*

The measured SMTD values collected during the post-construction and 12-month surface condition assessment are very similar, as shown in Figure 6.10 and Figure 6.11 for the slow and fast lanes respectively. A notable increase in the mean surface texture can be observed as both the slow and fast lane values, presented in red, collected during the 12-month assessment plot slightly above the post construction values, presented in blue. The SMTD was consistent both longitudinally and transversely. Additionally, the deviation between the slow and fast lane measured values between project chainages 3950 and 4800 during the post-construction surface condition assessment is no longer apparent. The entire trial pavement alignment provided minimum texture depth in excess of the Austroads (2011a) recommended criteria of 0.6 mm.

**Figure 6.10: Summary results from 12-month texture assessment of slow lane**

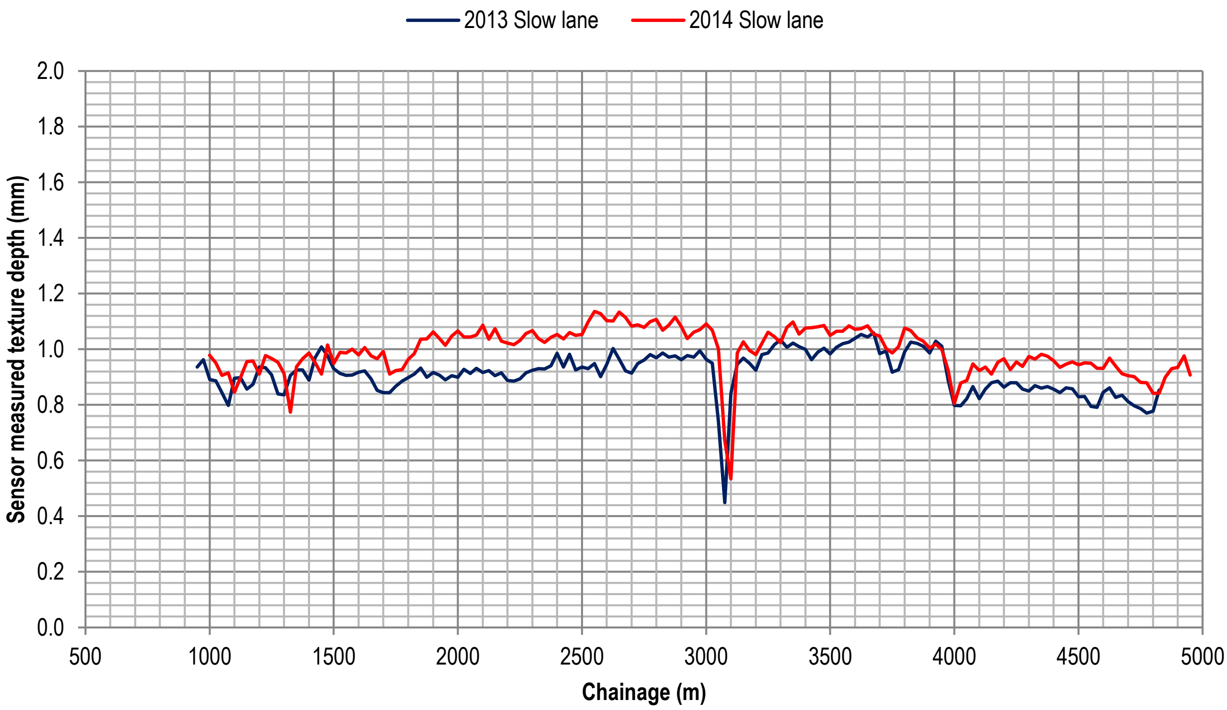
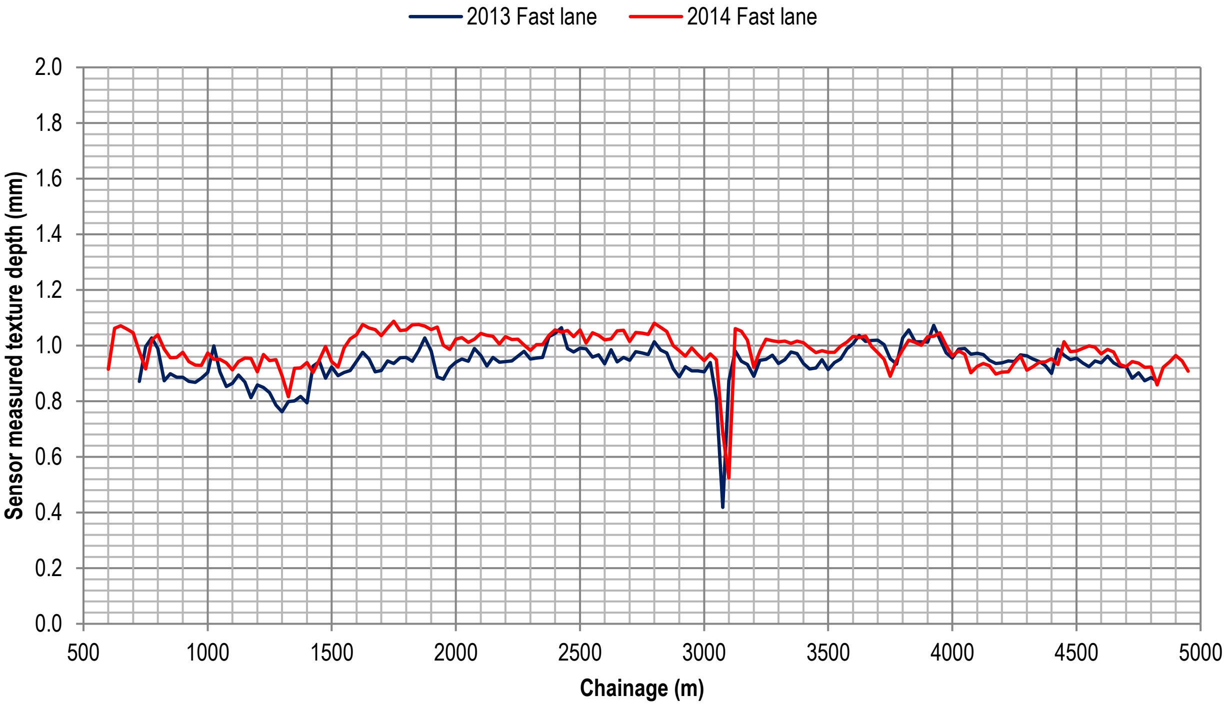


Figure 6.11: Summary results from 12-month texture assessment of fast lane




## 6.5 24-month Assessment (2015)

The 24-month surface condition assessment was conducted in October 2015, two years after the opening of the trial pavement to traffic. The methods and procedures for the assessment were identical to those observed for the post construction and 12-month assessments. A summary of the surface condition assessment is provided in Table 6.3. The pavement condition had not changed significantly over the preceding 12-month period. The mean roughness and surface texture values were consistent between the 12- and 24-month assessments. However, a slight increase in the mean rutting value (≈ 0.45 mm) can be observed, with significant variability in the individual measurements both longitudinally and transversely. The increased rutting measurements were observed in both the slow and fast traffic lanes. Similar to the post construction and 12-month assessments, no cracking was observed in the pavement surface.

Table 6.3: 24-month surface condition assessment summary

| Property | Slow lane | | Fast lane | |
|---|---|---|---|---|
| | Mean | σ | Mean | σ |
| IRI Roughness (m/km) | 1.69 | 0.59 | 1.60 | 0.78 |
| Rutting (mm) | 4.1 | 0.9 | 5.2 | 1.7 |
| Cracking (m) | 0 | - | 0 | - |
| SMTD (mm) | 0.98 | 0.08 | 1.01 | 0.10 |

### *6.5.1 Roughness*

The measured IRI values collected during the post-construction (2013) and 24-month (2015) surface condition assessment are very similar as shown in Figure 6.12 and Figure 6.13 for the slow and fast lanes respectively. While the mean values indicate a slight increase in the fast lane roughness, the individual values for both the slow (solid) and fast (dashed) lanes are consistent between the post construction (blue) and 24-month (red) assessments. The majority of the trial pavement could be categorised as having excellent condition (IRI < 1.8) with isolated areas categorised as mediocre (3.3 < IRI < 6.0). The high level of repeatability of the NSV can also be observed as the general trends are replicated between the surveys.

**Figure 6.12: Summary results from 24-month roughness assessment of slow lane**

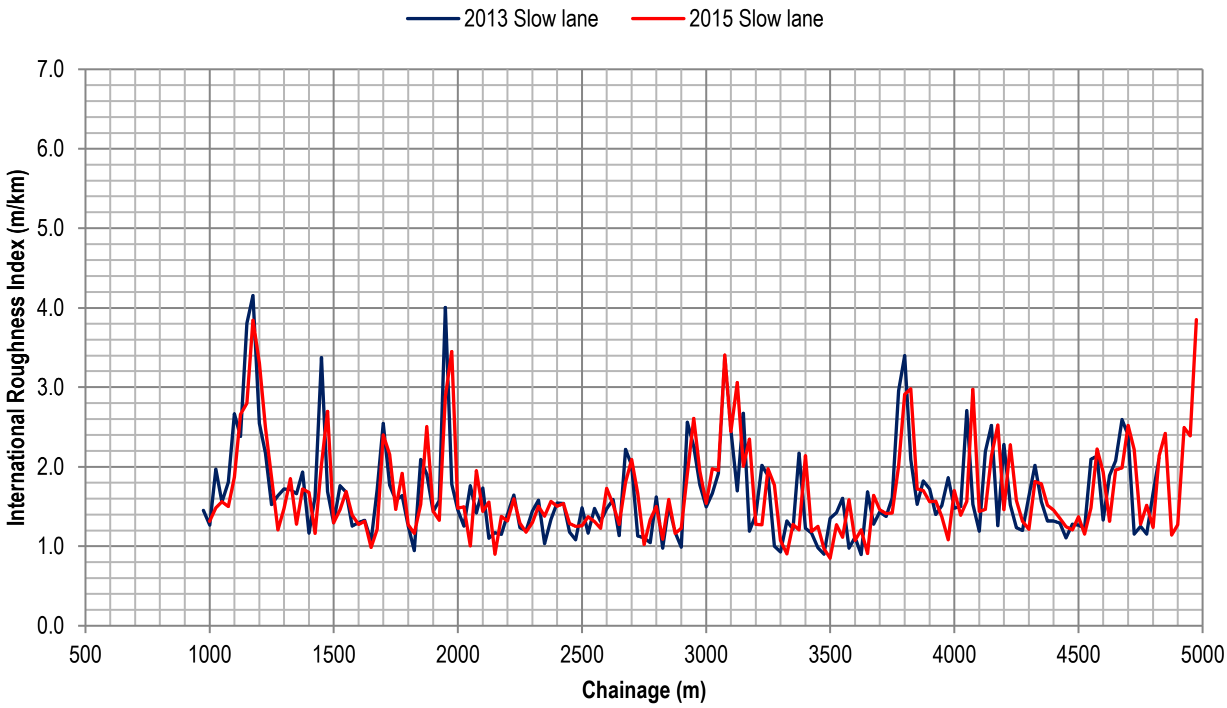
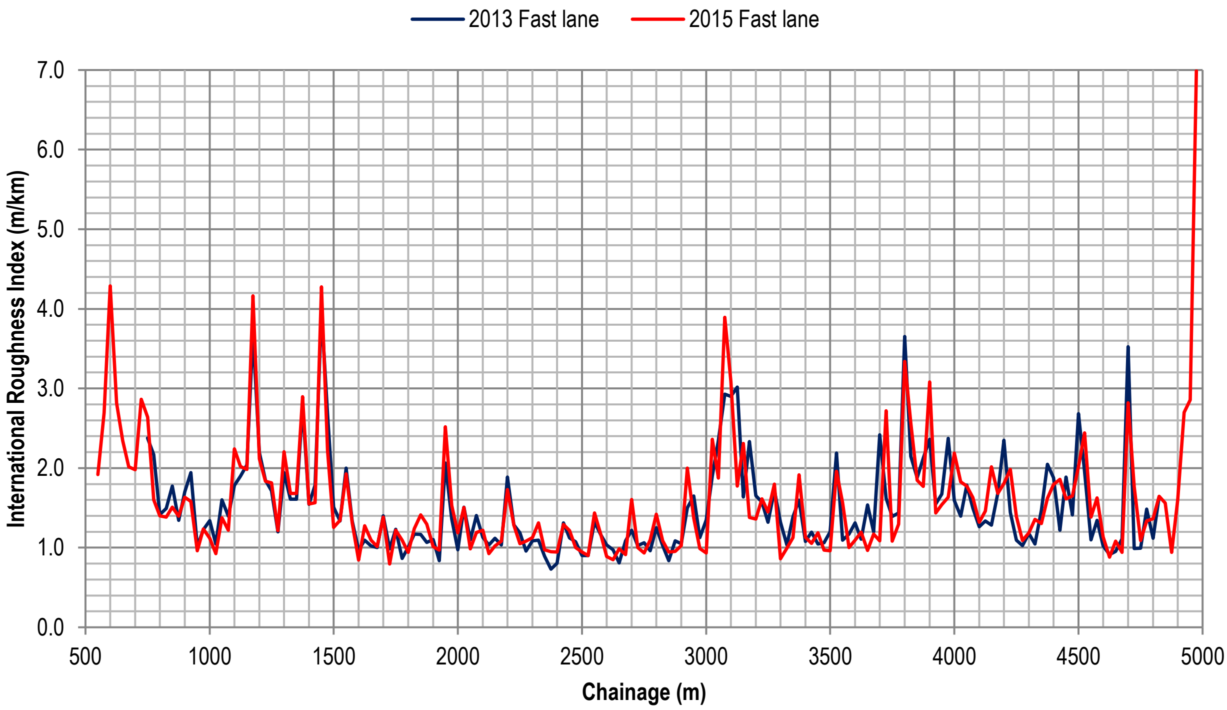



**Figure 6.13: Summary results from 24-month roughness assessment of fast lane**



### 6.5.2 Rutting

The measured rutting values collected during the post-construction and 24-month surface condition assessment are very similar as shown in Figure 6.14 and Figure 6.15 for the slow and fast lanes respectively. A slight increase in the individual measurements of maximum rutting for both the slow (solid) and fast (dashed) lanes can be observed between the post construction (blue) and 24 month (red) assessments. Almost the entire trial pavement section can be categorised as having excellent condition (rutting < 10 mm), with the exception of an isolated area of the fast lane between chainage 4350 m and 4550 m that would be categorised as mediocre (10 mm < rutting < 20 mm).

**Figure 6.14: Summary results from 24-month rutting assessment of slow lane**

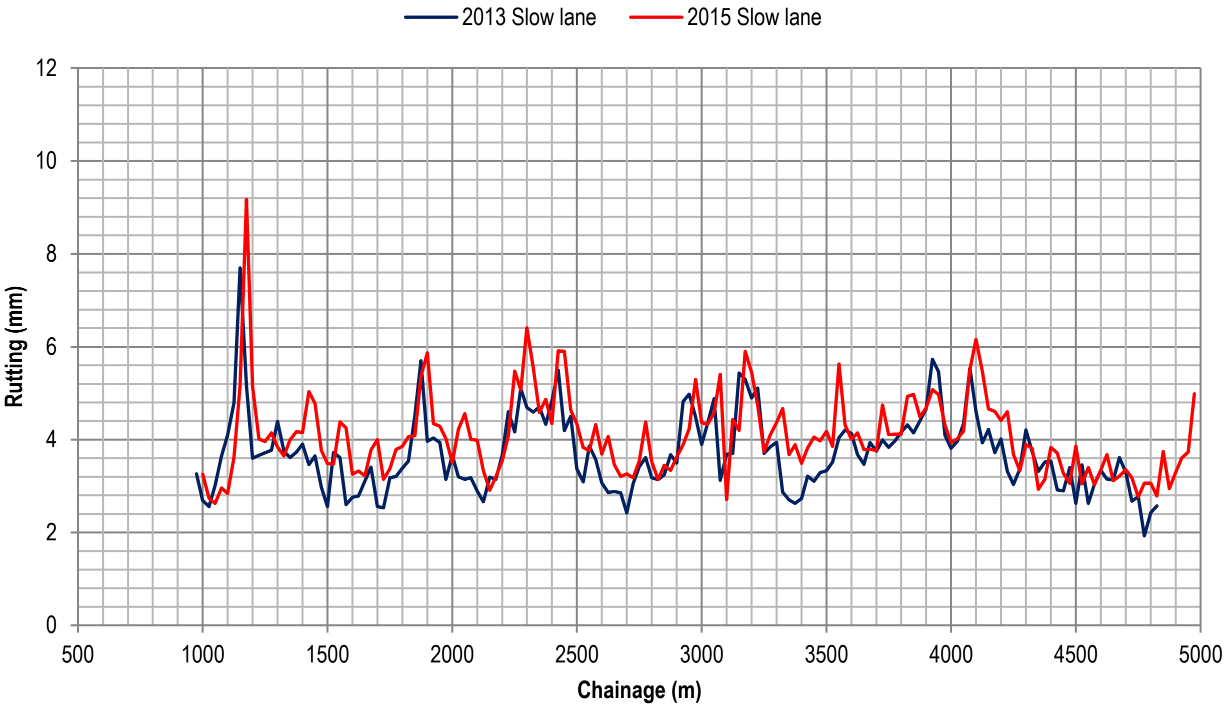
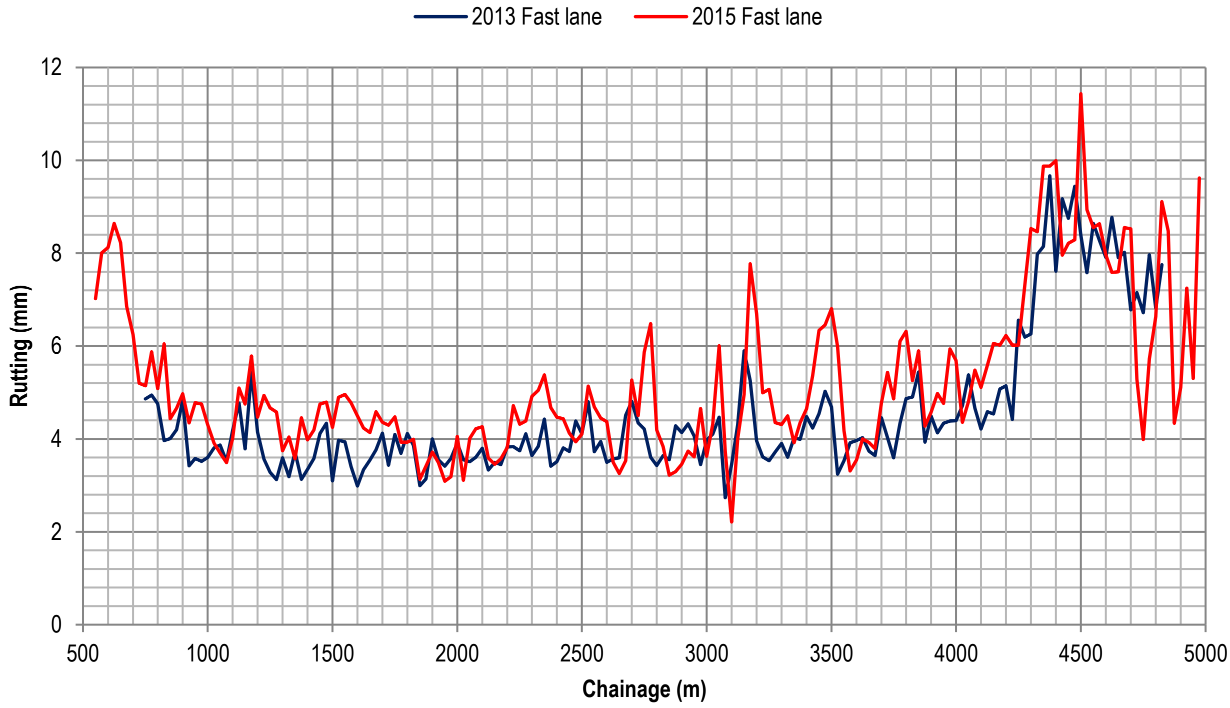


**Figure 6.15: Summary results from 24-month rutting assessment of fast lane**




The excessive rutting measurements collected during the post-construction assessment between project chainages 4300 m and 4800 m have been replicated in the 24-month surface condition assessment. The mean rutting values over this section of the alignment have increased by approximately 0.20 mm, which is less than the relative increase of approximately 0.45 mm for the total trial section. The reduced relative rutting rate supports the hypothesis that the excessive deformation is the result of poor construction practice (inadequate compaction) and the section is nearing a densification equilibrium state. However, intervention may still be required should the mean rutting values in the section exceed 15 mm.

### 6.5.3 Cracking

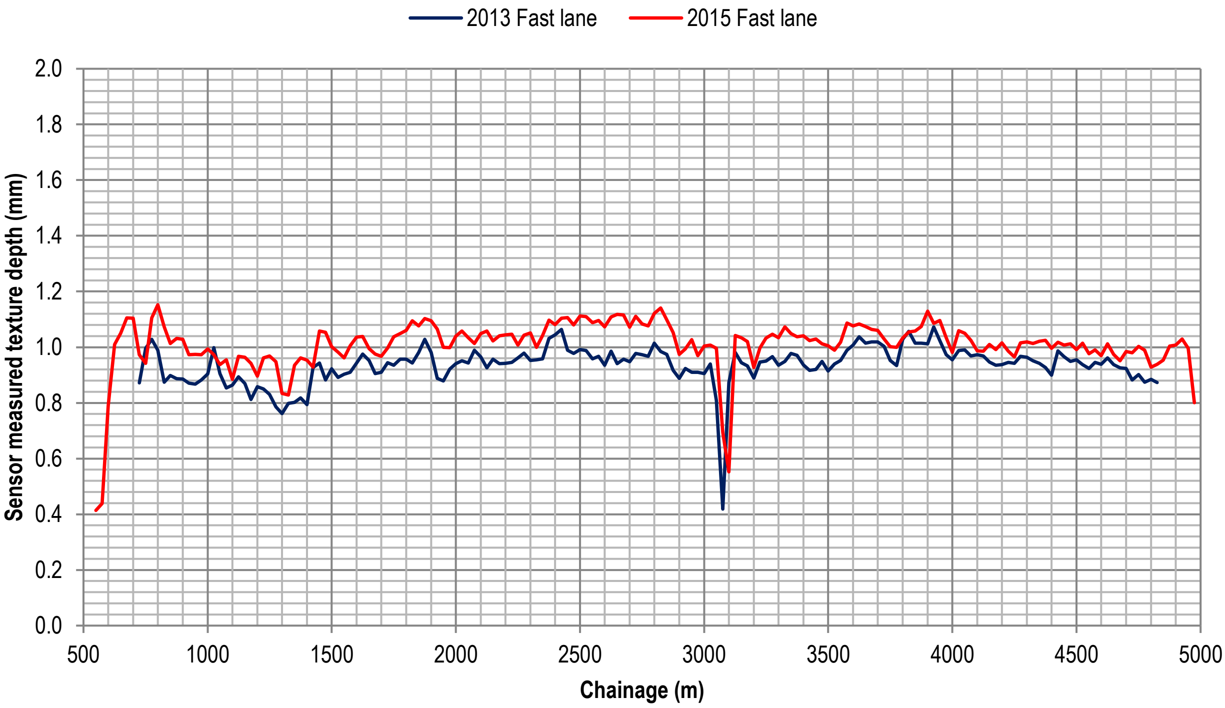
No evidence of cracking was observed during the 24-month surface condition assessment. The occurrence of cracking will continue to be monitored in future assessments.

### 6.5.4 Texture

The measured SMTD values collected during the post-construction and 24-month surface condition assessment are very similar as shown in Figure 6.16 and Figure 6.17 for the slow and fast lanes respectively. A slight increase in the mean surface texture can be observed as both the slow and fast lane values, solid and dashed red lines respectively, collected during the 24-month assessment plot slightly above the post construction values (solid and dashed blue lines). The SMTD was consistent both longitudinally and transversely. The entire trial pavement alignment provided minimum texture depth in excess of the Austroads (2011a) recommended criteria of 0.6 mm for highways with travel speeds in excess of 80 km/h.

**Figure 6.16: Summary results from 24-month texture assessment of slow lane**


**Figure 6.17: Summary results from 24-month texture assessment of fast lane**



## 6.6 36-month Assessment (2016)

A surface condition assessment was conducted in October 2016, three years after the opening of the trial pavement to traffic. The methods and procedures for the assessment were identical to those observed for the post construction and the previous 12-month and 24-month assessments. A summary of the surface condition assessment is provided in Table 6.4. There were decreases in rutting values observed in the fast lane between Chainage 4450 to Chainage 4750. However, a visual assessment done during the site inspection could not confirm the decrease in rutting. This anomaly maybe caused by the inaccuracy of the equipment or the specific geometrics of the fast lane. Pavement history also confirmed that no repair or rehabilitation was conducted on that part of the road. The pavement condition had not changed significantly over the preceding 12-month period.

**Table 6.4: 36-month surface condition assessment summary**

| Property | Slow lane | | Fast lane | |
|---|---|---|---|---|
| | Mean | σ | Mean | σ |
| IRI Roughness (m/km) | 2.03 | 0.74 | 1.90 | 0.80 |
| Rutting (mm) | 4.4 | 1.0 | 4.8 | 1.7 |
| SMTD (mm) | 0.95 | 0.10 | 0.98 | 0.08 |

### *6.6.1 Roughness*

The measured IRI values collected after 36-month (2016) were higher than the previous measurements as shown in Figure 6.18 and Figure 6.19 for the slow and fast lanes respectively. For instance, the mean slow lane IRI value increased from 1.69 m/km in 2015 to 2.03 m/km in 2017. 43% sections of the slow lane and 54% sections of the fast lane have IRI < 1.8. between 1 - 2% sections in both lanes have IRI in excess of 5.0.

Figure 6.18: Summary results from 36-month roughness assessment of slow lane

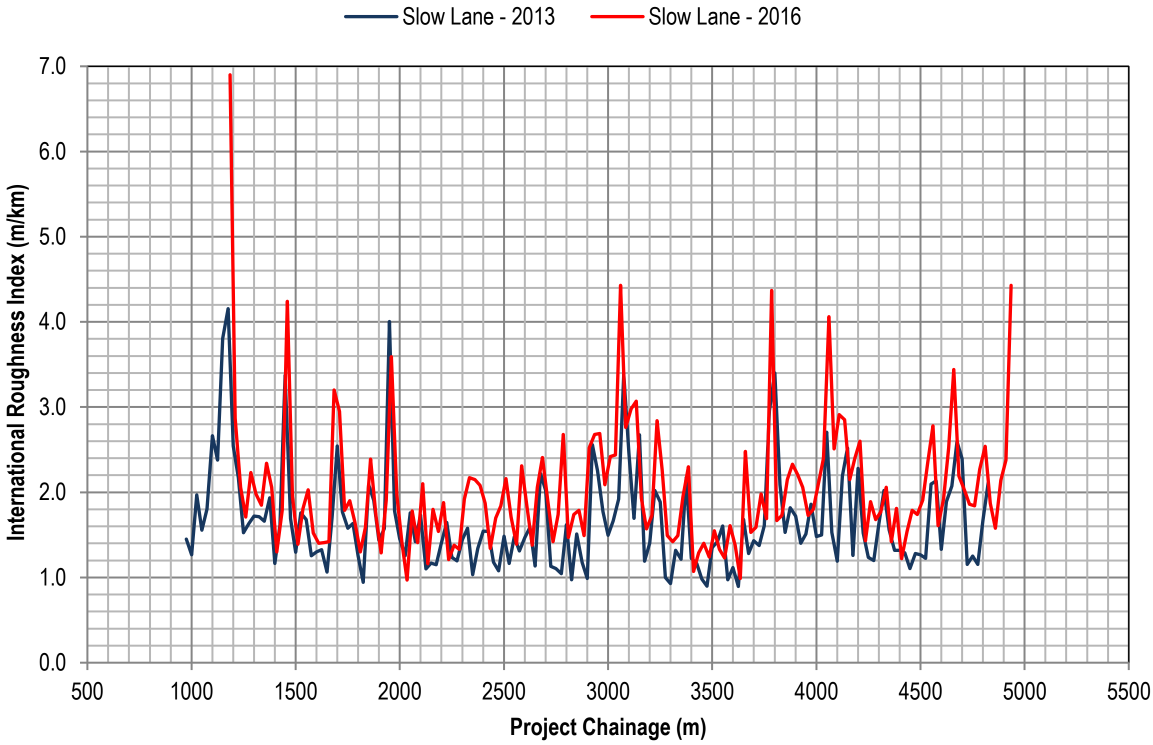
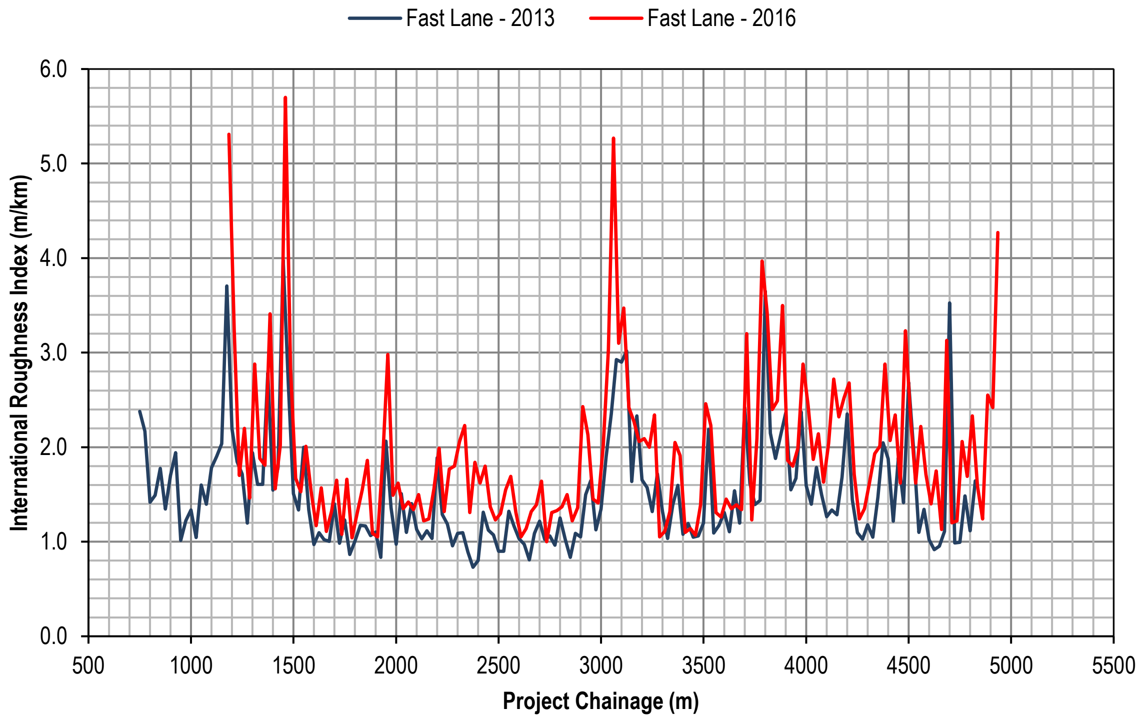



Figure 6.19: Summary results from 36-month roughness assessment of fast lane



### 6.6.2 Rutting

The measured rutting values collected during the post-construction and 36-month surface condition assessment are very similar as shown in Figure 6.20 and Figure 6.21 for the slow and fast lanes respectively. A slight increase in the individual measurements of maximum rutting for both the slow and fast lanes can be observed between the post construction (blue) and 36-month (red) assessments. The entire trial pavement performs well with rutting less than 10 mm.

For the fast lane, the post-construction rutting (Year 2013) between chainage 4300 m and 4800 m were reported to be higher than the rest of the trial pavement site. This area has been flagged as performing poorly immediately after construction (prior to trafficking). Even though the 36-month rutting reading over this area reports a sudden decrease, this is not believed to be reflecting the condition of the pavement because the project team cannot identify any repair or maintenance work that has been undertaken to explain the decrease in measured rutting. Surface condition testing in future years should validate this finding.

**Figure 6.20: Summary results from 36-month rutting assessment of slow lane**

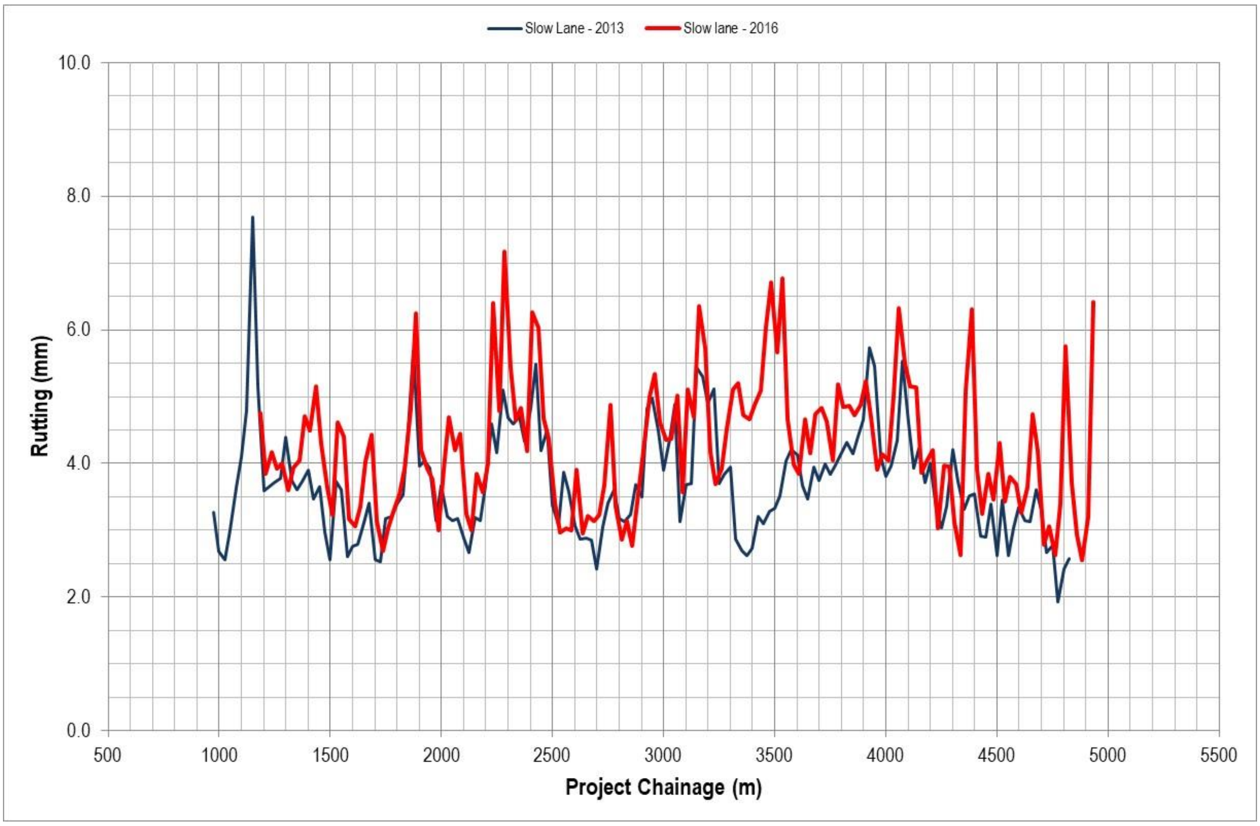
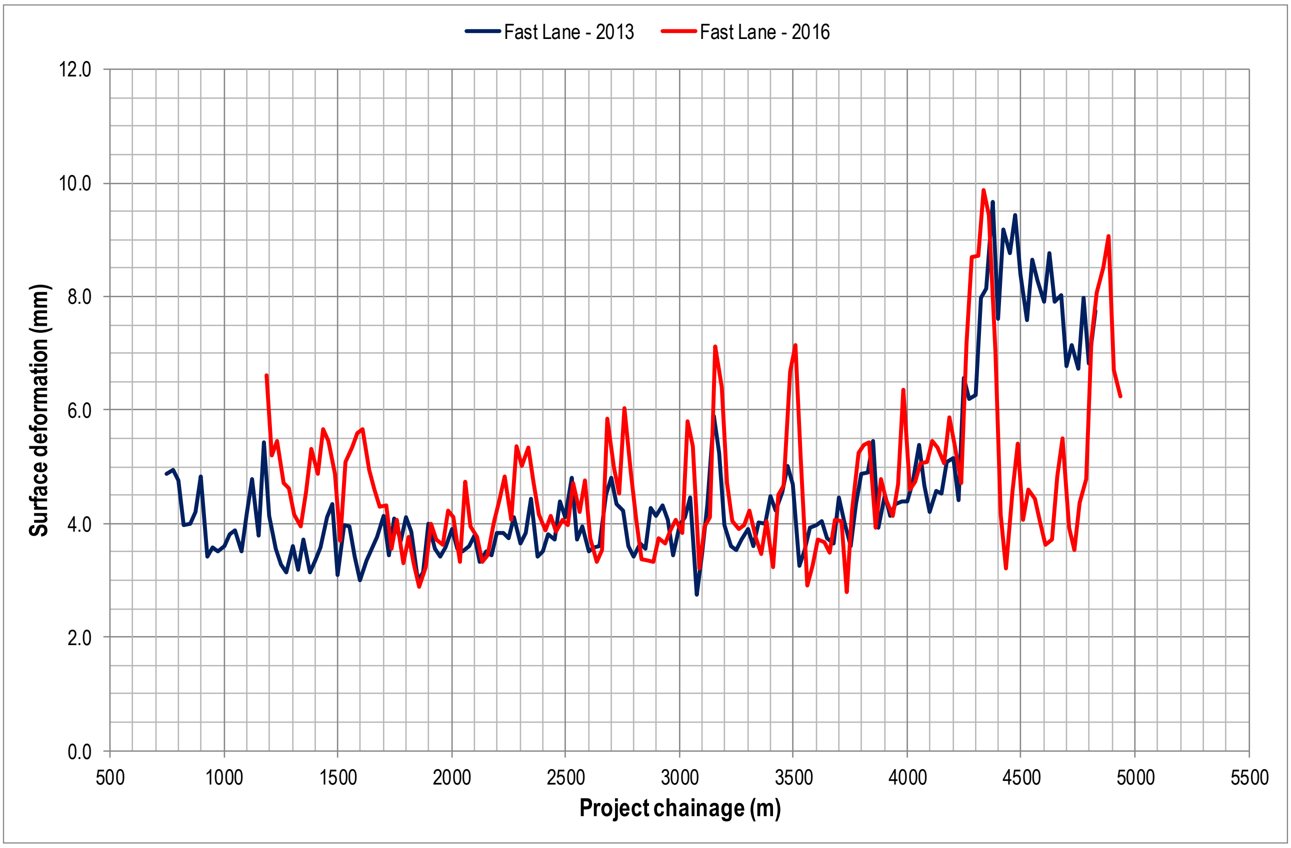


Figure 6.21: Summary results from 36-month rutting assessment of fast lane




### 6.6.3 Texture

The measured SMTD values collected during the post-construction and 36-month surface condition assessment are very similar as shown in Figure 6.22 and Figure 6.23 for the slow and fast lanes respectively. A slight decrease in the mean surface texture can be observed in both the slow and lanes (solid red line). The SMTD was consistent both longitudinally and transversely and does not show noticeable difference between the slow and fast lane. The entire trial pavement (except a localised transient reading near chainage 3100 m) provided minimum texture depth in excess of the Austroads (2011a) recommended criteria of 0.6 mm for highways with travel speeds in excess of 80 km/h.

**Figure 6.22: Summary results from 36-month texture assessment of slow lane**

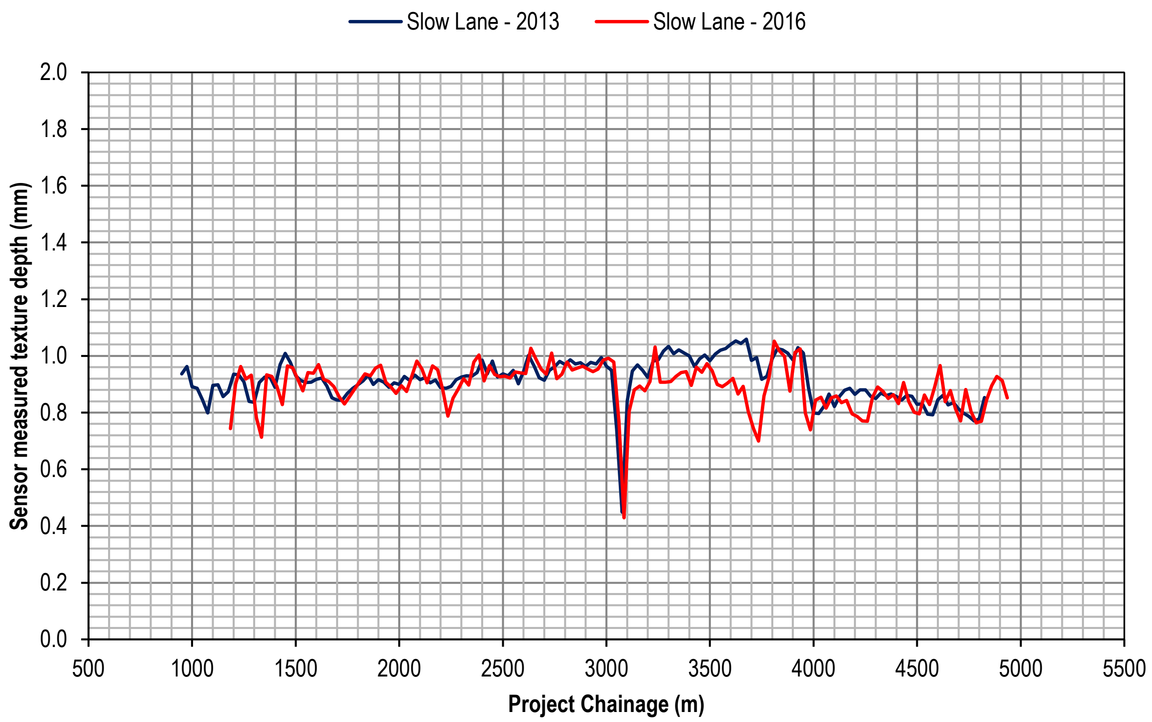
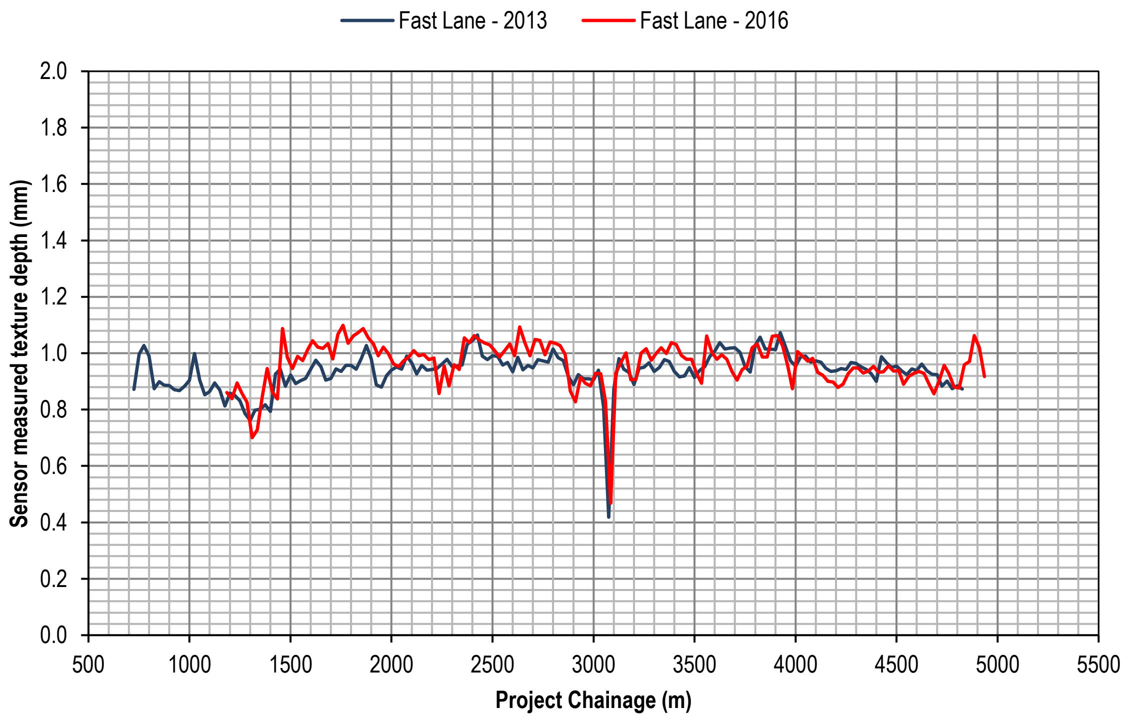



**Figure 6.23: Summary results from 36-month texture assessment of fast lane**



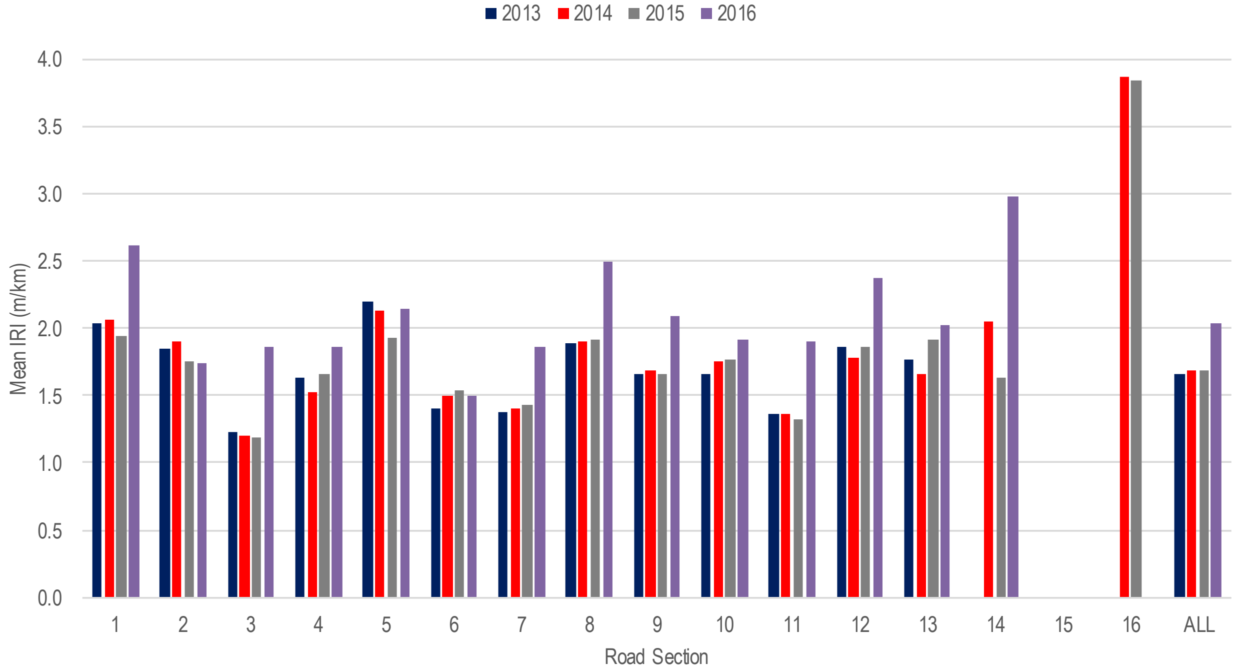
## 6.7 Surface Condition Progression

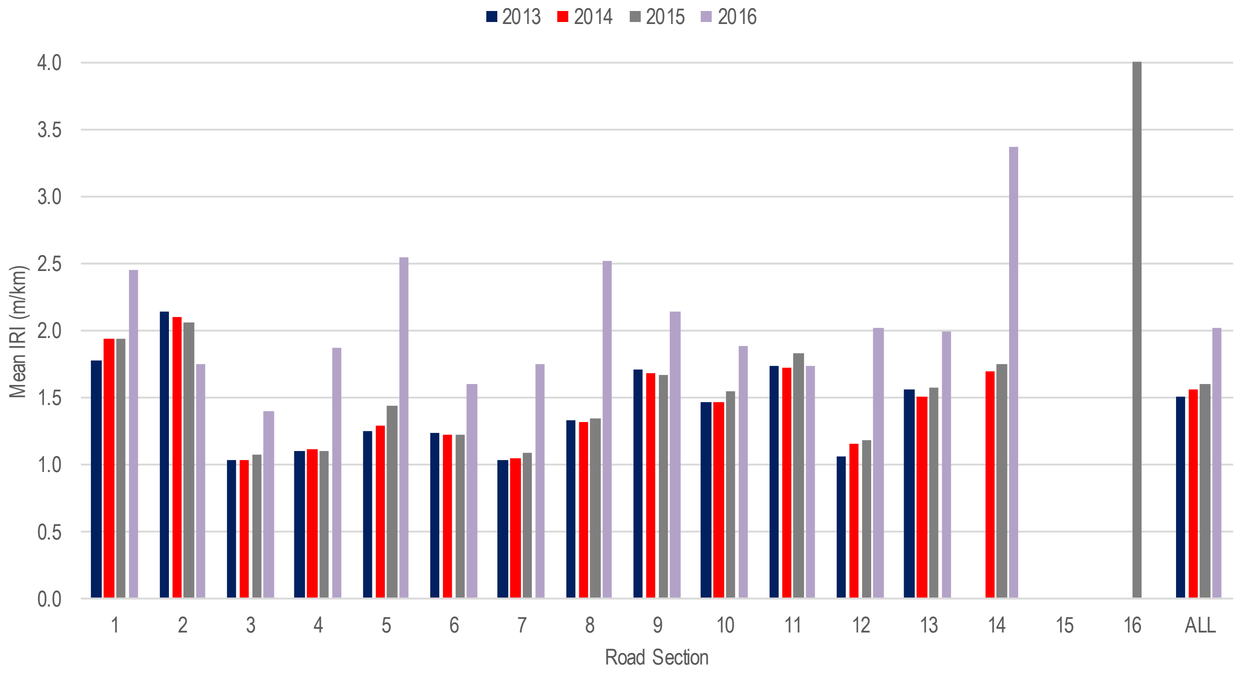
In addition to conducting annual assessments of roughness, rutting and surface texture, the relative change or progression in surface condition was evaluated to enable predictions of long-term performance. The mean roughness, rutting and surface texture values for each of the sixteen structural sections along the project site (Table 4.1) were compared year-over-year to examine the relative change in surface condition. Additionally, the as-constructed, 12-month, 24-month and 36 month assessment values for each section were referenced to calculate the relative change or progression rate for roughness, rutting and surface texture. A linear trend was used to develop the progression rate estimate.

### *6.7.1 Roughness*

The mean roughness values (IRI) for the sixteen structural sections measured in 2013, 2014 and 2015 are presented in Figure 6.24. There is an increase in IRI in 2016 in both the slow and fast lane. In particular, the yearly increase in IRI is more significant in the fast lane than the slow lane.

Figure 6.24: Mean roughness values for slow (top) and fast (bottom) lane by assessment year



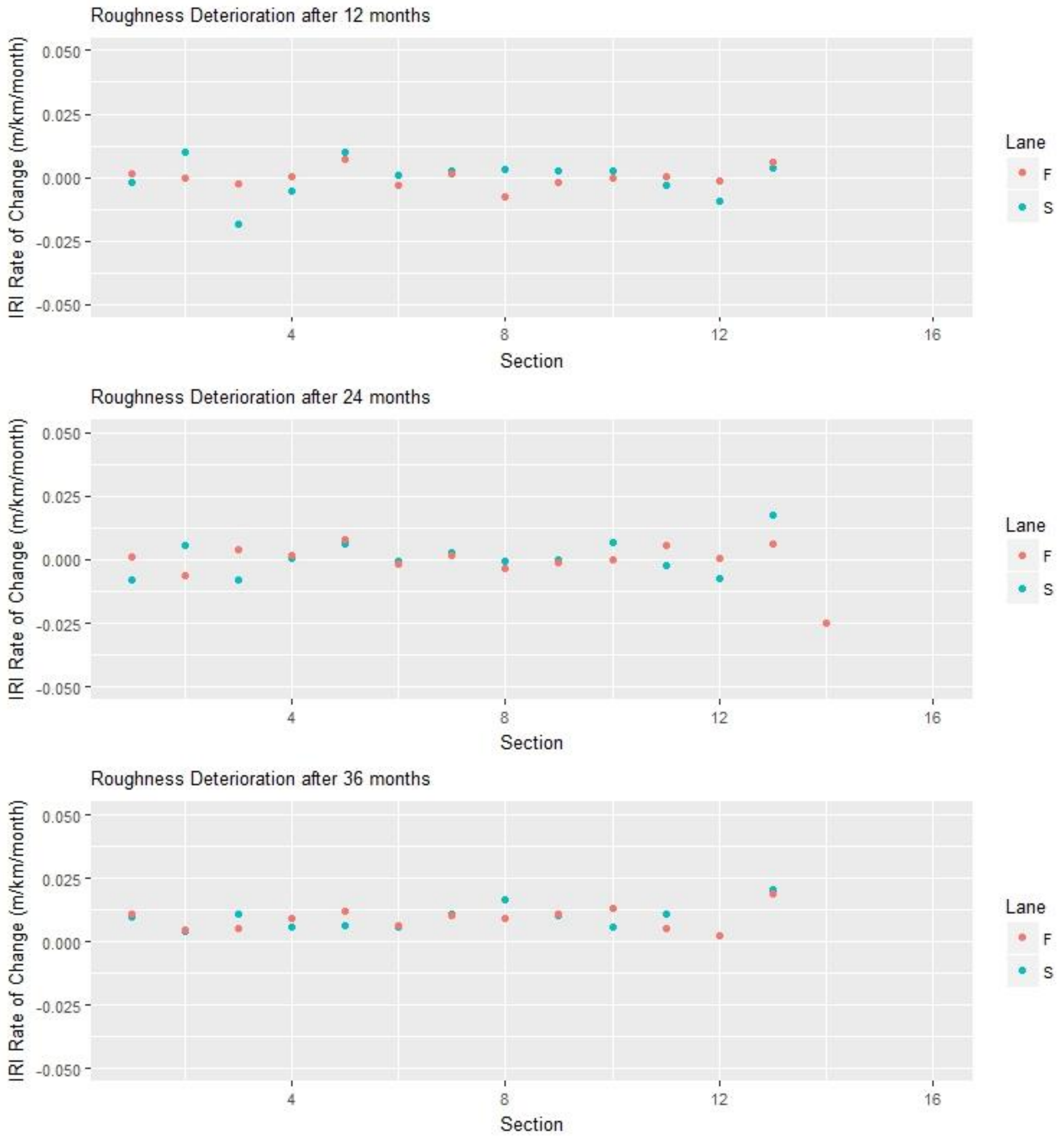

The relative linear progression rates, presented in IRI per month, are shown in Table 6.5, and the same linear progression rates are plotted in Figure 6.27. The rate of change in IRI per month is similar across the slow and fast lane. However, the average rate of change shows a fast increase between 0 – 36 months when compared against the previous reporting years (i.e. 0 – 12 months and 0 – 24 months).

**Table 6.5: Mean roughness relative linear progression rates**

| Road section | Start chainage (m) | End chainage (m) | Δ IRI (m/km/month) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Left (slow) lane | | | Right (fast) lane | | |
| | | | *0-12 months* | *0-24 months* | *0-36 months* | *0-12 months* | *0-24 months* | *0-36 months* |
| 1 | 575 | 1465 | -0.002 | -0.008 | 0.010 | 0.001 | 0.001 | 0.011 |
| 2 | 1465 | 1608 | 0.010 | 0.006 | 0.004 | 0.000 | -0.006 | 0.005 |
| 3 | 1608 | 1692 | -0.018 | -0.008 | 0.011 | -0.002 | 0.004 | 0.005 |
| 4 | 1692 | 1855 | -0.006 | 0.000 | 0.006 | 0.000 | 0.002 | 0.009 |
| 5 | 1855 | 1995 | 0.010 | 0.006 | 0.006 | 0.007 | 0.008 | 0.012 |
| 6 | 1995 | 2307 | 0.001 | 0.000 | 0.006 | -0.003 | -0.002 | 0.006 |
| 7 | 2307 | 2905 | 0.003 | 0.003 | 0.011 | 0.001 | 0.002 | 0.010 |
| 8 | 2905 | 3005 | 0.003 | -0.001 | 0.017 | -0.007 | -0.003 | 0.009 |
| 9 | 3005 | 4155 | 0.003 | 0.000 | 0.010 | -0.002 | -0.001 | 0.011 |
| 10 | 4155 | 4405 | 0.003 | 0.007 | 0.006 | 0.000 | 0.000 | 0.013 |
| 11 | 4405 | 4580 | -0.003 | -0.002 | 0.011 | 0.001 | 0.006 | 0.005 |
| 12 | 4580 | 4680 | -0.009 | -0.007 | 0.003 | -0.001 | 0.000 | 0.002 |
| 13 | 4680 | 4880 | 0.004 | 0.018 | 0.021 | 0.006 | 0.006 | 0.019 |
| 14 | 4880 | 4955 | - | -0.071 | - | - | -0.025 | - |
| 15 | 4955 | 4975 | - | - | - | - | - | - |
| 16 | 4975 | 5155 | - | - | - | - | - | - |
| ALL | 575 | 5155 | 0.001 | 0.010 | 0.010 | 0.000 | 0.000 | 0.011 |

Average roughness deterioration rate for different period is shown in Figure 6.25.

**Figure 6.25: Average roughness deterioration rate between 0-12 months, 0-24 months and 0-36 months**

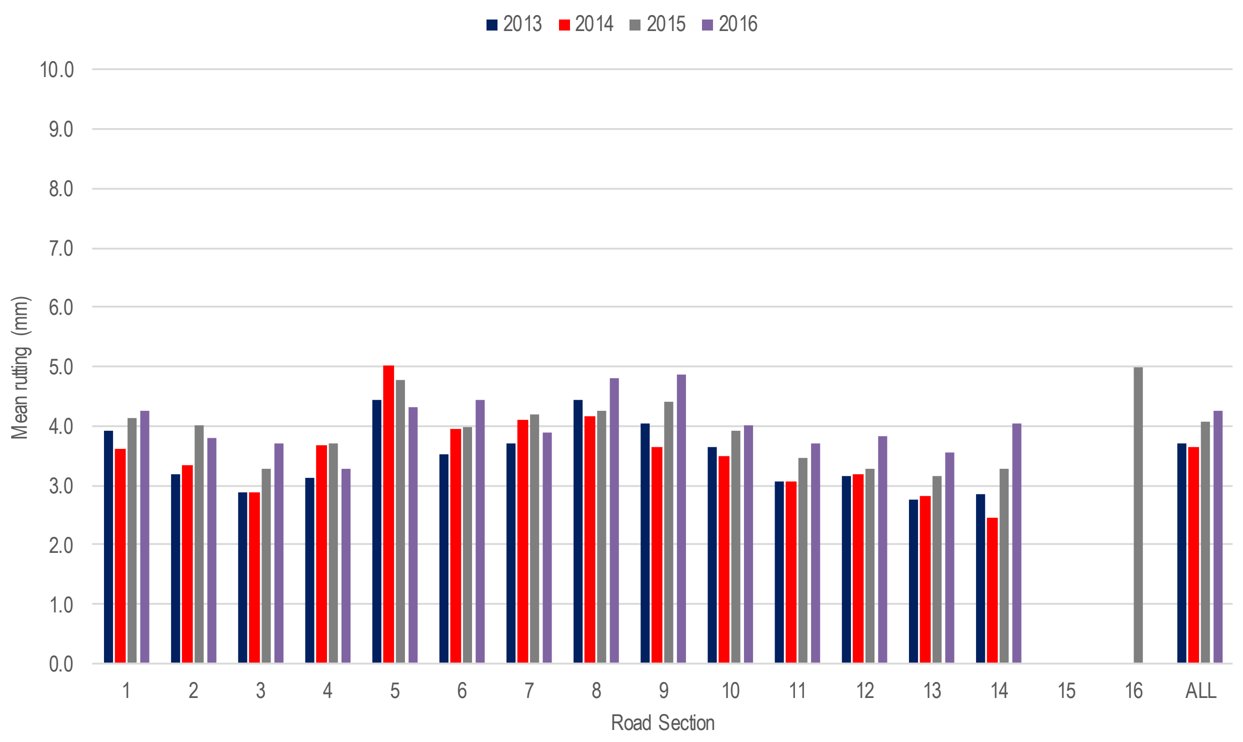


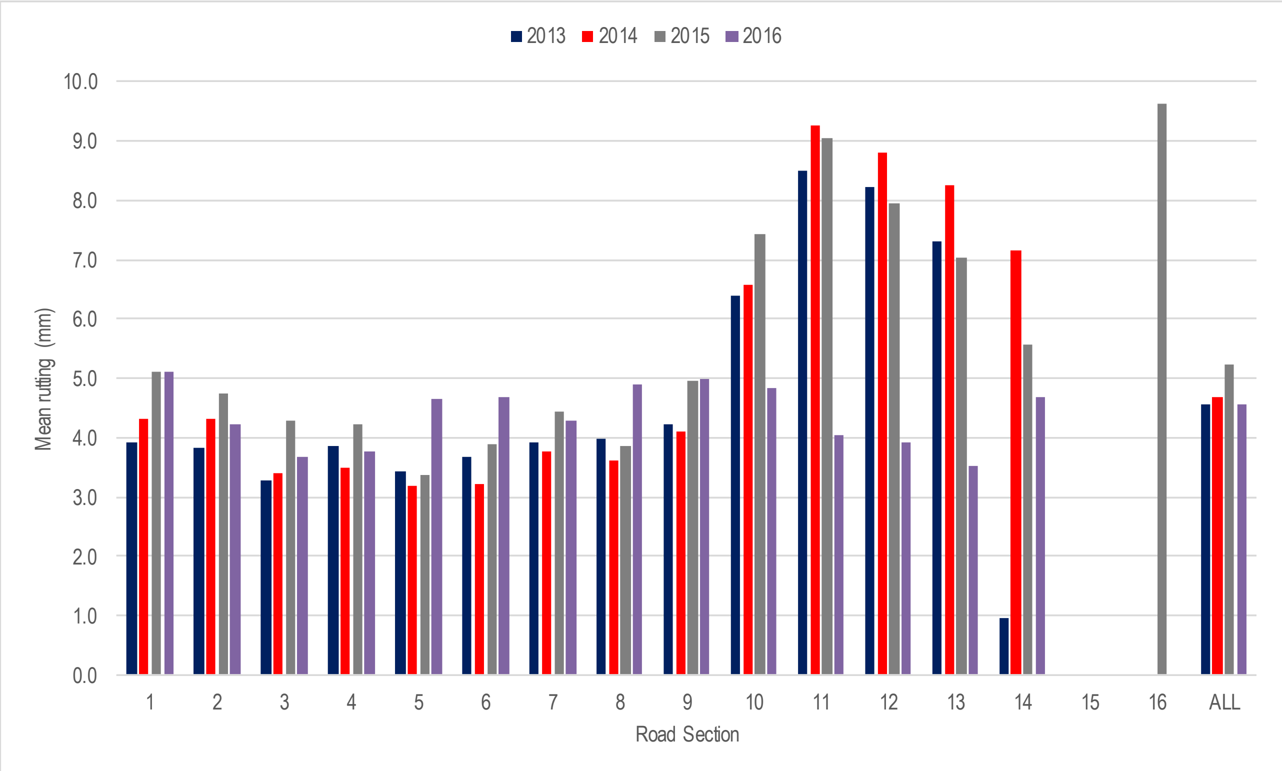

Note: F = Fast Lane; S = Slow Lane

### 6.7.2 Rutting

The mean rutting values for the sixteen structural sections measured in 2013, 2014 and 2015 are presented in Figure 6.26. There is a slight increase in mean rutting across all reported road sections in the slow lane. The increase in mean rutting is considered low for a 3 years old pavement. However, for the fast lane, the rutting trend measured this year shows a slight decrease in rutting between road sections 1 – 10. The decrease is small but the project team cannot explain the reason behind the reduction in rutting. One possible reason can be due to a shift in the driving line during data collection. Condition survey in future years should validate these observations.

**Figure 6.26: Mean rutting values for slow (top) and fast (bottom) lane by assessment year**



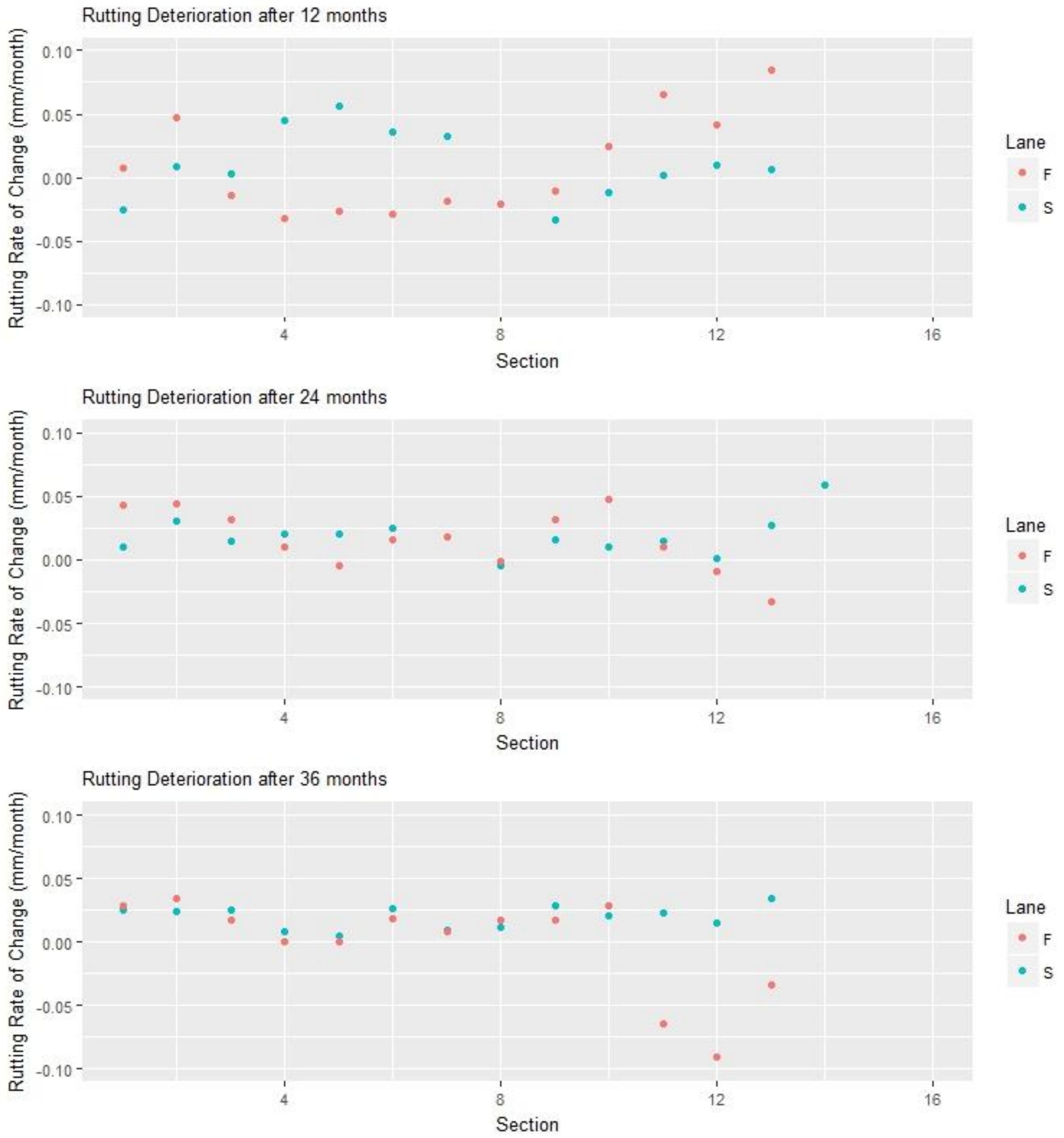

Note: Sections 10 – 14 reported a decrease in the mean rutting in the fast lane. The reasons were explained in Section 6.5.2.

The relative linear progression rates, presented in millimetres per month, are shown in Table 6.6. The same dataset is plotted in Figure 6.27. The difference in rutting progression rates was large across the fast and slow lane between 0 – 12 months after construction. However, subsequent reporting period indicates similar linear progression rates across the lanes and the rate is similar between 0 – 24 months and 0 – 36 months, as presented in this reporting period.

**Table 6.6: Mean rut depth (mm) relative linear progression rates**

| Road section | Start chainage (m) | End chainage (m) | Δ Rutting (mm/month) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Left (slow) lane | | | Right (fast) lane | | |
| | | | *0-12 months* | *0-24 months* | *0-36 months* | *0-12 months* | *0-24 months* | *0-36 months* |
| 1 | 575 | 1465 | -0.025 | 0.010 | 0.025 | 0.008 | 0.043 | 0.028 |
| 2 | 1465 | 1608 | 0.009 | 0.030 | 0.025 | 0.047 | 0.045 | 0.034 |
| 3 | 1608 | 1692 | 0.003 | 0.014 | 0.025 | -0.014 | 0.032 | 0.018 |
| 4 | 1692 | 1855 | 0.045 | 0.020 | 0.008 | -0.033 | 0.011 | 0.000 |
| 5 | 1855 | 1995 | 0.056 | 0.021 | 0.005 | -0.027 | -0.004 | 0.000 |
| 6 | 1995 | 2307 | 0.036 | 0.025 | 0.026 | -0.029 | 0.016 | 0.019 |
| 7 | 2307 | 2905 | 0.032 | 0.018 | 0.010 | -0.019 | 0.018 | 0.008 |
| 8 | 2905 | 3005 | -0.021 | -0.004 | 0.012 | -0.021 | -0.002 | 0.018 |
| 9 | 3005 | 4155 | -0.033 | 0.016 | 0.029 | -0.011 | 0.032 | 0.017 |
| 10 | 4155 | 4405 | -0.012 | 0.010 | 0.021 | 0.024 | 0.047 | 0.028 |
| 11 | 4405 | 4580 | 0.001 | 0.014 | 0.023 | 0.066 | 0.011 | -0.064 |
| 12 | 4580 | 4680 | 0.009 | 0.001 | 0.016 | 0.042 | -0.009 | -0.090 |
| 13 | 4680 | 4880 | 0.006 | 0.028 | 0.034 | 0.085 | -0.033 | -0.034 |
| 14 | 4880 | 4955 | - | 0.058 | - | - | -0.133 | - |
| 15 | 4955 | 4975 | - | - | - | - | - | - |
| 16 | 4975 | 5155 | - | - | - | - | - | - |
| ALL | 575 | 5155 | -0.001 | 0.017 | 0.023 | 0.000 | 0.022 | 0.006 |

**Figure 6.27: Average rutting deterioration rate between 0-12 months, 0-24 months and 0-36 months**

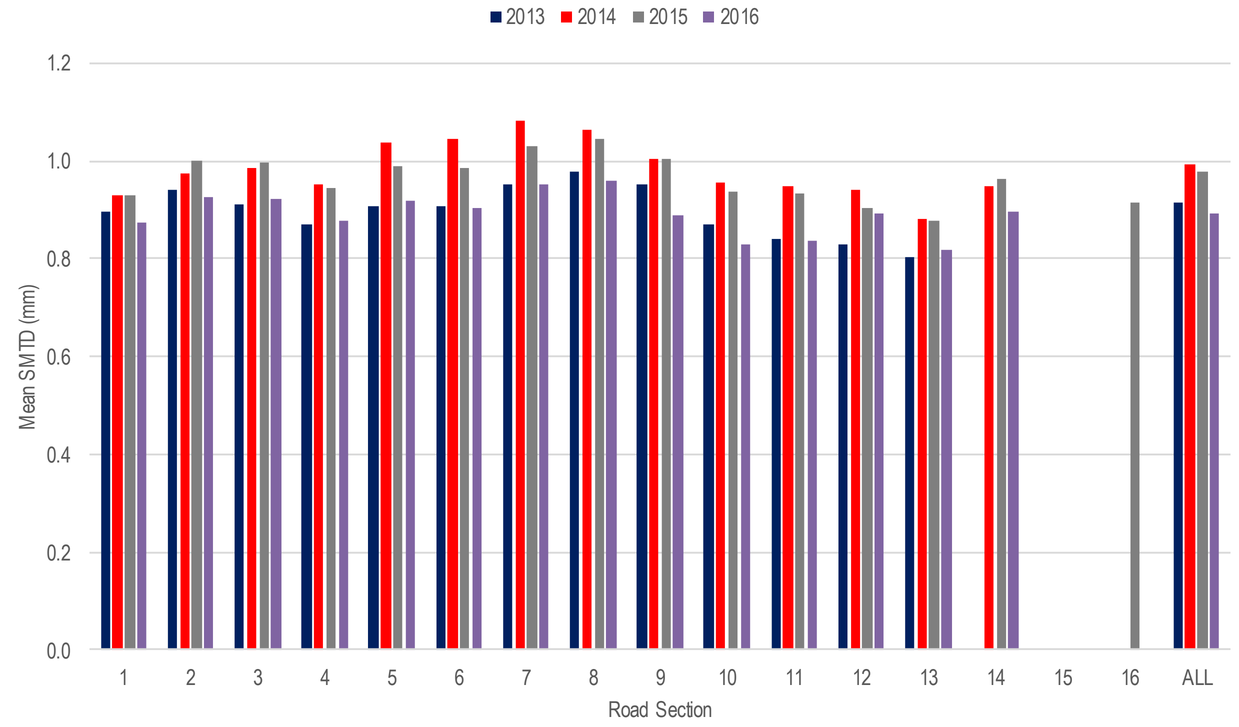


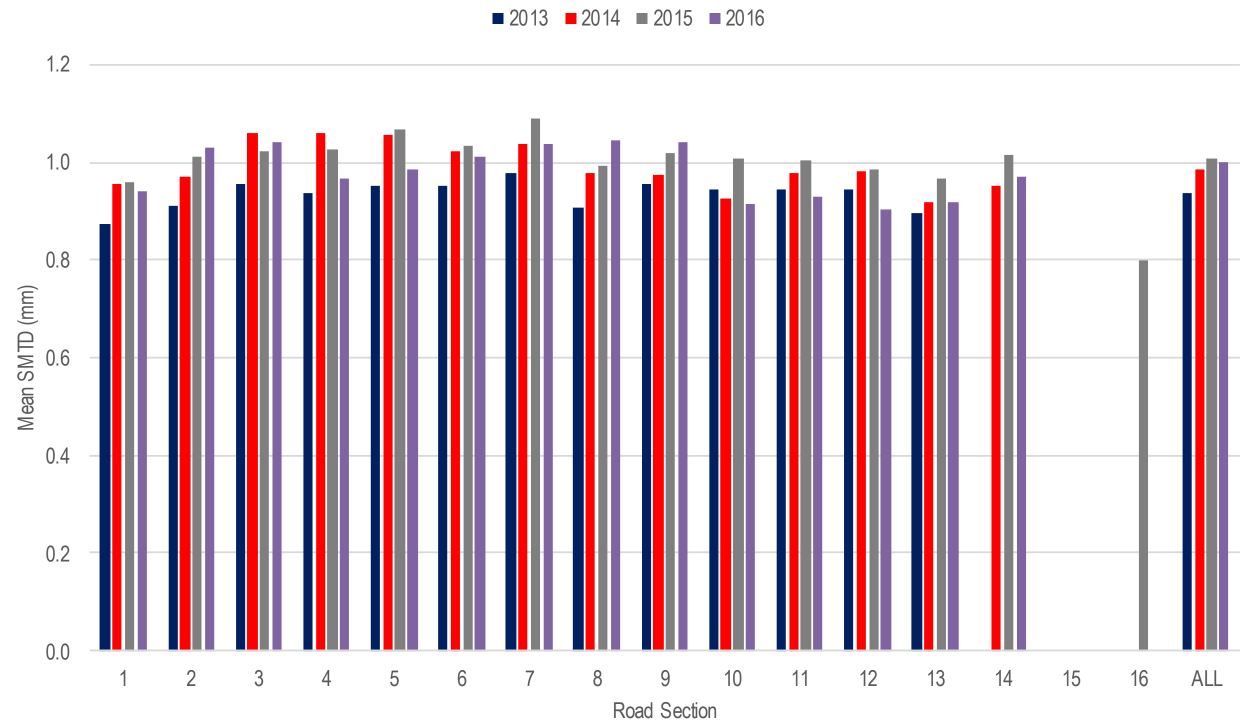

Note: F = Fast Lane; S = Slow Lane

### 6.7.3 Surface texture

The mean surface texture values (SMTD) for the sixteen structural sections measured in 2013, 2014 and 2015 are presented in Figure 6.28.

**Figure 6.28: Mean surface texture values for slow (top) and fast (bottom) lane by assessment year**



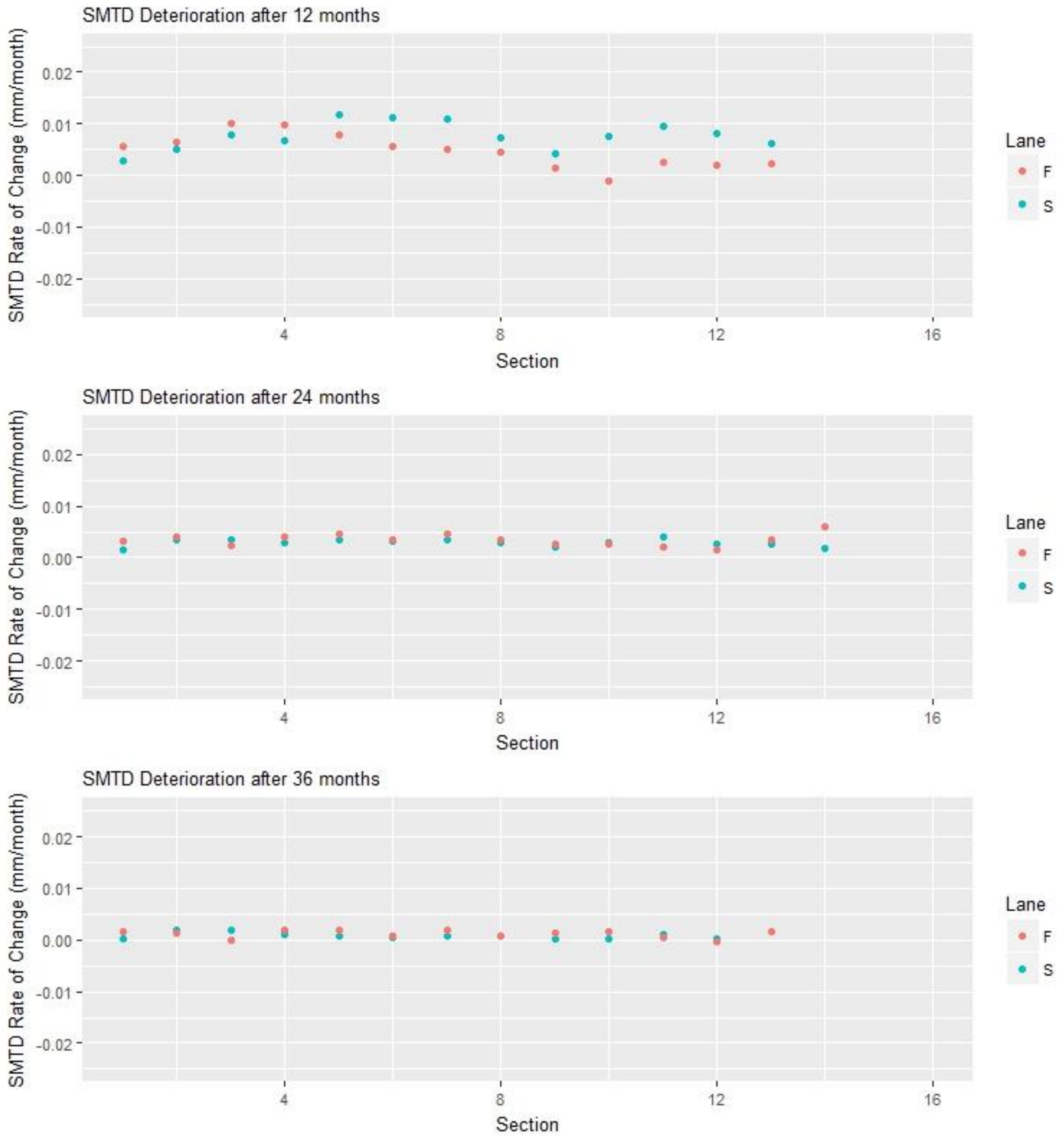

For most of the road sections, there is a decrease in the mean SMTD during 2015 and 2016. This is consistent with the understanding that as the aggregates in the sprayed seal surface polished under traffic, there will be a loss in texture depth with age. The relative linear progression rates, presented in millimetres per month, are shown in Table 6.7 and the same dataset is plotted in

Figure 6.29. There is no noticeable difference in the linear progression rates between the reporting periods of 0 – 24 and 0 – 36 months.

**Table 6.7: Mean surface texture relative linear progression rates**

| Road section | Start chainage (m) | End chainage (m) | Δ SMTD (mm/month) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Left (slow) lane | | | Right (fast) lane | | |
| | | | *0-12 months* | *0-24 months* | *0-36 months* | *0-12 months* | *0-24 months* | *0-36 months* |
| 1 | 575 | 1465 | 0.003 | 0.001 | 0.000 | 0.006 | 0.003 | 0.001 |
| 2 | 1465 | 1608 | 0.005 | 0.004 | 0.002 | 0.006 | 0.004 | 0.001 |
| 3 | 1608 | 1692 | 0.008 | 0.004 | 0.002 | 0.010 | 0.002 | 0.000 |
| 4 | 1692 | 1855 | 0.007 | 0.003 | 0.001 | 0.010 | 0.004 | 0.002 |
| 5 | 1855 | 1995 | 0.012 | 0.003 | 0.001 | 0.008 | 0.005 | 0.002 |
| 6 | 1995 | 2307 | 0.011 | 0.003 | 0.001 | 0.005 | 0.004 | 0.001 |
| 7 | 2307 | 2905 | 0.011 | 0.003 | 0.001 | 0.005 | 0.005 | 0.002 |
| 8 | 2905 | 3005 | 0.007 | 0.003 | 0.001 | 0.005 | 0.004 | 0.001 |
| 9 | 3005 | 4155 | 0.004 | 0.002 | 0.000 | 0.001 | 0.003 | 0.001 |
| 10 | 4155 | 4405 | 0.008 | 0.003 | 0.000 | -0.001 | 0.003 | 0.002 |
| 11 | 4405 | 4580 | 0.010 | 0.004 | 0.001 | 0.003 | 0.002 | 0.000 |
| 12 | 4580 | 4680 | 0.008 | 0.003 | 0.000 | 0.002 | 0.002 | 0.000 |
| 13 | 4680 | 4880 | 0.006 | 0.003 | 0.002 | 0.002 | 0.003 | 0.002 |
| 14 | 4880 | 4955 | - | 0.002 | - | - | 0.006 | - |
| 15 | 4955 | 4975 | - | - | - | - | - | - |
| 16 | 4975 | 5155 | - | - | - | - | - | - |
| ALL | 575 | 5155 | 0.007 | 0.003 | 0.001 | 0.004 | 0.003 | 0.001 |

**Figure 6.29: Average SMTD deterioration rate between 0-12 months, 0-24 months and 0-36 months**




Note: F = Fast Lane; S = Slow Lane

## 6.8 Site Visit in February 2017

On February 14, 2017, a visual inspection visit has been conducted by ARRB Group and TMR E&T engineers. Some of the photographs taken on the day are shown in Figure 6.30 along the northbound lanes of the Centenary Highway (TMR Road 910).

**Figure 6.30: Photograph from site visit**

| | |
|---|---|
| <br>Typical condition of the northbound lanes | <br>Typical condition of the northbound lanes |
| <br>Slow lane with medium rutting | <br>Flushing and minor rutting at the change of sprayed seal interface near the south end of the project |
| <br>Typical shallow embankment in the verge zone and near surface rock outcrops | <br>Typical pavement condition of the northbound lanes taken when driving over the site |

The objective of the visit was to confirm the condition survey information collected in October 2016. Overall, the pavement sections have performed well and not in need of treatment.

Some flushing in the sprayed seal was found at the southern end of the project. However, it was confirmed that the flushed area is not within the high standard granular pavement trial area. Some of the flushing was found in the taper transition area where the high standard granular pavement were tied in with the adjacent existing pavement.

When driving over the section of the trial pavement, the project team experienced a ride quality consistent with the measured IRI values. As highlighted in Figure 6.21, there is a section on the fast lane between chainage 4300 m and 4800 m where the there is a reported decrease in rutting. During the site visit, the project team confirmed that there was no visible repair in the vicinity.

# 7 STRUCTURAL CAPACITY

## 7.1 Introduction

The structural condition of pavements is commonly investigated to quantify the remaining capacity to withstand traffic and environmental loading (TMR 2012a). Assessment of the structural capacity of the Centenary Motorway duplication by measuring the surface deflections using the falling weight deflectometer (FWD). The FWD is a trailer-mounted device that measures displacement of the pavement surface through geophones at fixed distances, typically ranging from 0 mm to 1500 mm, resulting from an impact load. The load is applied by allowing weights dropped from a fixed height to transmit the resulting load to the pavement surface through a 300 mm diameter rigid plate. Typically, applied loads range from 40 kN to 80 kN. The FWD utilised for the structural survey of the HSG trial pavement is shown in Figure 7.1.

Testing was carried out in both the slow (left) and fast (right) lanes in October 2013 and March 2017. For each lane the deflections were measured both the outer wheelpath (OWP) and the between wheelpaths (BWP) at 50 m intervals. The FWD testing was carried out in accordance with Austroads test method AG:AM/T006, *Pavement Deflection Measurement with a Falling Weight Deflectometer (FWD)* (Austroads 2011c).

**Figure 7.1: Falling weight deflectometer (FWD) assessing structural capacity of fast lane outside wheelpath**


## 7.2 Assessment Methodology

### *7.2.1 Deflection*

The vertical displacement, or deflection, of the pavement surface resulting from an impact load provides valuable information about the stiffness characteristics of the underlying structure. A direct relationship between deflection under load and pavement response (performance) does not exist. However, it is commonly accepted that pavements with reduced deflection will, have better long-term performance (Merrill, van Dommelen & Gaspar 2006). The deflection bowl measured can be further analysed to estimate layer elastic moduli and allowable traffic loading (ESA).

### *7.2.2 Allowable Traffic Loading*

*Maximum Deflection*

The TMR *Pavement Rehabilitation Manual* (2012a) presents a method for determining the allowable loading on in situ pavements based upon measurements of surface deflection. Chapter 2 (TMR 2012a) outlines the procedure for determining the 90$^{th}$ percentile representative $D_0$ and $D_{900}$ values, and estimation of subgrade bearing capacity (CBR). Figure 5.9 of the pavement rehabilitation manual (TMR 2012a) presents the maximum allowable ESA loading for a given combination of characteristic surface deflection values and estimated subgrade CBR.

The tolerable deflection approach mentioned above is currently considered a low-level analysis procedure. The tolerable deflection chart presented in Figure 5.9 of the pavement rehabilitation manual (TMR 2012a) was prepared based on the following assumptions:

- A maximum granular base modulus of 350 MPa
- Design traffic loading less than 1 x $10^7$ ESAs

For the project along the Centenary Highway, the modulus of the HSG base is expected to be in excess of 350 MPa. Furthermore, the 10-years design traffic is in excess of the maximum traffic loading that the tolerable deflection chart is applicable. Based on these, the remaining life calculated using this method is not representative of the HSG pavement.

*Back-Calculated Moduli*

As an alternative to the tolerable deflection method, the deflection bowls collected during structural assessment with the FWD can be employed to back-calculate elastic moduli for uniform pavement sections. Back-calculation is an iterative process that attempts to match the deflection bowls measured with the FWD to the theoretical deflections of an identical structure with varying layer modulus values. The iterative process is repeated until the best fit is obtained within the provided boundaries.

EFROMD3 software from ARRB was utilised to calculate the layer moduli at the time of testing. The back-calculated layer moduli were input into the CIRCLY 5.0 pavement design software package to estimate critical vertical compressive strains within the pavement structure resulting from a standard ESA load. The critical strain values, calculated according to the Austroads (2012) subgrade strain criterion, were utilised to estimate the allowable loading to an unacceptable level of pavement surface deformation according to Equation 7.

$$N = \left(\frac{9300}{\mu\varepsilon}\right)^{7} \qquad 7$$

where

N = allowable number of repetitions of a standard axle

με = vertical compressive strain under the standard axle on top of subgrade (microns).

Back-calculation was carried out over 340 individual deflection test points collected in years 2013 and 2017. Climate records were examined prior to FWD testing in 2013 and 2017. This examination revealed that FWD testing in 2013 was carried out at the end of a dry period, requiring that moisture adjustment by applied. Based on the locality the deflections collected between wheelpaths were increased by a factor of 1.21.

After the back-calculation, a general mechanistic procedure (GMP) has been carried out. The back-calculation results and estimate of the remaining life based on the GMP is presented in Section 0 of this report.

## 7.3 Post Construction Assessment

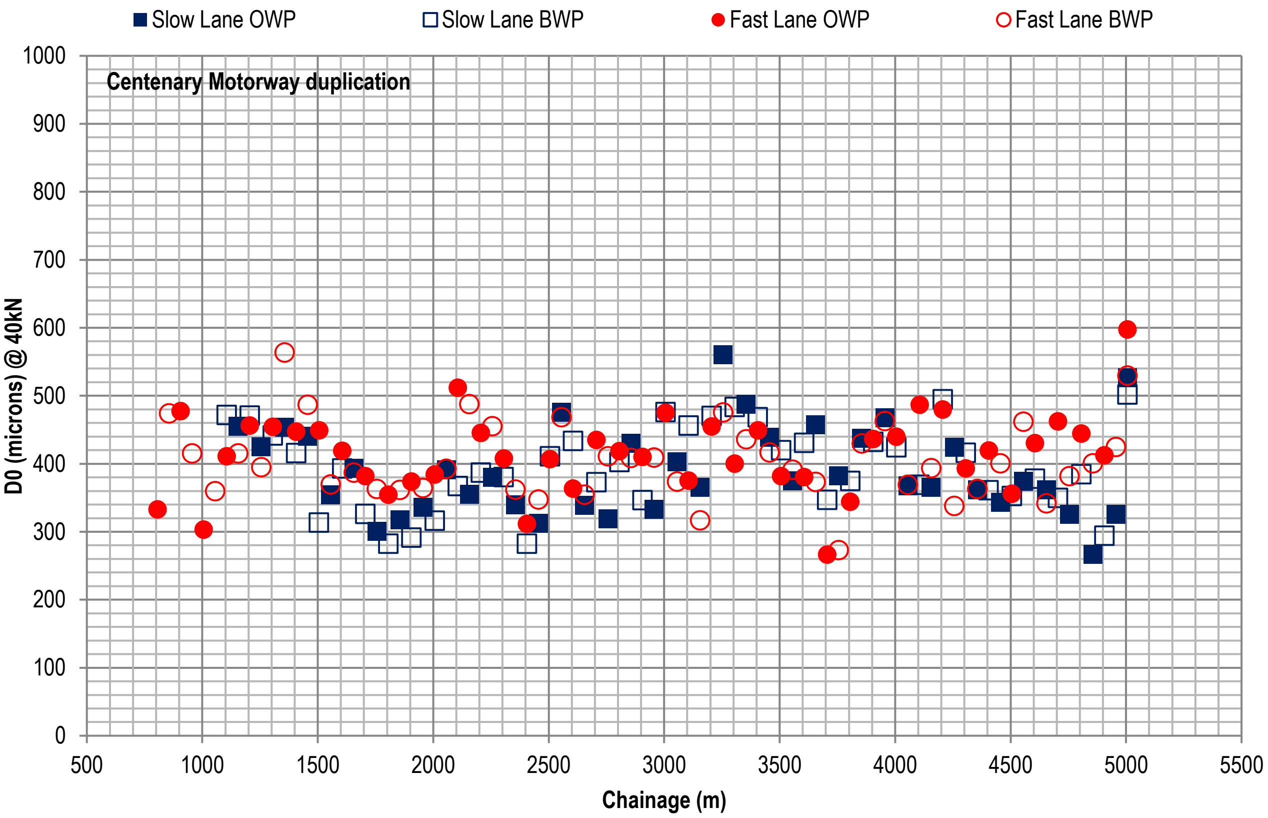
### *7.3.1 Deflection results*

The post-construction structural capacity assessment was conducted in October 2013, prior to opening to traffic. The deflections were measured at 50m intervals in the outer wheel path and between wheel paths of both the slow and fast lanes. The deflections have been normalised to values of 40 kN (566 kPa) and no seasonal moisture adjustments have been applied to the measured deflections.

FWD deflection measurements are summarised in Appendix A.

The surface deflections measured at the centre ($D_0$) of the loading plate are presented in Figure 7.2. The $D_0$ measurements are consistent along the alignment and range from 0.30 mm to 0.50 mm, indicative of a stiff unbound granular pavement. The consistency of the $D_0$ measurements reflects the consistency of the HSG base layer; probably resulting from close control of material properties, moisture conditions and compactive effort.

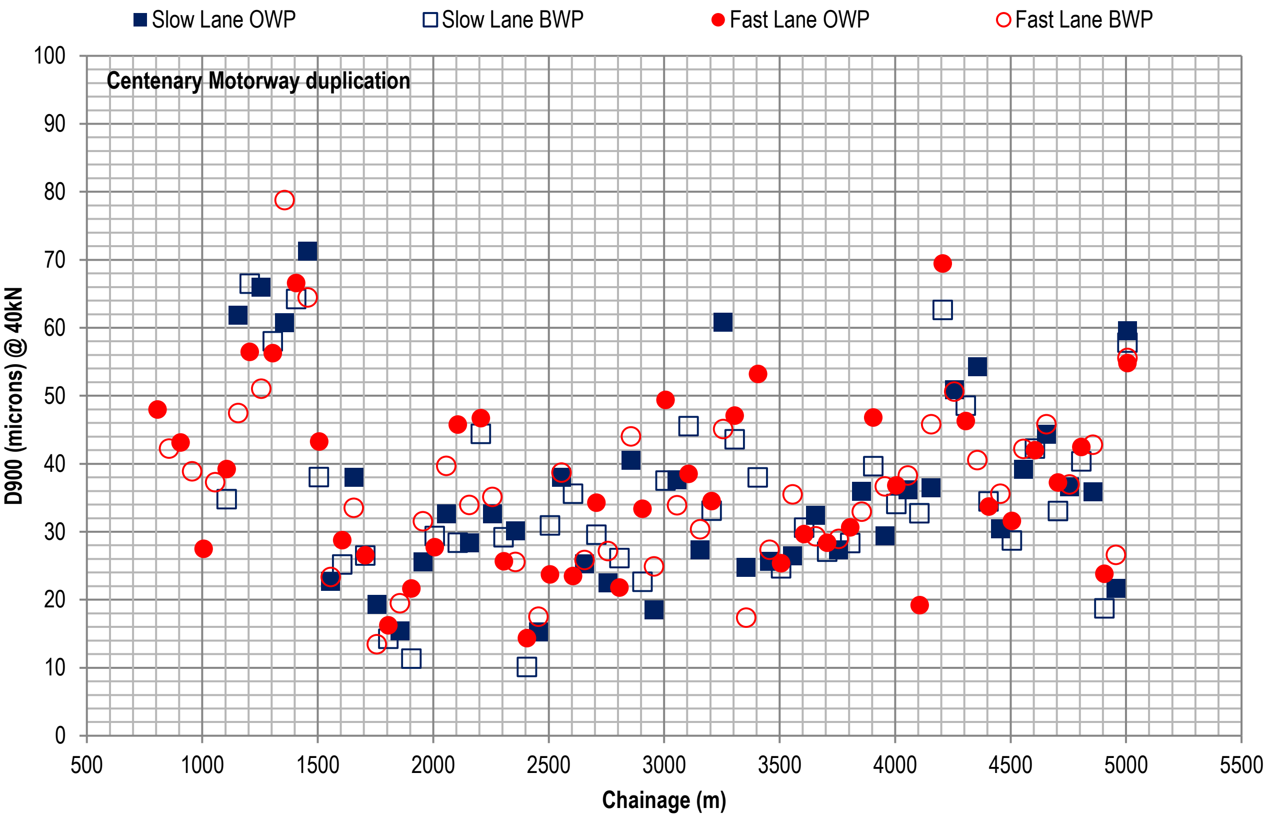
Figure 7.2: Surface deflections measured at the centre of the loading plate ($D_0$) in 2013




As discussed in Section 6.3.2 and Section 6.4.2, isolated excessive rutting values were measured in the OWP of the fast lane between project chainages 4300 and 4800 during both the post construction, 12-month and 24-month surface condition assessments. Increased $D_0$ values, indicative of a weak pavement, were not observed between project chainages 4300 m and 4800 m. The consistent $D_0$ values and absence of shoving indicates that the measured rutting has probably resulted from early consolidation of the pavement layers under construction traffic (TMR 2012a).

The surface deflections measured 900 mm from the centre of the loading plate ($D_{900}$) are presented in Figure 7.3. The measured $D_{900}$ values exhibit greater variability than the $D_0$ values. $D_{900}$ is unaffected by the overlying pavement structure and can be used to estimate the subgrade CBR at the time of testing (TMR 2012a). The relationship between $D_{900}$ and subgrade CBR is presented in Figure 2.16 in the TMR *Pavement Rehabilitation Manual* (TMR 2012a). In summary, $D_{900}$ values of 340 µm, 235 µm, 190 µm and 145 µm correlate with CBR values of 3%, 5%, 7% and 10% respectively.

**Figure 7.3: Surface deflections 900 mm from the centre of the FWD loading plate ($D_{900}$) in 2013**




The variation in measured $D_{900}$ values presented in Figure 7.3 is not unexpected, since in situ subgrade conditions determined during the preliminary site investigation varied widely, as presented in Figure 4.3. The maximum $D_{900}$ value measured for the trial pavement, 79 µm, is representative of a CBR of approximately 25%. However, isolated areas with increased $D_{900}$ values can be observed at approximate project chainages 1150 to 1500 m, 4200 to 4400 m and 5000 to 5100 m.

Deflection ratio (DR) is the ratio of the surface deflections measured 250 mm from the centre of the loading plate ($D_{250}$) to the maximum deflection ($D_0$). DR can be used to identify variations in pavement configuration and potential weak areas. DR values ranging from 0.6 to 0.7 are representative of a high-quality unbound granular pavement. DR values less than 0.6 are indicative of a potentially weak structure (TMR 2012a). The DR values for the trial pavement are presented in Figure 7.4.

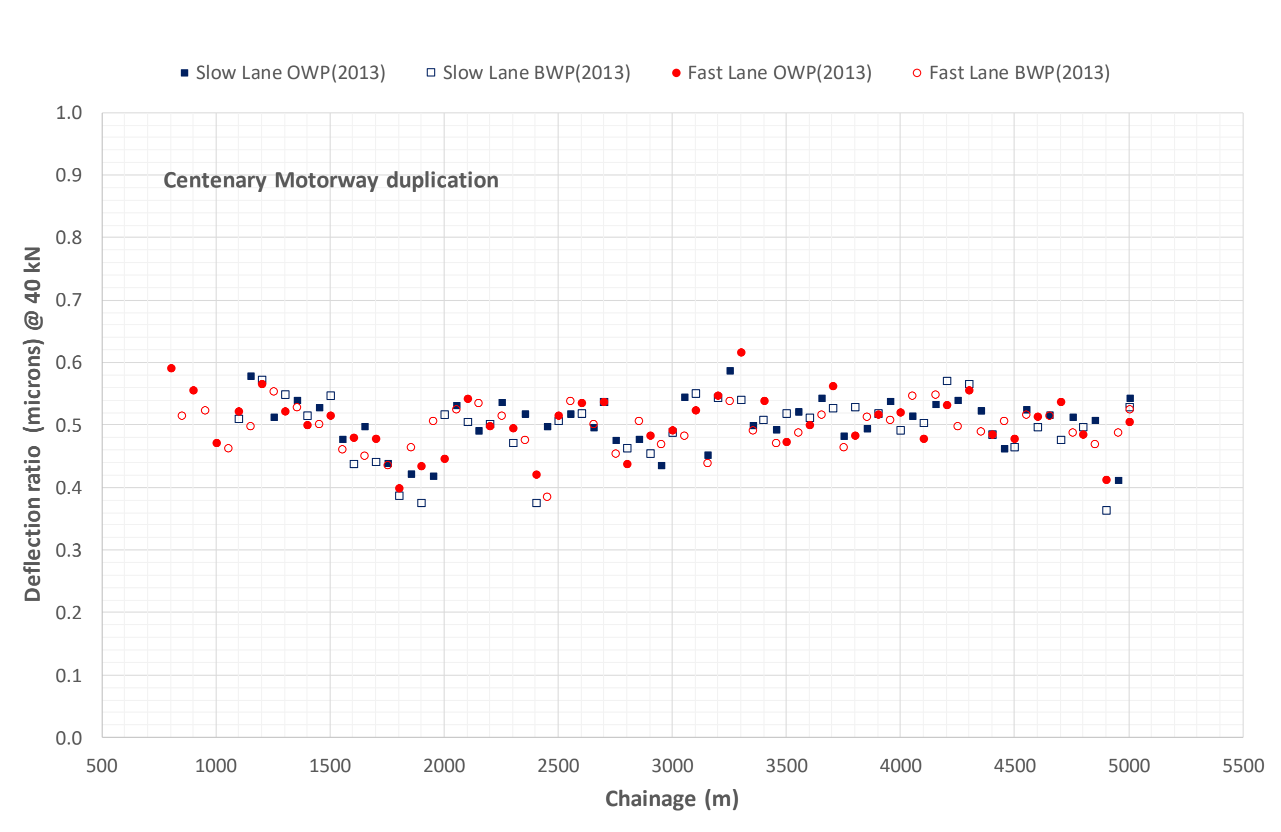
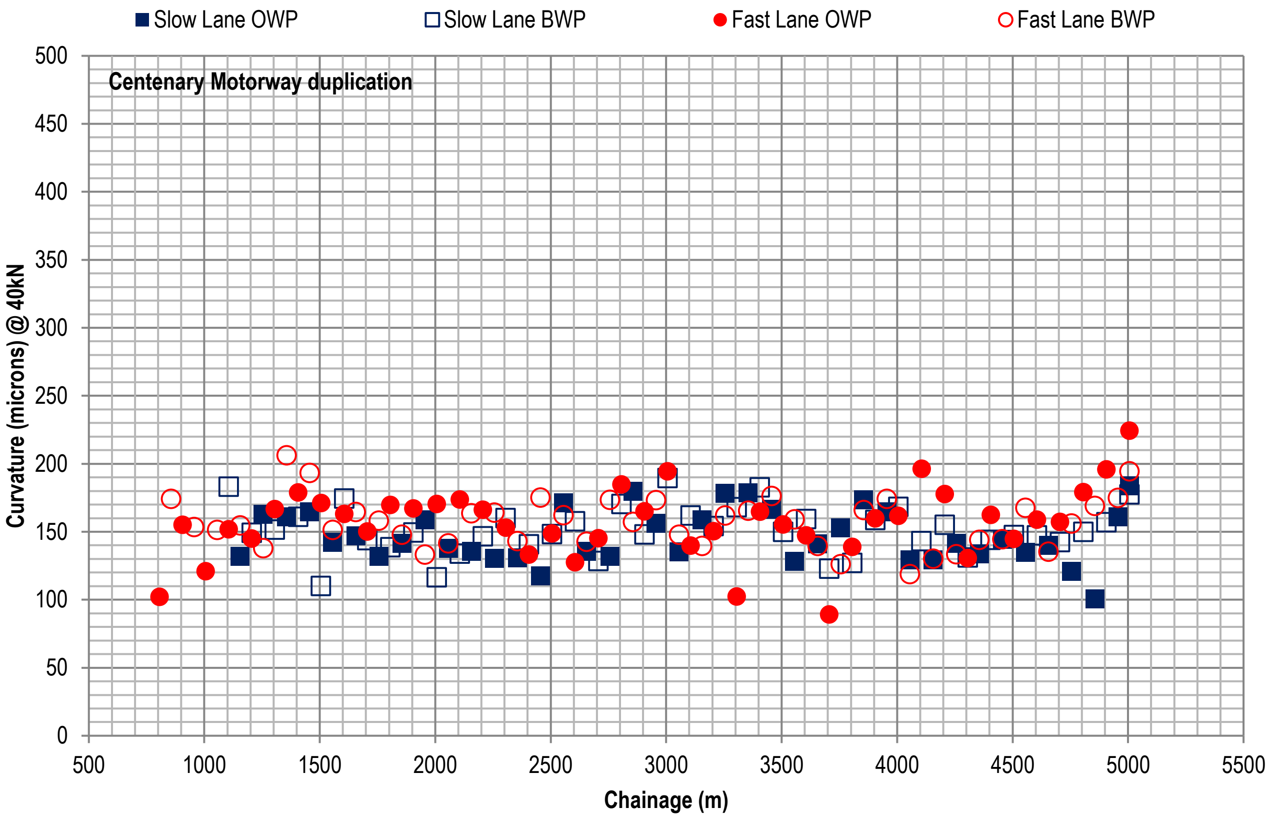



Figure 7.4: Deflection ratio for HSG trial pavement in 2013

Review of the calculated DR values shows great consistency along the alignment, similar to the $D_0$ measurements. However, almost all of the values are below the 0.6 performance threshold recommended in the TMR *Pavement Rehabilitation Manual* (TMR 2012a). Newly constructed or rehabilitated unbound granular pavements undergo an initial 'settling' period, during which construction and traffic loads induce particle rotation and relocation until a dense, stable fabric is achieved (Bartley Consultants 1997). As the testing was conducted early in the pavement life, it is assumed that the DR values will increase as the particle orientations stabilise and the equilibrium moisture content is reached.

The curvature function is the difference between the maximum deflection ($D_0$) and the deflection measured 200 mm from the centre of the loading plate ($D_{200}$). The curvature function is indicative of the shape of the deflection bowl with small values representing a shallow bowl (stiff pavement) and large values representing a deep bowl (weak pavement). Curvature is often used to evaluate the fatigue life of asphalt overlays, but can also be used to estimate relative stiffness in unbound granular pavements, with values greater than 400 µm indicative of insufficient stiffness and values smaller than 200 µm indicative of a stiff structure (TMR 2012a). The curvature values for the trial pavement are presented in Figure 7.5.

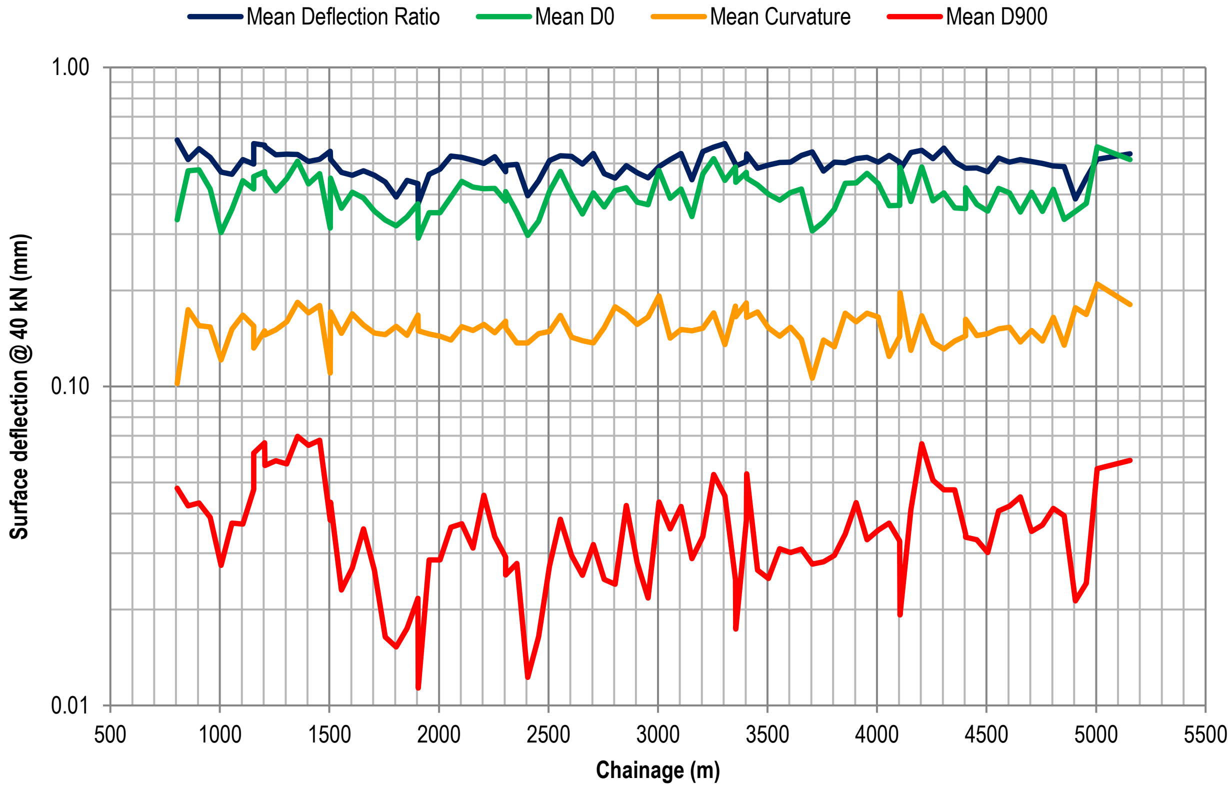
**Figure 7.5: Curvature function for HSG trial pavement in 2013**




Review of the calculated curvature function along the alignment shows great consistency, similar to the $D_0$ and DR measurements. Additionally, almost every value is less than 200 µm, indicative of a stiff unbound granular pavement. The magnitude and consistency of the curvature and $D_0$ values are indicative of a stiff base layer constructed to a high standard in contrast to the deflection ratio findings

A summary of the deflection measures along the trial pavement alignment is presented in Figure 7.6. The mean $D_0$, $D_{900}$, DR and curvature function values were calculated by averaging the slow and fast lane measurements at a given project chainage. Figure 7.6 provides a general overview of the variation in structural stiffness parameters along the trial pavement. The consistency of the $D_0$, DR and curvature values is readily apparent. Additionally, these values are unaffected by the significant variability in $D_{900}$. This suggests a strong, resilient pavement structure has been provisioned. However, the early-life DR values are below the performance threshold (0.6) provided in the TMR *Pavement Rehabilitation Manual* (TMR 2012a).

Figure 7.6: Deflection summary for Centenary Motorway duplication trial pavement in 2013?




## 7.4 43-month Assessment (2017)

### 7.4.1 Deflection results

According to the original plan, FWD testing was to be carried out in October 2016 (3 years after the opening of the road to traffic). FWD deflection measurements at 40, 60 and 80 kN were conducted in October 2016 but the results are not reported because some “non-decreasing deflection” basins were observed in the data.

To ensure high-quality deflection data was analysed a second set of FWD deflection measurements were taken in May 2017. This data were collected after 43-months and no moisture correction factor has been allowed because the data were collected near the end of the wet season in South East Queensland.

The maximum deflection ($D_0$), surface deflection at 900 mm offset ($D_{900}$), the deflection ratio ($D_{250}/D_0$) and the curvature function are reported between Figure 7.7 and Figure 7.10. The mean maximum deflection for all sixteen structural section ranges between 0.36 and 0.75 mm for a normalised 40 kN load. All surface deflections at 900 mm offset were less than 100 microns, which correlates to a strong insitu subgrade CBR support. The curvature function is typically ranges between 150 – 250 microns and the deflection ratio ($D_{250}/D_0$) is reported to be generally between 50% and 60%.

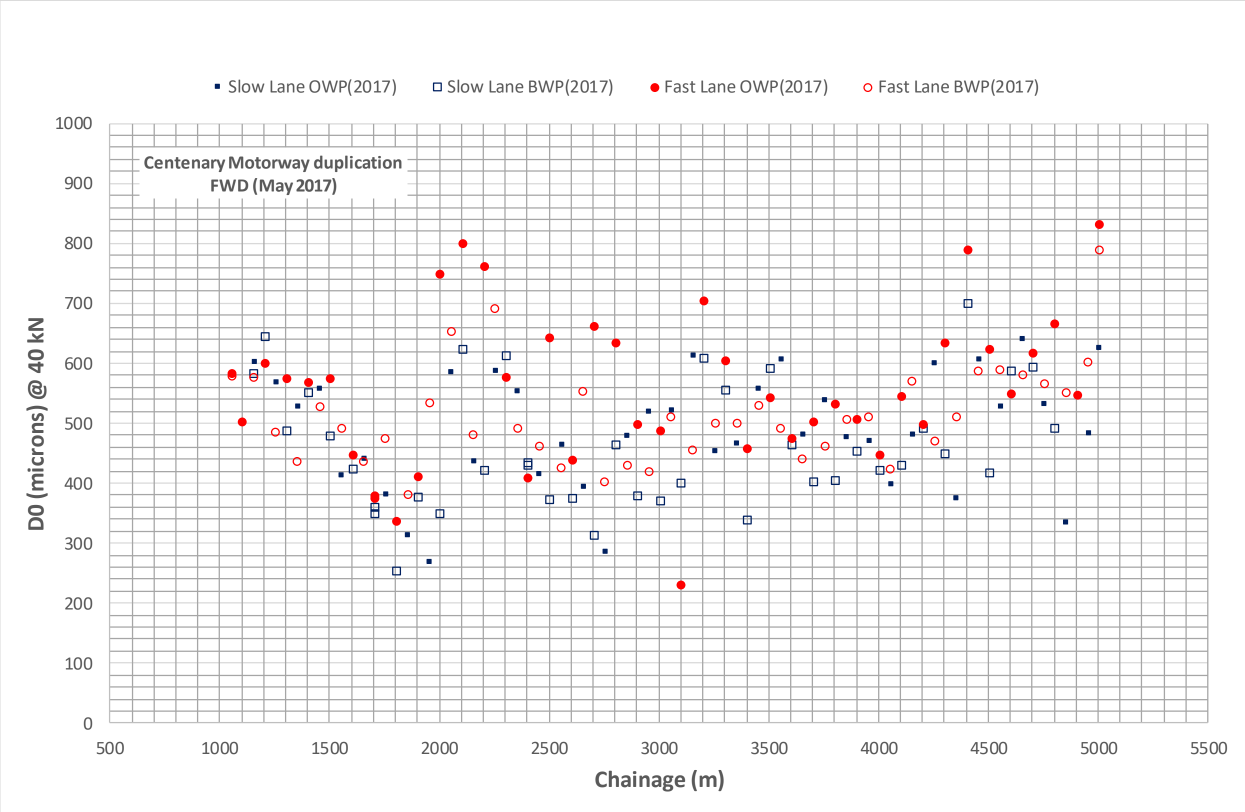
Deflection ratio is often used as a qualitative measure of the general performance of the pavement. Even though a deflection ratio of less than 60% was often assumed to indicate a possible weakness in an unbound pavement, the performance to-date does not suggest a weak unbound pavement. For more detailed analysis of the trial site, back-calculation results would provide more indicative performance measure than the deflection ratio approach. It is also noted that the data was measured near the end of the wet season, and may represent a weaker state when compared with the measurement made during the dry season.

As discussed in the previous year's deflection analysis, the deflection ratio has increased between the 2013 and 2017 reading. This is consistent with the hypothesis highlighted earlier in that it is expected for the base aggregate to reorientate during the early years of the pavement and as the aggregate orientation begins to settle, the deflection ratio is expected to increase as observed in this set of readings.

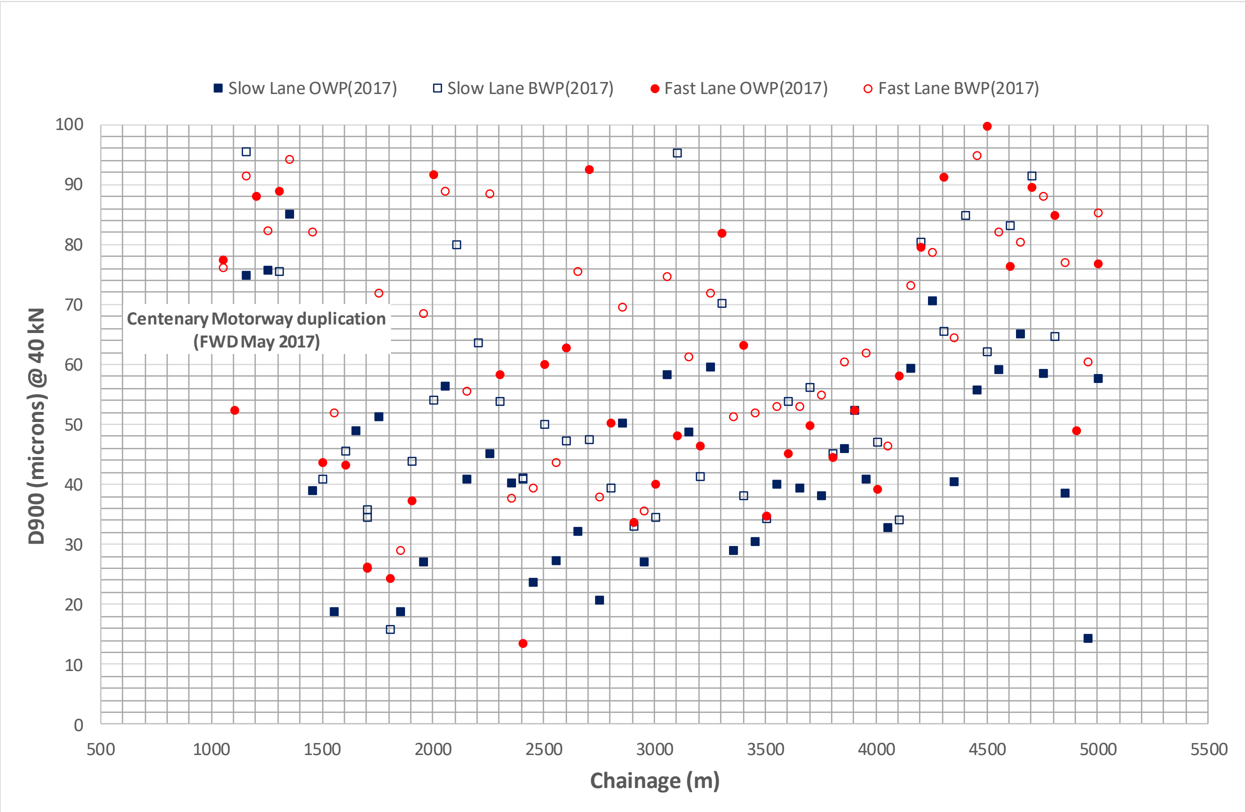
The curvature reading also confirms that the trial pavement has a stiff base, with the majority of the reported curvature measurement being less than 0.2 mm.

FWD deflection measurements are summarised in Appendix A.

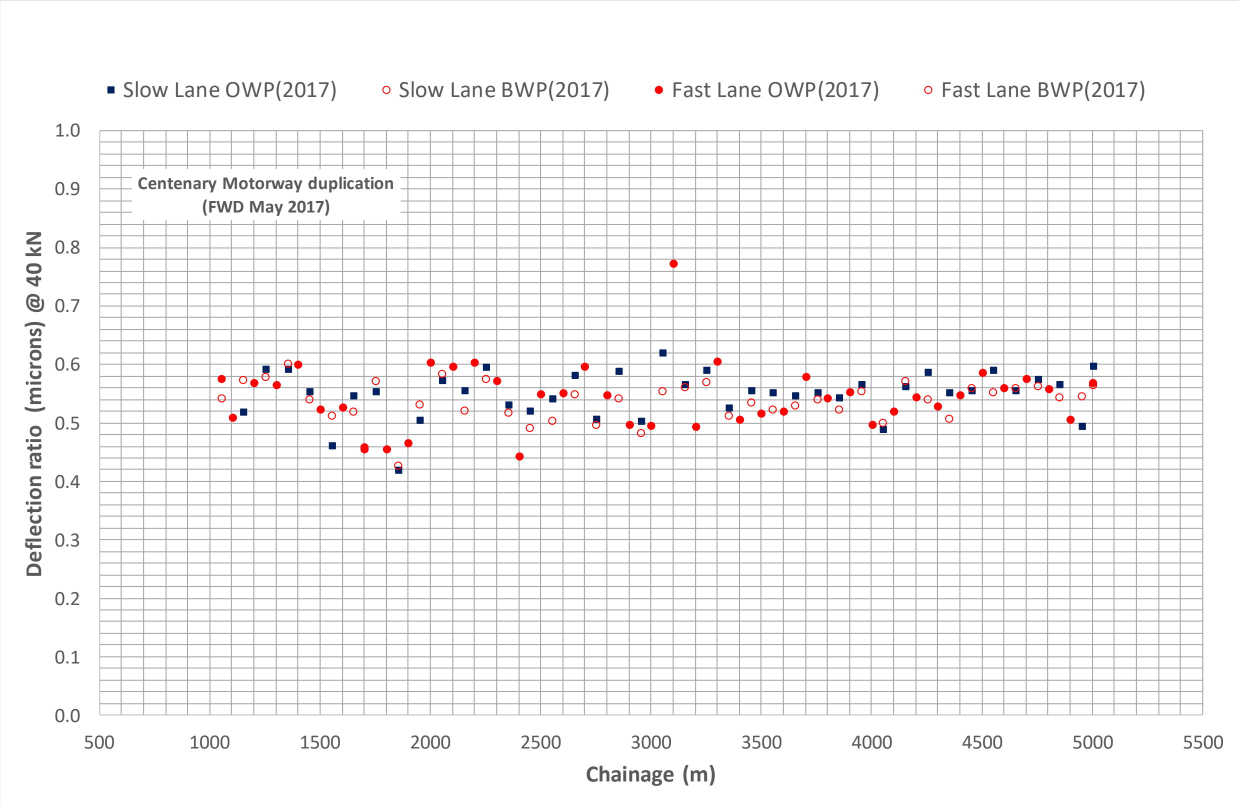
## Figure 7.7: Surface deflections measured at the centre of the loading plate ($D_0$) in 2017



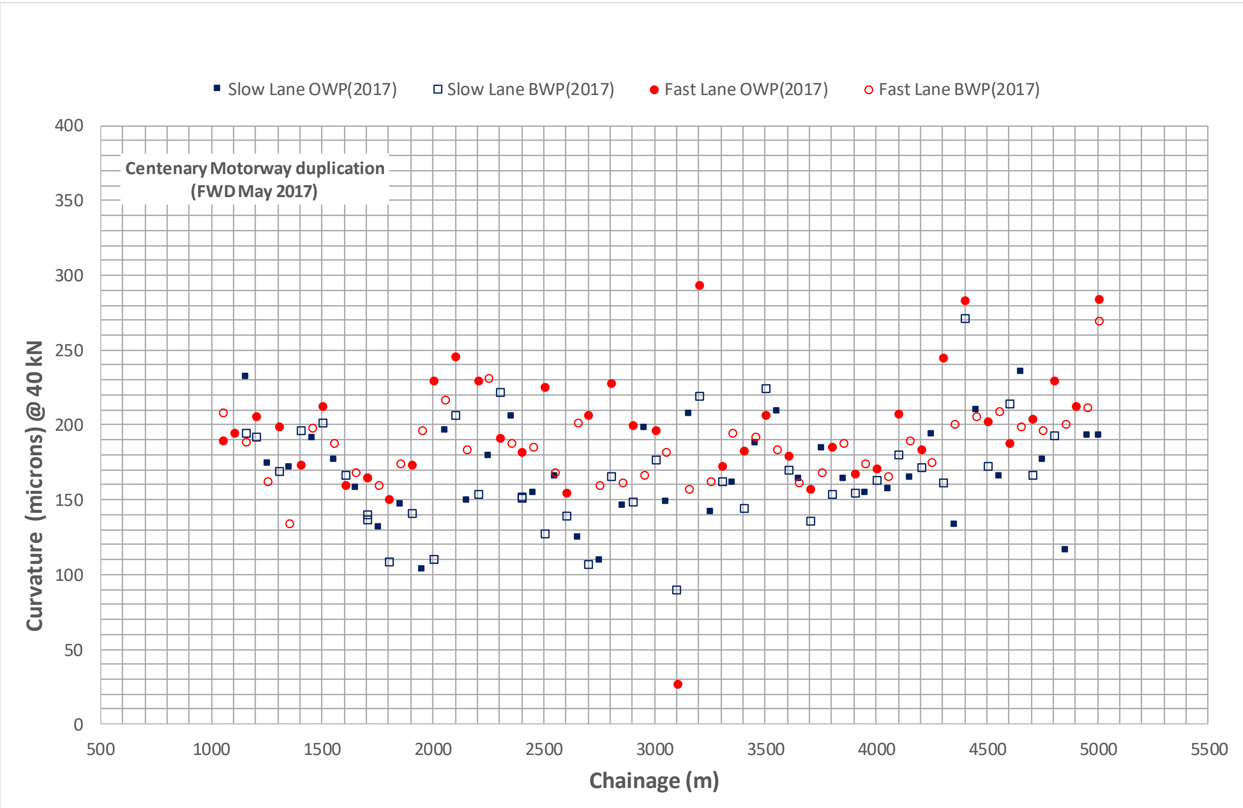

## Figure 7.8: Surface deflections 900 mm from the centre of the FWD loading plate ($D_{900}$) in 2017



### Figure 7.9: Deflection ratio for HSG trial pavement in 2017




### Figure 7.10: Curvature function for HSG trial pavement in 2017



## 7.5 Structural Capacity Progression

The 2013 and 2017 deflections are shown in Figure 7.11 to Figure 7.14. In this analysis, only the deflections measured in the outer wheel path (OWP) are presented because this is usually the most critical in terms of the pavement structural performance.

It was found that the maximum deflection ($D_0$) have been increased between the 2013 and 2017. This may have been due to the accumulated traffic since the opening of traffic in 2013. The data is also believed to be affected by the different months in which the deflection data was collected (October 2013 vs May 2017).

As shown in Figure 7.12, the $D_{900}$ variation between 2013 and 2016 suggests a slight decrease in subgrade support. Despite the increase in the reported $D_{900}$ value, the entire section still have values less than 100 microns. The increase in $D_{900}$ may be the reason $D_0$ has increased as the granular base appears to have increased in modulus with loading.

In Figure 7.13, it was found that the deflection ratio ($D_{250}/D_0$) has increased between 2013 and 2017. This indicate that the high standard granular pavement base has increased its stiffness over the past three years.

Lastly, as shown in Figure 7.14, there is a slight increase in the curvature function between 2013 and 2017. However, most of the trial pavement has a curvature typically around 0.2 mm, and this is an indicator of a stiff pavement.

**Figure 7.11: Comparison of the maximum surface deflections ($D_0$) measured in 2013 and 2017**

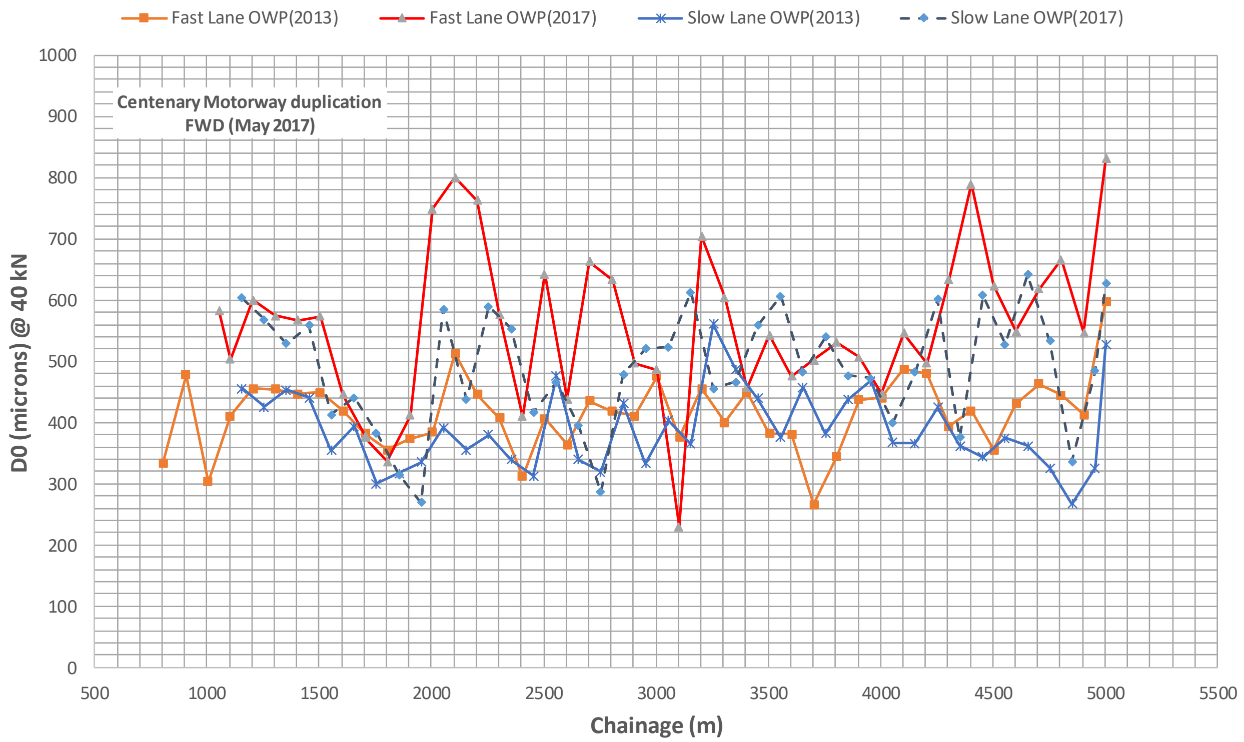



**Figure 7.12: Comparison of the deflections at 900 mm offset ($D_{900}$) measured in 2013 and 2017**

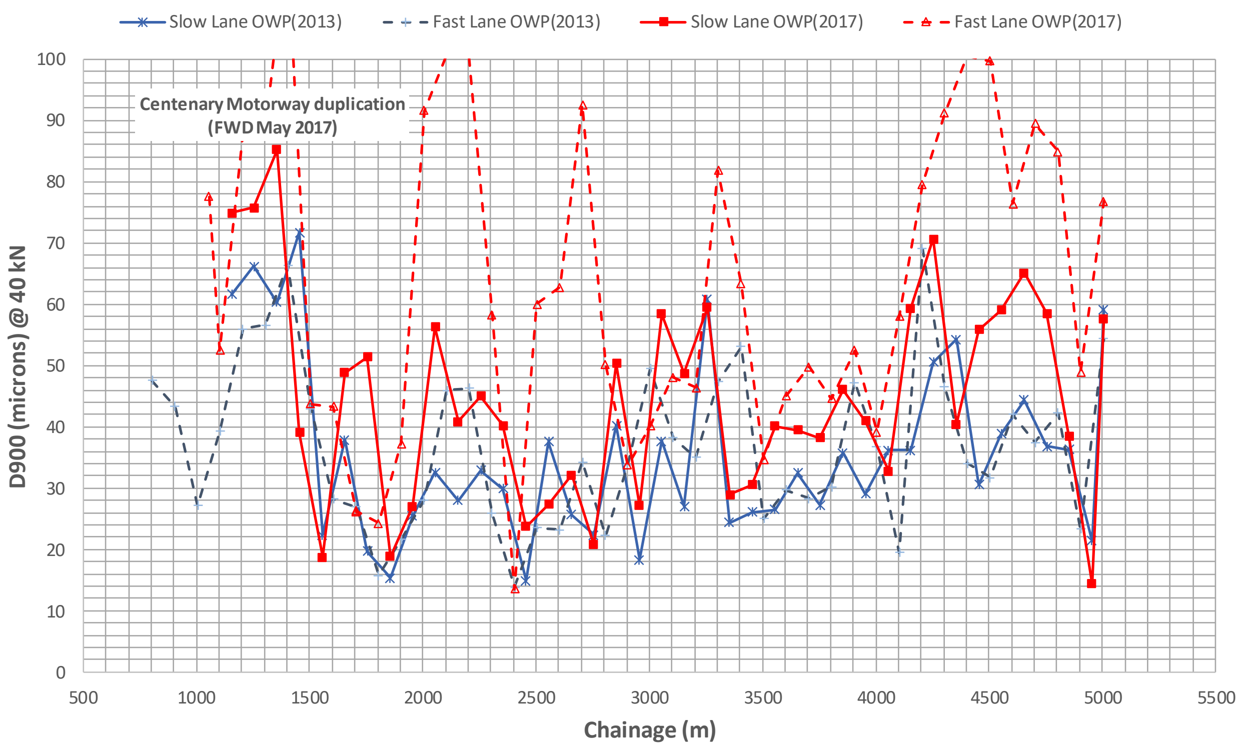


**Figure 7.13: Comparison of the deflection ratio for HSG trial pavement measured in 2013 and 2017**

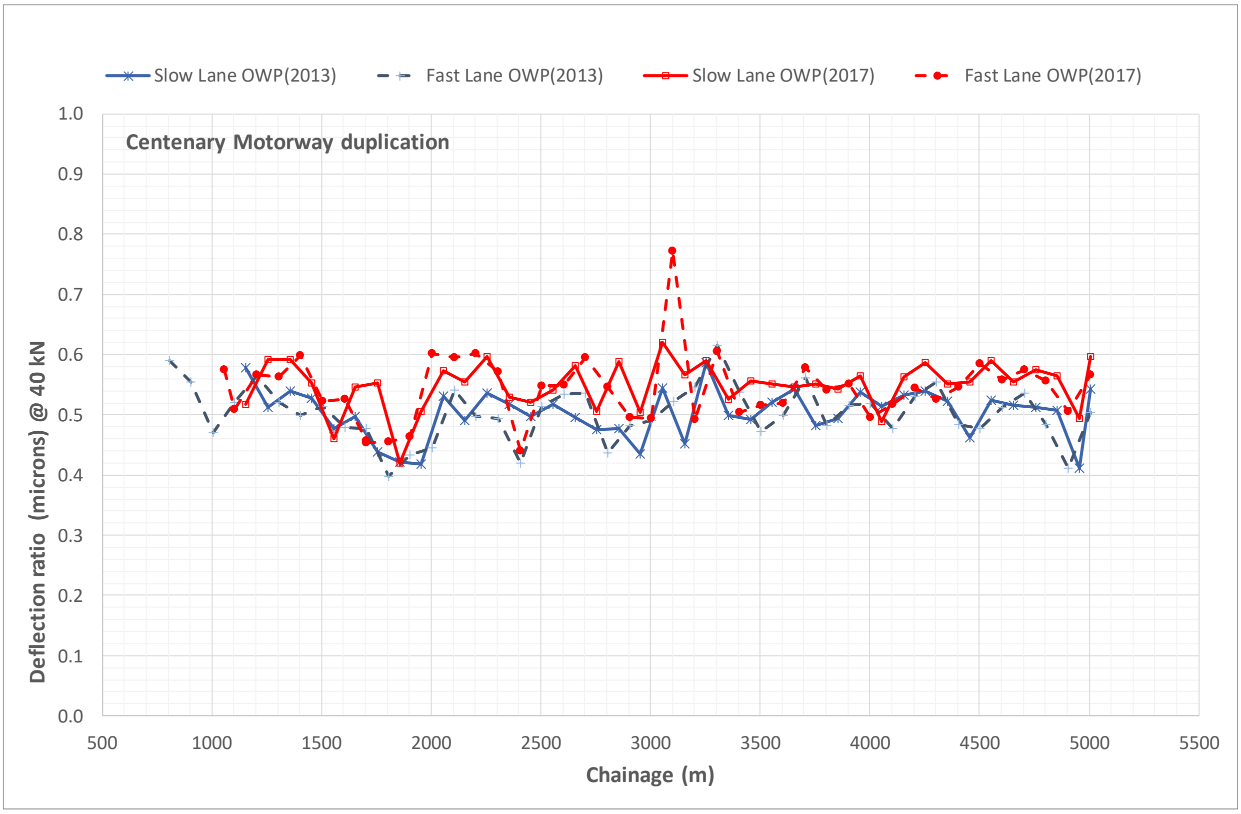
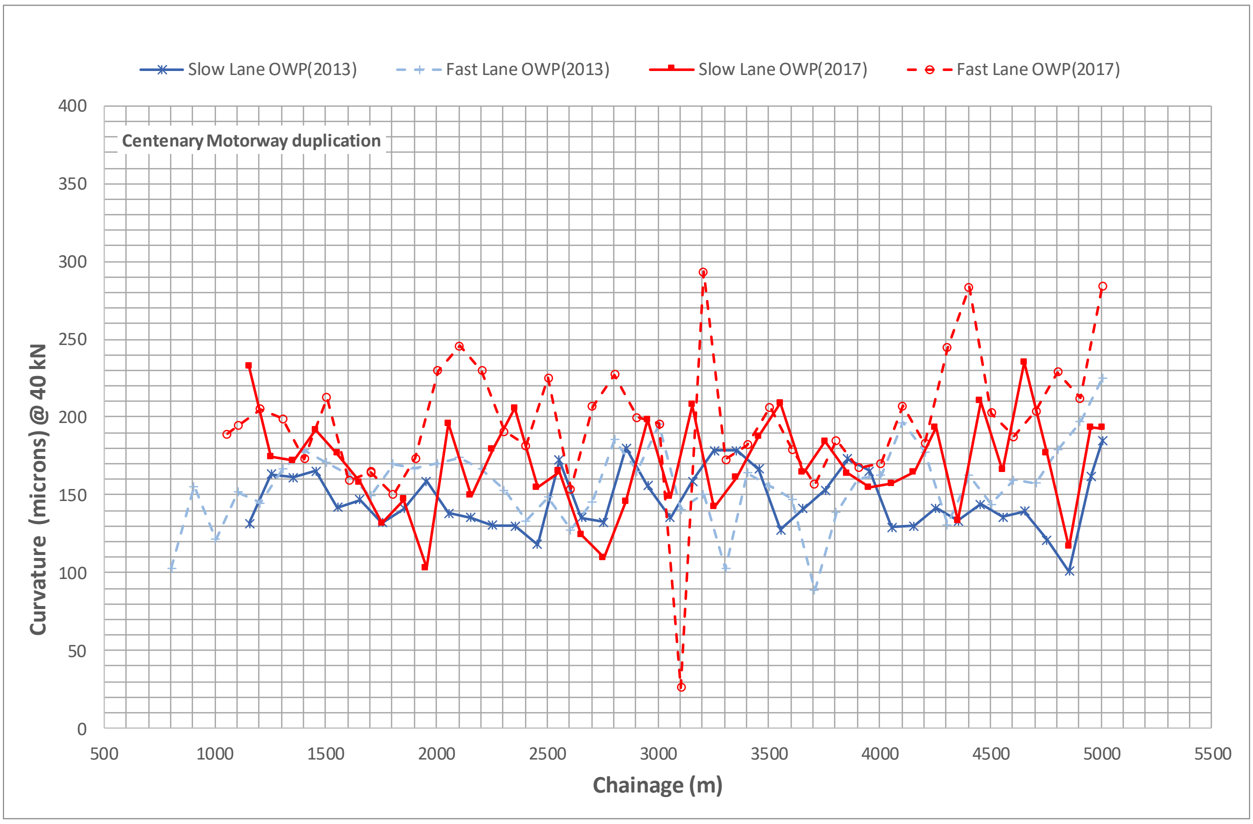



**Figure 7.14: Comparison of the curvature function for HSG trial pavement measured in 2013 and 2017**



## 7.6 Results from back-calculation and general mechanistic procedure

As discussed in Section 7.2.2, an alternative method of estimating the allowable traffic loading is to back-calculate the moduli of the pavement layers and subgrade from the measured deflections and use these values with the general mechanistic procedure (Austroads 2011).

Appendix B list the back-calculated moduli from the 2013 and 2017 deflection measurements.

Using the back-calculated moduli and the layer thicknesses, the subgrade strains were predicted and the allowable traffic loading calculated using the Austroads subgrade strain relationship. In these predictions, the subgrade was modelled as three layers; 300 mm upper layer, 500 mm middle layer and an infinite half space for the lower layer.

In order to simply this part of the analysis, instead of the 16 sub-sections, the project length was grouped into three sites based on the pavement structure reported. The pavement profiles are listed below:

- Site 1: 220 mm granular base on 150 mm granular subbase (over 140 test points)
- Site 2: 220 mm granular base on 150 mm granular upper subbase on 100 mm granular lower subbase (4 test points)
- Site 3: 220 mm granular base on 150 mm granular upper subbase on 140 mm granular lower subbase (24 test points)

Table 7.1 summarises the pavement structure at each site.

**Table 7.1: Pavement profile thickness and material type for Site 1, Site 2 and Site 3**

| Site | Layer | Material type | Thickness (mm) |
|---|---|---|---|
| 1 | 1 | HSG base | 220 |
| | 2 | Granular subbase | 150 |
| | 3 | Subgrade | 300 |
| | 4 | Subgrade | 500 |
| | 5 | Subgrade | 0 |
| 2 | 1 | HSG base | 220 |
| | 2 | Granular upper subbase | 150 |
| | 3 | Granular lower subase | 100 |
| | 4 | Subgrade | 300 |
| | 5 | Subgrade | 500 |
| | 6 | Subgrade | 0 |
| 3 | 1 | HSG base | 220 |
| | 2 | Granular upper subase | 150 |
| | 3 | Granular lower subbase | 140 |
| | 4 | Subgrade | 300 |
| | 5 | Subgrade | 500 |
| | 6 | Subgrade | 0 |

A summary of the back-calculated moduli values for 2013, including the HSG base, TMR Type 2.3 upper and lower subbase, in addition to the subgrade layers, are presented in Table 7.2.

**Table 7.2: Summary of back-calculated elastic moduli values for 2013 deflection data**

| Section | Start chainage (m) | End chainage (m) | Average back-calculated modulus (MPa) | | | | | | Average error (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | HSG base | Type 2.3 | Type 2.3 | Subgrade (0-300 mm) | Subgrade (300-800mm) | Subgrade (below 800 mm) | |
| 1 | 575 | 1465 | 713 | 102 | 579 | 310 | 252 | | 3.4 |
| 2 | 1465 | 1608 | 666 | 140 | 433 | 255 | 531 | | 4.9 |
| 3 | 1608 | 1692 | 591 | 146 | 185 | 978 | 400 | 365 | 4.5 |
| 4 | 1692 | 1855 | 635 | 129 | 779 | 753 | 736 | 781 | 6.9 |
| 5 | 1855 | 1995 | 620 | 210 | 215 | 837 | 502 | 698 | 4.5 |
| 6 | 1995 | 2307 | 690 | 98 | 524 | 346 | 391 | | 4.4 |
| 7 | 2307 | 2905 | 691 | 119 | 513 | 411 | 555 | | 4.7 |
| 8 | 2905 | 3005 | 614 | 158 | 282 | 206 | 641 | | 5.4 |
| 9 | 3005 | 4155 | 706 | 138 | 354 | 315 | 427 | 385 | 4.4 |
| 10 | 4155 | 4405 | 663 | 179 | 170 | 869 | 429 | 259 | 4.0 |
| 11 | 4405 | 4580 | 702 | 108 | 641 | 446 | 364 | | 4.4 |
| 12 | 4580 | 4680 | 677 | 229 | 134 | 787 | 236 | 316 | 3.7 |
| 13 | 4680 | 4880 | 757 | 118 | 634 | 391 | 328 | | 3.6 |
| 14 | 4880 | 4955 | 580 | 238 | 282 | 366 | 527 | 631 | 3.6 |
| 15 | 4955 | 4975 | Inadequate deflection bowl | | | | | | |
| 16 | 4975 | 5155 | 558 | 76 | 588 | 152 | 245 | | 3.4 |

Similarly, Table 7.3 lists the moduli estimated from the 2017 deflections. One way to evaluate the performance of the HSG base between 2013 and 2017 is to compare the back-calculated modulus value over the years. Figure 7.15 shows the calculated modulus for 2013 and 2017 in each pavement layer. Figure 7.15(c) compares the HSG base moduli for 2013 and 2017. Based on the results presented here, the HSG moduli measured in 2017 are generally higher than the values measured in 2013 (except for Sections 10, 11 and 12). It is also noted that the modulus values in the lower layers fluctuates between 2013 and 2017. This is likely to have been caused by differences in moisture condition in those layers at the time of taking the readings.

**Table 7.3: Summary of back-calculated elastic moduli values and estimated allowable traffic loading for 2017 deflection data**

| Section | Start chainage (m) | End chainage (m) | Average Back-calculated modulus (MPa) | | | | | | Average Error (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | HSG base | Type 2.3 | Type 2.3 | Subgrade | Subgrade | Subgrade | |
| 1 | 575 | 1465 | 731 | 101 | 273 | 162 | 231 | | 2.0 |
| 2 | 1465 | 1608 | 675 | 156 | 314 | 353 | 531 | | 5.9 |
| 3 | 1608 | 1692 | 706 | 245 | 143 | 172 | 400 | 649 | 2.5 |
| 4 | 1692 | 1855 | 797 | 171 | 460 | 611 | 736 | 628 | 5.7 |
| 5 | 1855 | 1995 | 747 | 220 | 182 | 354 | 502 | 489 | 4.4 |
| 6 | 1995 | 2307 | 741 | 97 | 126 | 242 | 391 | | 3.4 |
| 7 | 2307 | 2905 | 778 | 144 | 235 | 288 | 555 | | 5.1 |
| 8 | 2905 | 3005 | 660 | 107 | 495 | 485 | 641 | | 3.7 |
| 9 | 3005 | 4155 | 740 | 124 | 174 | 240 | 427 | 322 | 3.7 |
| 10 | 4155 | 4405 | 616 | 172 | 84 | 201 | 429 | 263 | 2.6 |
| 11 | 4405 | 4580 | 660 | 176 | 109 | 154 | 364 | | 2.4 |
| 12 | 4580 | 4680 | 611 | 181 | 57 | 138 | 236 | 297 | 2.0 |
| 13 | 4680 | 4880 | 768 | 126 | 141 | 181 | 328 | | 2.2 |
| 14 | 4880 | 4955 | 645 | 137 | 70 | 300 | 527 | 608 | 5.5 |
| 15 | 4955 | 4975 | Inadequate deflection bowl | | | | | | |
| 16 | 4975 | 5155 | 587 | 73 | 73 | 144 | 245 | | 2.9 |

The allowable traffic loadings estimated from the moduli back-calculated from the 2013 and 2017 deflections are shown in Table 7.4 and Table 7.5, respectively. The forward calculations was conducted on selected representative deflection bowl (where the maximum deflection is equal to or exceed the 90$^{th}$ percentile $D_0$ deflection within Site 1, Site 2 & Site 3, respectively). This approach should provide a conservative estimation of the allowable traffic loading for the three sections. The locations of the three deflection bowl is shown in Figure 7.16. It is noted that the selected deflection bowls for all three sites are located between Ch. 4000 and 5000 m.

**Figure 7.15: Modulus values measured in 2013 and 2017**

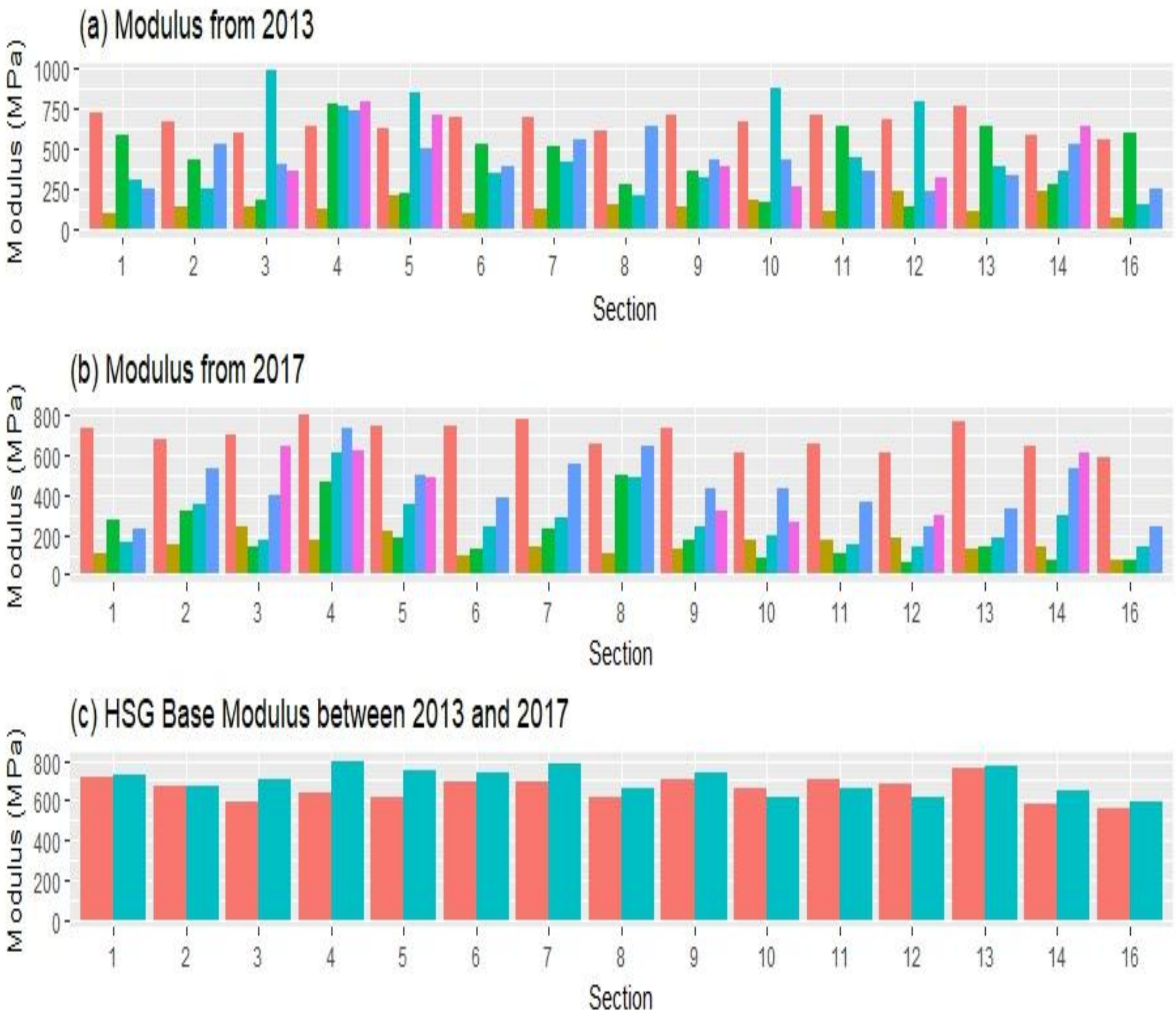
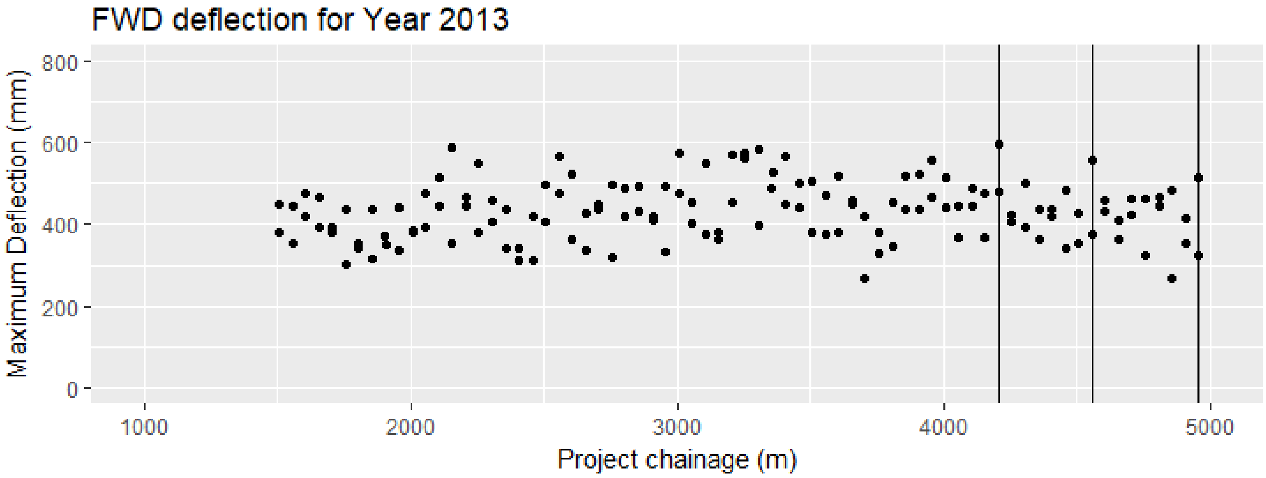


**Figure 7.16: Maximum FWD deflection measured in 2013 and 2017 and location of the three deflection bowl selected for forward calculations**



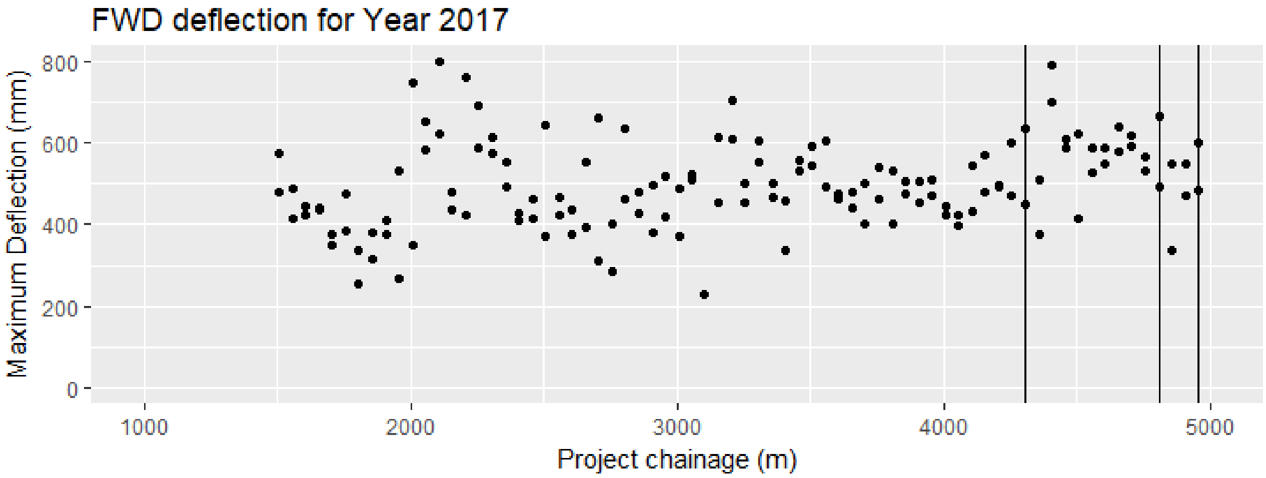



Table 7.4: General mechanistic procedure allowable traffic loadings from the 2013 FWD deflection data

| Site | Layer | Material type | Thickness (mm) | Modulus of representative bowl | Allowable traffic loading (ESAs) |
|---|---|---|---|---|---|
| 1 | 1 | HSG base | 220 | 546 | 1.47E+11 |
| | 2 | Granular subbase | 150 | 73 | |
| | 3 | Subgrade | 300 | 338 | |
| | 4 | Subgrade | 500 | 249 | |
| | 5 | Subgrade | 0 | 283 | |
| 2 | 1 | HSG base | 220 | 548 | 2.67E+09 |
| | 2 | Granular upper subbase | 150 | 169 | |
| | 3 | Granular lower subase | 100 | 95 | |
| | 4 | Subgrade | 300 | 151 | |
| | 5 | Subgrade | 500 | 349 | |
| | 6 | Subgrade | 0 | 498 | |
| 3 | 1 | HSG base | 220 | 624 | 4.44E+12 |
| | 2 | Granular upper subase | 150 | 207 | |
| | 3 | Granular lower subbase | 140 | 92 | |
| | 4 | Subgrade | 300 | 1000 | |
| | 5 | Subgrade | 500 | 143 | |
| | 6 | Subgrade | 0 | 212 | |

**Table 7.5: General mechanistic procedure allowable traffic loadings from the 2017 FWD deflection data**

| Case | Layer | Material type | Thickness (mm) | Modulus of representative bowl | Allowable traffic loading (ESAs) |
|---|---|---|---|---|---|
| 1 | 1 | Granular | 220 | 591 | 6.49E+07 |
| | 2 | Granular | 150 | 79 | |
| | 3 | Subgrade | 300 | 103 | |
| | 4 | Subgrade | 500 | 154 | |
| | 5 | Subgrade | 0 | 248 | |
| 2 | 1 | Granular | 220 | 599 | 1.93E+09 |
| | 2 | Granular | 150 | 111 | |
| | 3 | Granular | 100 | 50 | |
| | 4 | Subgrade | 300 | 132 | |
| | 5 | Subgrade | 500 | 318 | |
| | 6 | Subgrade | 0 | 360 | |
| 3 | 1 | Granular | 220 | 534 | 5.29E+08 |
| | 2 | Granular | 150 | 206 | |
| | 3 | Granular | 140 | 63 | |
| | 4 | Subgrade | 300 | 93 | |
| | 5 | Subgrade | 500 | 202 | |
| | 6 | Subgrade | 0 | 262 | |

Based on the GMP method on the representative deflection bowl for Site 1, Site 2 and Site 3. From the 2013 and 2017 deflection data the minimum allowable traffic loading was estimated to be 2.7 x $10^9$ ESA and 6.5 x $10^7$ ESA, respectively. These values exceed the original 10 year design traffic loading of 1.0 x $10^7$ ESA. In addition it is noted that since being opened to traffic 30-40% of the 10 year design traffic is expected to have already passed. With this in mind, the pavement is considered to be performing well.

# 8 SUMMARY

Unbound granular pavement structures can be an economical pavement alternative and are utilised widely throughout Australia. However, reduced structural capacity and reliability (compared to more expensive pavement alternatives such as asphalt, cement stabilised or concrete (rigid) pavements), has typically restricted the use of unbound pavements to rural applications with light to moderate traffic. HSG base is a premium quality unbound granular material providing improved mechanical properties and consistency. HSG base has been successfully used both nationally and internationally, but the associated production infrastructure, quality assurance techniques and construction experience are not common to Queensland.

The performance of a heavy-duty unbound granular pavement, SG(HD), incorporating HSG base in a moderate to heavy traffic rural application is being demonstrated as part of the duplication of the Centenary Motorway (TrackStar Alliance project) - this project is part of Stage 2 of the Darra to Springfield transport corridor development. The HSG base and seal trial included approximately 4.65 km of the northbound pavement structure between Springfield Parkway and the Logan Motorway interchange. Construction of the trial pavement began in June 2013 and was completed in October 2013.

The use of HSG base was previously demonstrated in Queensland as part of the Gatton Bypass duplication. The Gatton Bypass trial began exhibiting severe distress within six months of construction as a result of a number of factors. Based on this along with the general rise in underperformance of unbound granular pavements in Queensland (Creagh, Wijeyakulasuriya & Williams 2006) close investigation of the Centenary Motorway HSG base trial is warranted to ensure the feasibility of the technology is objectively assessed.

Observation of the Centenary Motorway trial began in August 2013, and was followed by subsequent monitoring surveys conducted using the NSV and the FWD. Based on the information available to-date, after being trafficked for approximately 40% of the pavements 10 year design life, the heavy duty unbound granular pavement constructed on the Centenary Highway as part of the TrackStar Alliance Project is performing satisfactorily.

While there are some signs of continuing pavement deterioration (for example, increased roughness, increased rutting and increased deflection), the pavement is considered to be performing as expected. Throughout the four year monitoring period, the data collected and observations made on the pavement do not suggest earlier maintenance intervention is required.

FWD testing and back analysis of the deflection data shows the overall pavement strength has reduced since initial construction, however the modulus of the base course has generally increased or remained steady. Overall the remaining pavement life calculated still significantly exceeds the residual design life anticipated for the pavement.

It is suggested that the condition of the pavement continue to be monitored to gauge its performance against other pavement types across the full design life (and potentially beyond).

For future monitoring it is noted that the section between Ch. 4300 – 4800 m in the fast lane continues to have poorer performance when compared with the rest of the project. This is believed to be the result of inherent compaction problem as reported back in 2013. This section needs detailed monitoring accordingly.

## 8.1 Conclusions and Recommendations

A project specification was developed to increase reliability and mitigate the risk of premature failure associated with HSG base material quality and construction practice. The specification took the form of MRTS05 (TMR 2011a) modified with a project-specific annexure MRTS05.01 (TrackStar Alliance 2013). Modifications to MRTS05 included conformance testing of both stockpile and in-pavement material, tighter material property limits, mandatory use of a mechanical aggregate spreader, determination of a maximum DOS limit from repeat-load triaxial testing, and submission of the HSG mix design and CMS for administrator approval prior to construction.

Material properties and subsequent characterisation testing for selection and ranking of candidate material is critical to ensuring long-term performance. The HSG material requirements were developed in consideration of Australian best practice, as exhibited by Class 1 unbound granular materials in Victoria (VicRoads 2011). The conformance testing results for hardness/toughness, soundness, particle shape and plasticity characteristics were consistent and, for the most part, conforming to the project specification. However, significant variability was observed in the distribution of particle sizes, as demonstrated in Figure 4.13.

The blending of crushed aggregates and fines in the required proportions for HSG material is best conducted using instrumented conveyor belts and a pug mill as opposed to on the quarry floor, as was undertaken for production of the HSG basecourse material on the TrackStar project. Precise metering allows for better control of the end product and would likely have reduced the number of nonconforming lots. It should be noted that 70% of the in-pavement HSG base material lots were observed to be nonconforming due to excessive coarse material (13.2 mm to 2.36 mm). This is probably the result of improper sampling techniques, but could also be the consequence of a minor degree of segregation.

The impact of pavement construction practices on the quality of the final product is well established. The structural capacity of the constructed pavement generally meets or exceeds the expectation from the initial design. The excessive rutting measurements (recorded prior to opening to traffic) were probably the result of improper compaction and moisture control in underlying layers. Despite the additional specification provisions for the HSG base, unsatisfactory construction practice utilised for the subgrade and subbase layers has likely resulted in a less-than-desirable as-constructed pavement.

The provision of a SG(HD) pavement incorporating HSG base, consistent with best practice, was pursued through the application of project specific design, material specification and construction practices. Best practice was established by referencing requirements for Class 1 and G1 unbound granular materials in Victoria (VicRoads 2011) and South Africa (COLTO 1998) respectively.

The HSG material production and underlying layer construction practices adopted by the project resulted in the provision of an unbound granular pavement representative of the current best practice in Queensland.

With the exception of improvements that could be made in the blending of the product at the quarry, this project has demonstrated the successful application of the HSG base technology in Queensland. When selecting the appropriate pavement type for a project, other project-specific factors not considered in this study also needs to be taken into account. Professional engineers with relevant experience and knowledge should consult with the Queensland Department of Transport and Main Roads to decide the most appropriate pavement solution to meet the district's needs.

**Recommendations**

Recommendations resulting from the investigation include:

- Conformance requirements should include only testing methods indicative of pavement performance measured at the appropriate frequency. Additionally, immediate corrective action should be taken when non-conformances are detected.
- Repeat-load triaxial and wheel tracking tests should be routinely utilised to assess moisture sensitivity and permanent deformation resistance. However, the associated material ranking and selection methodology requires additional investigation.
- The maintenance program for the Centenary Motorway duplication trial pavement should focus on minimising potential for moisture intrusion, due to the negative effect of elevated moisture contents (> 60% OMC) on the modulus and permanent deformation resistance of the HSG material. The performance of unbound granular pavements depends on the DOS limits not being exceeded in all layers, particularly in base layers, during the service life.
- Replication of Australian aggregate production best practice, as demonstrated in Victoria, should be pursued through engagement with Queensland aggregate producers.
- Assessment of critical pavement performance measures, such as surface evenness and horizontal deviation, should be conducted throughout construction, as opposed to at completion, to allow for early modification of practice to ensure a conforming structure is produced.
- High risk projects, such as the Centenary Motorway duplication, require high-standard materials, construction practice and quality control processes.

## 8.2 Implementation

Specifying high standard granular base materials provides the opportunity for unbound pavements to be constructed in traffic environments that would conventionally have been considered unsuitable.

When selecting these heavy duty unbound [SG(HD)] pavements as an alternative to traditional solutions such as heavy duty asphalt or cement stabilised pavements, it must be understood that the initial capital cost saving may be offset by some performance risks that may be lead to an increase in maintenance expenditure.

While early maintenance intervention has not been required on the Centenary Motorway heavy duty unbound pavement, these pavements may be more prone to underperformance as a result of only slight departures from the ideal construction or specification requirements when compared to other pavement types in the same traffic environment.

To facilitate the future use of heavy duty unbound pavements in Queensland, TMR published the following documents in July 2017, based in part on the outcomes of this research project along with industry feedback.

- An update to Technical Specification MRTS05 *Unbound Pavements,* specifying the requirements for High Standard Granular Base as Type 1 (HSG), and
- Technical Note 171 Use of High Standard Granular (HSG) Bases in Heavy Duty Unbound Granular Pavements

Additional guidance regarding the use of SG(HD) pavements is also available in TMR's *Pavement Design Supplement.*

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# APPENDIX A SUMMARY FWD DEFLECTION DATA

| Year (Month) | Testing Control Line | Measured Chainage (m) | Load (kN) | Stress (kPa) | Deflection in microns at distance from load in mm | | | | | | | | | Normalised to 566 kPa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0 | 200 | 300 | 450 | 600 | 750 | 900 | 1200 | 1500 | D0 | D900 | Curvature | Deflection Ratio |
| 2013 (October) | Fast Lane BWP | 1775 | 40.4 | 571 | 467 | 276 | 173 | 106 | 75 | 60 | 45 | 34 | 22 | 463 | 45 | 189 | 0.48 |
| 2013 (October) | Fast Lane BWP | 1825 | 40.3 | 570 | 361 | 216 | 149 | 92 | 62 | 49 | 35 | 28 | 20 | 358 | 35 | 144 | 0.51 |
| 2013 (October) | Fast Lane BWP | 1875 | 40.4 | 571 | 381 | 260 | 161 | 96 | 67 | 56 | 45 | 35 | 24 | 378 | 45 | 120 | 0.55 |
| 2013 (October) | Fast Lane BWP | 1925 | 40.1 | 567 | 260 | 148 | 88 | 56 | 43 | 36 | 28 | 24 | 20 | 259 | 28 | 112 | 0.45 |
| 2013 (October) | Fast Lane BWP | 1975 | 40.4 | 571 | 259 | 148 | 93 | 54 | 41 | 35 | 28 | 22 | 16 | 257 | 28 | 110 | 0.47 |
| 2013 (October) | Fast Lane BWP | 2025 | 40.2 | 569 | 340 | 189 | 123 | 74 | 54 | 45 | 36 | 28 | 19 | 338 | 36 | 150 | 0.46 |
| 2013 (October) | Fast Lane BWP | 2075 | 40.1 | 567 | 384 | 215 | 142 | 86 | 65 | 55 | 44 | 34 | 23 | 383 | 44 | 169 | 0.46 |
| 2013 (October) | Fast Lane BWP | 2125 | 40.3 | 570 | 432 | 265 | 181 | 117 | 89 | 74 | 58 | 44 | 29 | 429 | 58 | 166 | 0.52 |
| 2013 (October) | Fast Lane BWP | 2475 | 38.1 | 539 | 344 | 183 | 109 | 62 | 43 | 36 | 29 | 22 | 15 | 361 | 30 | 169 | 0.42 |
| 2013 (October) | Fast Lane BWP | 2525 | 37.9 | 536 | 374 | 210 | 143 | 89 | 57 | 45 | 33 | 24 | 14 | 395 | 35 | 173 | 0.47 |
| 2013 (October) | Fast Lane BWP | 2575 | 37.8 | 535 | 325 | 171 | 108 | 65 | 48 | 40 | 31 | 22 | 13 | 344 | 33 | 163 | 0.43 |
| 2013 (October) | Fast Lane BWP | 2625 | 37.9 | 536 | 339 | 193 | 121 | 75 | 55 | 43 | 30 | 23 | 15 | 358 | 32 | 154 | 0.46 |
| 2013 (October) | Fast Lane BWP | 2676 | 37.5 | 530 | 281 | 149 | 93 | 54 | 37 | 30 | 23 | 17 | 11 | 300 | 25 | 141 | 0.43 |
| 2013 (October) | Fast Lane BWP | 2725 | 37.6 | 532 | 271 | 153 | 83 | 37 | 21 | 17 | 13 | 13 | 12 | 288 | 14 | 126 | 0.44 |
| 2013 (October) | Fast Lane BWP | 2775 | 38.1 | 539 | 418 | 279 | 187 | 112 | 70 | 55 | 39 | 28 | 16 | 439 | 41 | 146 | 0.56 |
| 2013 (October) | Fast Lane BWP | 2825 | 37.3 | 528 | 256 | 126 | 70 | 40 | 28 | 24 | 19 | 15 | 11 | 274 | 20 | 139 | 0.38 |
| 2013 (October) | Fast Lane BWP | 2875 | 37.5 | 531 | 273 | 159 | 101 | 64 | 44 | 37 | 29 | 22 | 14 | 291 | 31 | 121 | 0.48 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane BWP | 2925 | 37.7 | 533 | 282 | 178 | 110 | 66 | 46 | 37 | 27 | 20 | 13 | 299 | 29 | 110 | 0.51 |
| 2013 (October) | Fast Lane BWP | 2975 | 36.9 | 522 | 339 | 218 | 142 | 91 | 61 | 49 | 36 | 27 | 18 | 367 | 39 | 131 | 0.53 |
| 2013 (October) | Fast Lane BWP | 3025 | 37.2 | 526 | 316 | 193 | 128 | 78 | 54 | 42 | 30 | 22 | 14 | 340 | 32 | 132 | 0.51 |
| 2013 (October) | Fast Lane BWP | 3075 | 37.3 | 527 | 343 | 204 | 130 | 80 | 57 | 44 | 31 | 24 | 16 | 368 | 33 | 149 | 0.49 |
| 2013 (October) | Fast Lane BWP | 3125 | 37.0 | 524 | 322 | 208 | 130 | 76 | 51 | 42 | 32 | 24 | 15 | 348 | 35 | 123 | 0.52 |
| 2013 (October) | Fast Lane BWP | 3175 | 37.5 | 530 | 436 | 282 | 176 | 105 | 75 | 59 | 42 | 32 | 21 | 466 | 45 | 164 | 0.53 |
| 2013 (October) | Fast Lane BWP | 3225 | 37.4 | 529 | 356 | 226 | 143 | 87 | 58 | 46 | 34 | 26 | 17 | 381 | 36 | 139 | 0.52 |
| 2013 (October) | Fast Lane BWP | 3275 | 37.6 | 532 | 274 | 153 | 101 | 62 | 39 | 32 | 25 | 18 | 10 | 291 | 27 | 129 | 0.46 |
| 2013 (October) | Fast Lane BWP | 3325 | 37.9 | 536 | 379 | 245 | 148 | 91 | 57 | 43 | 28 | 17 | 6 | 400 | 30 | 141 | 0.52 |
| 2013 (October) | Fast Lane BWP | 3375 | 37.3 | 528 | 226 | 116 | 57 | 24 | 16 | 15 | 14 | 10 | 5 | 242 | 15 | 118 | 0.38 |
| 2013 (October) | Fast Lane BWP | 3425 | 37.7 | 533 | 360 | 233 | 148 | 84 | 59 | 48 | 36 | 25 | 13 | 382 | 38 | 135 | 0.53 |
| 2013 (October) | Fast Lane BWP | 3475 | 37.6 | 532 | 342 | 216 | 134 | 75 | 45 | 36 | 26 | 19 | 11 | 364 | 28 | 134 | 0.51 |
| 2013 (October) | Fast Lane BWP | 3526 | 37.3 | 527 | 397 | 263 | 177 | 108 | 74 | 57 | 39 | 28 | 17 | 426 | 42 | 144 | 0.55 |
| 2013 (October) | Fast Lane BWP | 3575 | 37.3 | 527 | 256 | 156 | 98 | 57 | 31 | 21 | 11 | 8 | 4 | 275 | 12 | 107 | 0.50 |
| 2013 (October) | Fast Lane BWP | 3625 | 37.0 | 524 | 383 | 248 | 161 | 100 | 71 | 54 | 36 | 27 | 17 | 414 | 39 | 146 | 0.53 |
| 2013 (October) | Fast Lane BWP | 3675 | 37.8 | 535 | 389 | 251 | 156 | 90 | 59 | 48 | 36 | 26 | 16 | 411 | 38 | 146 | 0.52 |
| 2013 (October) | Fast Lane BWP | 3725 | 36.7 | 519 | 280 | 157 | 84 | 45 | 29 | 24 | 18 | 13 | 7 | 305 | 20 | 134 | 0.43 |
| 2013 (October) | Fast Lane BWP | 3775 | 36.9 | 522 | 321 | 198 | 132 | 80 | 59 | 48 | 37 | 28 | 18 | 348 | 40 | 133 | 0.51 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane BWP | 3826 | 36.8 | 521 | 265 | 160 | 109 | 70 | 51 | 43 | 35 | 25 | 15 | 288 | 38 | 114 | 0.51 |
| 2013 (October) | Fast Lane BWP | 3875 | 36.9 | 522 | 300 | 177 | 105 | 61 | 38 | 33 | 28 | 20 | 12 | 325 | 30 | 133 | 0.47 |
| 2013 (October) | Fast Lane BWP | 3925 | 36.8 | 521 | 329 | 202 | 123 | 74 | 51 | 44 | 36 | 28 | 20 | 357 | 39 | 138 | 0.49 |
| 2013 (October) | Fast Lane BWP | 3975 | 37.2 | 526 | 302 | 187 | 104 | 58 | 38 | 34 | 30 | 21 | 12 | 325 | 32 | 124 | 0.48 |
| 2013 (October) | Fast Lane BWP | 4025 | 37.7 | 533 | 400 | 261 | 170 | 106 | 70 | 54 | 38 | 27 | 16 | 425 | 40 | 148 | 0.54 |
| 2013 (October) | Fast Lane BWP | 4050 | 38.1 | 539 | 314 | 215 | 150 | 99 | 72 | 58 | 43 | 31 | 19 | 330 | 45 | 104 | 0.58 |
| 2013 (October) | Fast Lane BWP | 4125 | 37.4 | 529 | 337 | 199 | 133 | 79 | 47 | 37 | 27 | 20 | 12 | 360 | 29 | 148 | 0.49 |
| 2013 (October) | Fast Lane BWP | 4175 | 38.1 | 539 | 380 | 252 | 162 | 99 | 70 | 55 | 39 | 29 | 19 | 399 | 41 | 134 | 0.54 |
| 2013 (October) | Fast Lane BWP | 4225 | 37.7 | 533 | 462 | 294 | 189 | 120 | 86 | 67 | 47 | 34 | 21 | 491 | 50 | 178 | 0.52 |
| 2013 (October) | Fast Lane BWP | 4275 | 37.9 | 536 | 377 | 225 | 132 | 69 | 42 | 32 | 21 | 15 | 8 | 398 | 22 | 160 | 0.47 |
| 2013 (October) | Fast Lane BWP | 4325 | 37.7 | 533 | 365 | 235 | 167 | 108 | 72 | 57 | 42 | 31 | 20 | 388 | 45 | 138 | 0.55 |
| 2013 (October) | Fast Lane BWP | 4375 | 37.5 | 530 | 348 | 204 | 135 | 82 | 53 | 41 | 29 | 22 | 14 | 372 | 31 | 154 | 0.49 |
| 2013 (October) | Fast Lane BWP | 4425 | 38.4 | 543 | 424 | 272 | 182 | 100 | 60 | 46 | 31 | 22 | 13 | 442 | 32 | 158 | 0.54 |
| 2013 (October) | Fast Lane BWP | 4475 | 37.9 | 536 | 428 | 273 | 178 | 100 | 65 | 55 | 44 | 30 | 15 | 452 | 46 | 164 | 0.53 |
| 2013 (October) | Fast Lane BWP | 4525 | 37.4 | 529 | 324 | 193 | 125 | 79 | 53 | 41 | 29 | 23 | 16 | 347 | 31 | 140 | 0.49 |
| 2013 (October) | Fast Lane BWP | 4575 | 37.3 | 527 | 350 | 199 | 133 | 81 | 55 | 43 | 30 | 22 | 13 | 376 | 32 | 162 | 0.47 |
| 2013 (October) | Fast Lane BWP | 4625 | 37.5 | 530 | 321 | 183 | 112 | 69 | 45 | 35 | 24 | 18 | 11 | 343 | 26 | 147 | 0.46 |
| 2013 (October) | Fast Lane BWP | 5205 | 40.0 | 566 | 299 | 167 | 111 | 77 | 61 | 53 | 44 | 35 | 26 | 299 | 44 | 132 | 0.46 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane BWP | 5225 | 40.0 | 566 | 236 | 126 | 79 | 60 | 49 | 42 | 35 | 28 | 20 | 236 | 35 | 110 | 0.43 |
| 2013 (October) | Fast Lane BWP | 5275 | 40.4 | 571 | 363 | 223 | 144 | 92 | 68 | 57 | 45 | 36 | 26 | 360 | 45 | 139 | 0.51 |
| 2013 (October) | Fast Lane BWP | 5325 | 40.6 | 574 | 308 | 174 | 107 | 60 | 39 | 31 | 22 | 18 | 13 | 304 | 22 | 132 | 0.46 |
| 2013 (October) | Fast Lane BWP | 5375 | 40.6 | 575 | 389 | 225 | 147 | 85 | 57 | 47 | 37 | 29 | 21 | 383 | 36 | 161 | 0.48 |
| 2013 (October) | Fast Lane BWP | 5425 | 40.9 | 578 | 348 | 209 | 136 | 82 | 56 | 45 | 34 | 27 | 19 | 341 | 33 | 136 | 0.50 |
| 2013 (October) | Fast Lane BWP | 5475 | 41.0 | 580 | 334 | 199 | 134 | 88 | 55 | 45 | 34 | 27 | 19 | 326 | 33 | 132 | 0.50 |
| 2013 (October) | Fast Lane BWP | 5525 | 41.6 | 589 | 389 | 244 | 163 | 98 | 69 | 55 | 40 | 31 | 21 | 374 | 38 | 139 | 0.52 |
| 2013 (October) | Fast Lane BWP | 5575 | 41.4 | 586 | 353 | 217 | 143 | 91 | 66 | 55 | 43 | 34 | 24 | 341 | 42 | 131 | 0.51 |
| 2013 (October) | Fast Lane BWP | 5625 | 41.6 | 589 | 373 | 227 | 151 | 95 | 65 | 52 | 38 | 31 | 23 | 358 | 37 | 140 | 0.51 |
| 2013 (October) | Fast Lane BWP | 5675 | 41.9 | 593 | 375 | 239 | 153 | 92 | 62 | 49 | 36 | 28 | 19 | 358 | 34 | 130 | 0.52 |
| 2013 (October) | Fast Lane BWP | 5725 | 41.5 | 587 | 343 | 198 | 123 | 72 | 56 | 46 | 35 | 26 | 17 | 331 | 34 | 140 | 0.47 |
| 2013 (October) | Fast Lane BWP | 5775 | 42.3 | 599 | 385 | 232 | 148 | 92 | 66 | 54 | 42 | 33 | 23 | 364 | 40 | 145 | 0.49 |
| 2013 (October) | Fast Lane BWP | 5825 | 42.4 | 600 | 337 | 204 | 132 | 81 | 54 | 43 | 31 | 24 | 16 | 318 | 29 | 125 | 0.50 |
| 2013 (October) | Fast Lane BWP | 5875 | 43.3 | 613 | 364 | 214 | 130 | 82 | 60 | 48 | 36 | 27 | 18 | 336 | 33 | 138 | 0.47 |
| 2013 (October) | Fast Lane OWP | 1750 | 41.1 | 581 | 442 | 297 | 217 | 138 | 92 | 73 | 53 | 41 | 29 | 431 | 52 | 141 | 0.58 |
| 2013 (October) | Fast Lane OWP | 1800 | 41.7 | 590 | 460 | 288 | 186 | 114 | 79 | 63 | 47 | 37 | 27 | 441 | 45 | 165 | 0.52 |
| 2013 (October) | Fast Lane OWP | 1850 | 41.6 | 588 | 440 | 280 | 187 | 109 | 71 | 57 | 42 | 31 | 20 | 423 | 40 | 154 | 0.53 |
| 2013 (October) | Fast Lane OWP | 1900 | 41.0 | 580 | 413 | 252 | 162 | 97 | 69 | 57 | 44 | 36 | 27 | 403 | 43 | 157 | 0.50 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane OWP | 1950 | 41.2 | 583 | 274 | 150 | 100 | 64 | 46 | 38 | 29 | 22 | 14 | 266 | 28 | 120 | 0.46 |
| 2013 (October) | Fast Lane OWP | 2000 | 40.9 | 578 | 313 | 172 | 112 | 77 | 62 | 54 | 45 | 36 | 26 | 306 | 44 | 138 | 0.45 |
| 2013 (October) | Fast Lane OWP | 2050 | 41.0 | 580 | 360 | 216 | 134 | 85 | 63 | 52 | 40 | 30 | 20 | 351 | 39 | 140 | 0.49 |
| 2013 (October) | Fast Lane OWP | 2100 | 41.0 | 580 | 459 | 274 | 199 | 130 | 97 | 79 | 61 | 47 | 33 | 448 | 60 | 180 | 0.52 |
| 2013 (October) | Fast Lane OWP | 2140 | 41.6 | 589 | 459 | 304 | 204 | 129 | 92 | 77 | 61 | 47 | 32 | 441 | 59 | 149 | 0.55 |
| 2013 (October) | Fast Lane OWP | 2450 | 40.1 | 568 | 383 | 227 | 156 | 96 | 70 | 56 | 41 | 30 | 18 | 382 | 41 | 155 | 0.50 |
| 2013 (October) | Fast Lane OWP | 2500 | 40.0 | 566 | 297 | 151 | 93 | 54 | 33 | 27 | 20 | 15 | 9 | 297 | 20 | 146 | 0.41 |
| 2013 (October) | Fast Lane OWP | 2550 | 40.4 | 571 | 325 | 187 | 114 | 59 | 39 | 32 | 24 | 18 | 12 | 322 | 24 | 137 | 0.46 |
| 2013 (October) | Fast Lane OWP | 2600 | 40.0 | 566 | 308 | 157 | 103 | 57 | 41 | 34 | 27 | 22 | 16 | 308 | 27 | 151 | 0.42 |
| 2013 (October) | Fast Lane OWP | 2650 | 40.1 | 567 | 254 | 138 | 84 | 46 | 32 | 27 | 21 | 16 | 11 | 254 | 21 | 116 | 0.44 |
| 2013 (October) | Fast Lane OWP | 2700 | 39.9 | 565 | 249 | 128 | 80 | 51 | 30 | 23 | 16 | 11 | 5 | 249 | 16 | 121 | 0.42 |
| 2013 (October) | Fast Lane OWP | 2750 | 40.1 | 568 | 366 | 225 | 154 | 93 | 66 | 50 | 33 | 25 | 16 | 365 | 33 | 140 | 0.52 |
| 2013 (October) | Fast Lane OWP | 2800 | 39.7 | 562 | 263 | 128 | 64 | 30 | 19 | 16 | 13 | 11 | 9 | 265 | 13 | 136 | 0.37 |
| 2013 (October) | Fast Lane OWP | 2850 | 40.6 | 575 | 256 | 142 | 82 | 48 | 30 | 23 | 16 | 10 | 4 | 252 | 16 | 112 | 0.44 |
| 2013 (October) | Fast Lane OWP | 2900 | 39.5 | 559 | 330 | 202 | 125 | 77 | 58 | 47 | 35 | 27 | 19 | 334 | 35 | 130 | 0.50 |
| 2013 (October) | Fast Lane OWP | 2950 | 39.7 | 562 | 351 | 215 | 144 | 84 | 56 | 44 | 32 | 24 | 15 | 353 | 32 | 137 | 0.51 |
| 2013 (October) | Fast Lane OWP | 3000 | 39.4 | 557 | 399 | 262 | 183 | 116 | 84 | 66 | 48 | 34 | 20 | 405 | 49 | 139 | 0.56 |
| 2013 (October) | Fast Lane OWP | 3050 | 39.7 | 562 | 468 | 301 | 213 | 136 | 90 | 71 | 52 | 39 | 25 | 471 | 52 | 168 | 0.55 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane OWP | 3100 | 39.7 | 561 | 367 | 245 | 163 | 96 | 65 | 54 | 42 | 31 | 20 | 370 | 42 | 123 | 0.56 |
| 2013 (October) | Fast Lane OWP | 3150 | 39.5 | 559 | 360 | 220 | 133 | 80 | 59 | 51 | 42 | 32 | 21 | 364 | 43 | 142 | 0.49 |
| 2013 (October) | Fast Lane OWP | 3200 | 39.6 | 560 | 431 | 277 | 177 | 98 | 61 | 46 | 31 | 24 | 16 | 436 | 31 | 156 | 0.53 |
| 2013 (October) | Fast Lane OWP | 3250 | 39.6 | 560 | 360 | 210 | 127 | 71 | 49 | 39 | 29 | 23 | 17 | 364 | 29 | 152 | 0.47 |
| 2013 (October) | Fast Lane OWP | 3300 | 39.3 | 556 | 282 | 152 | 94 | 56 | 40 | 33 | 26 | 21 | 16 | 287 | 26 | 132 | 0.44 |
| 2013 (October) | Fast Lane OWP | 3350 | 39.7 | 562 | 286 | 150 | 79 | 45 | 29 | 22 | 14 | 10 | 6 | 288 | 14 | 137 | 0.40 |
| 2013 (October) | Fast Lane OWP | 3400 | 39.9 | 564 | 297 | 167 | 79 | 41 | 24 | 20 | 16 | 14 | 11 | 298 | 16 | 130 | 0.41 |
| 2013 (October) | Fast Lane OWP | 3450 | 39.5 | 559 | 335 | 211 | 139 | 84 | 46 | 34 | 22 | 16 | 9 | 339 | 22 | 126 | 0.52 |
| 2013 (October) | Fast Lane OWP | 3500 | 39.6 | 560 | 445 | 267 | 176 | 104 | 66 | 49 | 31 | 21 | 10 | 450 | 31 | 180 | 0.50 |
| 2013 (October) | Fast Lane OWP | 3550 | 39.2 | 555 | 362 | 219 | 143 | 90 | 56 | 42 | 28 | 22 | 16 | 369 | 29 | 146 | 0.50 |
| 2013 (October) | Fast Lane OWP | 3600 | 38.7 | 547 | 352 | 242 | 183 | 129 | 94 | 75 | 56 | 42 | 27 | 364 | 58 | 114 | 0.60 |
| 2013 (October) | Fast Lane OWP | 3650 | 39.1 | 553 | 407 | 245 | 171 | 105 | 69 | 54 | 38 | 29 | 19 | 416 | 39 | 166 | 0.51 |
| 2013 (October) | Fast Lane OWP | 3700 | 39.1 | 553 | 325 | 181 | 120 | 70 | 45 | 36 | 27 | 20 | 13 | 333 | 28 | 147 | 0.46 |
| 2013 (October) | Fast Lane OWP | 3750 | 39.1 | 553 | 338 | 186 | 113 | 64 | 41 | 34 | 26 | 21 | 15 | 346 | 27 | 156 | 0.44 |
| 2013 (October) | Fast Lane OWP | 3800 | 38.9 | 550 | 352 | 212 | 151 | 101 | 75 | 65 | 55 | 42 | 28 | 362 | 57 | 144 | 0.52 |
| 2013 (October) | Fast Lane OWP | 3850 | 38.5 | 545 | 286 | 156 | 95 | 54 | 37 | 31 | 24 | 20 | 16 | 297 | 25 | 135 | 0.44 |
| 2013 (October) | Fast Lane OWP | 3900 | 38.6 | 546 | 311 | 166 | 108 | 61 | 40 | 30 | 19 | 13 | 6 | 322 | 20 | 150 | 0.44 |
| 2013 (October) | Fast Lane OWP | 3950 | 39.2 | 554 | 378 | 216 | 138 | 80 | 54 | 43 | 32 | 26 | 20 | 386 | 33 | 165 | 0.47 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane OWP | 4000 | 39.4 | 558 | 368 | 204 | 133 | 80 | 61 | 48 | 35 | 27 | 19 | 373 | 35 | 166 | 0.46 |
| 2013 (October) | Fast Lane OWP | 4050 | 39.4 | 557 | 407 | 248 | 165 | 105 | 75 | 61 | 46 | 36 | 25 | 413 | 47 | 162 | 0.51 |
| 2013 (October) | Fast Lane OWP | 4100 | 38.9 | 551 | 243 | 116 | 78 | 59 | 45 | 37 | 28 | 21 | 13 | 250 | 29 | 130 | 0.40 |
| 2013 (October) | Fast Lane OWP | 4150 | 39.5 | 559 | 362 | 226 | 152 | 96 | 66 | 53 | 39 | 30 | 20 | 366 | 39 | 138 | 0.52 |
| 2013 (October) | Fast Lane OWP | 4200 | 39.2 | 554 | 354 | 211 | 149 | 98 | 71 | 57 | 43 | 32 | 20 | 362 | 44 | 146 | 0.51 |
| 2013 (October) | Fast Lane OWP | 4250 | 39.4 | 557 | 450 | 292 | 205 | 128 | 90 | 67 | 43 | 29 | 15 | 457 | 44 | 161 | 0.55 |
| 2013 (October) | Fast Lane OWP | 4300 | 39.9 | 564 | 394 | 228 | 144 | 79 | 45 | 31 | 16 | 11 | 6 | 395 | 16 | 167 | 0.47 |
| 2013 (October) | Fast Lane OWP | 4350 | 38.9 | 551 | 427 | 275 | 202 | 138 | 99 | 83 | 66 | 49 | 31 | 439 | 68 | 156 | 0.56 |
| 2013 (October) | Fast Lane OWP | 4400 | 39.5 | 559 | 367 | 235 | 159 | 96 | 63 | 48 | 32 | 24 | 15 | 372 | 32 | 134 | 0.54 |
| 2013 (October) | Fast Lane OWP | 4450 | 39.5 | 559 | 368 | 216 | 139 | 82 | 51 | 40 | 28 | 21 | 13 | 373 | 28 | 154 | 0.48 |
| 2013 (October) | Fast Lane OWP | 4500 | 38.9 | 551 | 406 | 247 | 167 | 97 | 61 | 49 | 36 | 28 | 20 | 417 | 37 | 163 | 0.51 |
| 2013 (October) | Fast Lane OWP | 4550 | 38.7 | 548 | 333 | 194 | 126 | 74 | 49 | 39 | 28 | 21 | 14 | 344 | 29 | 144 | 0.48 |
| 2013 (October) | Fast Lane OWP | 4600 | 38.5 | 545 | 320 | 188 | 131 | 81 | 54 | 40 | 26 | 19 | 12 | 332 | 27 | 137 | 0.50 |
| 2013 (October) | Fast Lane OWP | 4650 | 38.6 | 546 | 237 | 141 | 103 | 67 | 46 | 36 | 25 | 18 | 10 | 246 | 26 | 99 | 0.51 |
| 2013 (October) | Fast Lane OWP | 5205 | 39.4 | 557 | 271 | 159 | 107 | 74 | 59 | 52 | 44 | 37 | 29 | 275 | 45 | 114 | 0.49 |
| 2013 (October) | Fast Lane OWP | 5250 | 39.5 | 559 | 267 | 162 | 111 | 81 | 60 | 50 | 39 | 30 | 21 | 270 | 39 | 106 | 0.51 |
| 2013 (October) | Fast Lane OWP | 5300 | 39.8 | 563 | 346 | 214 | 145 | 93 | 64 | 52 | 40 | 32 | 23 | 348 | 40 | 133 | 0.52 |
| 2013 (October) | Fast Lane OWP | 5350 | 39.8 | 563 | 311 | 182 | 124 | 77 | 59 | 47 | 34 | 27 | 20 | 313 | 34 | 130 | 0.49 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Fast Lane OWP | 5400 | 40.0 | 566 | 288 | 174 | 120 | 75 | 52 | 42 | 32 | 25 | 17 | 288 | 32 | 114 | 0.51 |
| 2013 (October) | Fast Lane OWP | 5450 | 39.9 | 564 | 217 | 119 | 83 | 55 | 48 | 40 | 31 | 25 | 19 | 218 | 31 | 98 | 0.47 |
| 2013 (October) | Fast Lane OWP | 5500 | 40.5 | 573 | 350 | 228 | 147 | 87 | 58 | 47 | 35 | 27 | 18 | 346 | 35 | 120 | 0.54 |
| 2013 (October) | Fast Lane OWP | 5550 | 40.4 | 572 | 324 | 196 | 135 | 85 | 60 | 48 | 36 | 28 | 20 | 321 | 36 | 127 | 0.51 |
| 2013 (October) | Fast Lane OWP | 5600 | 40.2 | 569 | 292 | 173 | 124 | 85 | 65 | 55 | 44 | 34 | 24 | 290 | 44 | 118 | 0.51 |
| 2013 (October) | Fast Lane OWP | 5650 | 40.9 | 578 | 407 | 264 | 175 | 106 | 70 | 53 | 36 | 28 | 19 | 398 | 35 | 140 | 0.54 |
| 2013 (October) | Fast Lane OWP | 5700 | 40.3 | 570 | 298 | 185 | 128 | 82 | 58 | 48 | 37 | 29 | 21 | 296 | 37 | 112 | 0.53 |
| 2013 (October) | Fast Lane OWP | 5750 | 40.6 | 574 | 371 | 222 | 145 | 94 | 67 | 54 | 41 | 32 | 23 | 366 | 40 | 147 | 0.49 |
| 2013 (October) | Fast Lane OWP | 5800 | 40.6 | 574 | 391 | 242 | 146 | 82 | 58 | 49 | 40 | 31 | 21 | 385 | 39 | 147 | 0.50 |
| 2013 (October) | Fast Lane OWP | 5850 | 41.5 | 587 | 364 | 214 | 131 | 72 | 44 | 35 | 26 | 25 | 23 | 351 | 25 | 145 | 0.47 |
| 2013 (October) | Fast Lane OWP | 5900 | 40.6 | 575 | 317 | 193 | 135 | 85 | 58 | 44 | 30 | 22 | 13 | 312 | 30 | 122 | 0.52 |
| 2013 (October) | Slow Lane BWP | 2075 | 39.9 | 565 | 397 | 247 | 163 | 109 | 80 | 67 | 53 | 39 | 25 | 398 | 53 | 150 | 0.52 |
| 2013 (October) | Slow Lane BWP | 2125 | 39.9 | 565 | 398 | 239 | 164 | 112 | 85 | 72 | 58 | 46 | 33 | 399 | 58 | 159 | 0.51 |
| 2013 (October) | Slow Lane BWP | 2140 | 40.3 | 570 | 491 | 301 | 219 | 141 | 104 | 85 | 65 | 49 | 32 | 487 | 65 | 189 | 0.53 |
| 2013 (October) | Slow Lane BWP | 2450 | 36.5 | 516 | 301 | 166 | 101 | 64 | 48 | 40 | 31 | 22 | 13 | 330 | 34 | 148 | 0.44 |
| 2013 (October) | Slow Lane BWP | 2500 | 36.6 | 518 | 278 | 133 | 76 | 41 | 30 | 23 | 16 | 11 | 6 | 304 | 17 | 158 | 0.38 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane BWP | 2550 | 36.5 | 517 | 315 | 164 | 94 | 54 | 37 | 28 | 18 | 14 | 9 | 345 | 20 | 165 | 0.41 |
| 2013 (October) | Slow Lane BWP | 2600 | 37.0 | 523 | 374 | 225 | 150 | 92 | 64 | 51 | 38 | 27 | 16 | 405 | 41 | 161 | 0.50 |
| 2013 (October) | Slow Lane BWP | 2650 | 37.0 | 524 | 300 | 158 | 89 | 50 | 28 | 23 | 17 | 12 | 6 | 324 | 18 | 153 | 0.41 |
| 2013 (October) | Slow Lane BWP | 2700 | 36.8 | 520 | 246 | 133 | 76 | 43 | 30 | 23 | 16 | 12 | 7 | 268 | 17 | 123 | 0.42 |
| 2013 (October) | Slow Lane BWP | 2750 | 36.4 | 515 | 239 | 113 | 71 | 42 | 25 | 21 | 16 | 12 | 8 | 263 | 18 | 138 | 0.38 |
| 2013 (October) | Slow Lane BWP | 2800 | 36.2 | 512 | 225 | 98 | 52 | 27 | 15 | 14 | 12 | 10 | 7 | 249 | 13 | 140 | 0.33 |
| 2013 (October) | Slow Lane BWP | 2850 | 37.1 | 525 | 263 | 135 | 73 | 45 | 29 | 23 | 16 | 11 | 6 | 283 | 17 | 138 | 0.40 |
| 2013 (October) | Slow Lane BWP | 2900 | 36.1 | 511 | 249 | 128 | 78 | 52 | 37 | 31 | 24 | 19 | 13 | 276 | 27 | 134 | 0.41 |
| 2013 (October) | Slow Lane BWP | 2950 | 37.4 | 529 | 340 | 203 | 124 | 81 | 55 | 41 | 27 | 20 | 13 | 364 | 29 | 147 | 0.48 |
| 2013 (October) | Slow Lane BWP | 3000 | 37.3 | 527 | 372 | 230 | 153 | 95 | 64 | 48 | 32 | 24 | 15 | 399 | 34 | 152 | 0.51 |
| 2013 (October) | Slow Lane BWP | 3050 | 36.6 | 518 | 353 | 209 | 124 | 78 | 52 | 41 | 30 | 23 | 15 | 386 | 33 | 157 | 0.47 |
| 2013 (October) | Slow Lane BWP | 3100 | 37.4 | 529 | 421 | 265 | 176 | 108 | 71 | 53 | 34 | 30 | 25 | 450 | 36 | 167 | 0.52 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane BWP | 3150 | 36.4 | 515 | 283 | 153 | 92 | 59 | 39 | 34 | 29 | 23 | 17 | 311 | 32 | 143 | 0.43 |
| 2013 (October) | Slow Lane BWP | 3200 | 37.2 | 526 | 383 | 204 | 133 | 79 | 50 | 39 | 28 | 22 | 15 | 412 | 30 | 193 | 0.44 |
| 2013 (October) | Slow Lane BWP | 3250 | 37.0 | 524 | 347 | 206 | 130 | 73 | 50 | 38 | 26 | 19 | 12 | 375 | 28 | 152 | 0.48 |
| 2013 (October) | Slow Lane BWP | 3300 | 36.7 | 519 | 289 | 190 | 120 | 70 | 50 | 42 | 34 | 26 | 17 | 315 | 37 | 108 | 0.54 |
| 2013 (October) | Slow Lane BWP | 3350 | 36.9 | 522 | 244 | 122 | 62 | 31 | 16 | 14 | 12 | 9 | 5 | 265 | 13 | 132 | 0.38 |
| 2013 (October) | Slow Lane BWP | 3400 | 37.0 | 524 | 394 | 128 | 73 | 37 | 26 | 19 | 11 | 8 | 4 | 425 | 12 | 287 | 0.26 |
| 2013 (October) | Slow Lane BWP | 3450 | 37.3 | 527 | 371 | 231 | 135 | 74 | 45 | 34 | 23 | 17 | 10 | 398 | 25 | 150 | 0.49 |
| 2013 (October) | Slow Lane BWP | 3500 | 37.0 | 523 | 350 | 210 | 137 | 75 | 42 | 31 | 19 | 14 | 9 | 379 | 21 | 151 | 0.50 |
| 2013 (October) | Slow Lane BWP | 3550 | 37.3 | 527 | 343 | 208 | 128 | 80 | 57 | 44 | 30 | 22 | 13 | 368 | 32 | 145 | 0.49 |
| 2013 (October) | Slow Lane BWP | 3600 | 36.9 | 522 | 342 | 214 | 145 | 99 | 76 | 63 | 50 | 35 | 19 | 371 | 54 | 139 | 0.52 |
| 2013 (October) | Slow Lane BWP | 3650 | 36.7 | 519 | 329 | 206 | 128 | 79 | 54 | 42 | 30 | 22 | 14 | 359 | 33 | 134 | 0.51 |
| 2013 (October) | Slow Lane BWP | 3700 | 37.1 | 525 | 319 | 179 | 107 | 59 | 39 | 32 | 24 | 18 | 11 | 344 | 26 | 151 | 0.45 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane BWP | 3750 | 36.8 | 521 | 318 | 175 | 111 | 66 | 45 | 35 | 25 | 19 | 12 | 345 | 27 | 155 | 0.45 |
| 2013 (October) | Slow Lane BWP | 3800 | 37.1 | 525 | 328 | 203 | 134 | 83 | 60 | 48 | 36 | 28 | 19 | 354 | 39 | 135 | 0.51 |
| 2013 (October) | Slow Lane BWP | 3850 | 37.3 | 528 | 327 | 191 | 123 | 71 | 43 | 33 | 23 | 18 | 12 | 350 | 25 | 146 | 0.48 |
| 2013 (October) | Slow Lane BWP | 3900 | 37.3 | 527 | 290 | 170 | 113 | 64 | 41 | 29 | 17 | 13 | 8 | 311 | 18 | 129 | 0.49 |
| 2013 (October) | Slow Lane BWP | 3950 | 37.3 | 527 | 326 | 184 | 105 | 61 | 42 | 34 | 26 | 20 | 14 | 350 | 28 | 152 | 0.44 |
| 2013 (October) | Slow Lane BWP | 4000 | 37.0 | 523 | 363 | 218 | 149 | 88 | 57 | 45 | 33 | 25 | 16 | 393 | 36 | 157 | 0.51 |
| 2013 (October) | Slow Lane BWP | 4050 | 37.3 | 528 | 406 | 264 | 182 | 119 | 83 | 63 | 42 | 26 | 10 | 435 | 45 | 152 | 0.55 |
| 2013 (October) | Slow Lane BWP | 4100 | 37.3 | 527 | 377 | 226 | 148 | 84 | 54 | 41 | 27 | 19 | 11 | 405 | 29 | 162 | 0.50 |
| 2013 (October) | Slow Lane BWP | 4150 | 37.0 | 524 | 305 | 189 | 132 | 87 | 63 | 48 | 33 | 23 | 13 | 329 | 36 | 125 | 0.53 |
| 2013 (October) | Slow Lane BWP | 4200 | 37.1 | 525 | 401 | 255 | 181 | 108 | 73 | 57 | 40 | 29 | 18 | 432 | 43 | 157 | 0.54 |
| 2013 (October) | Slow Lane BWP | 4250 | 36.8 | 521 | 450 | 281 | 194 | 128 | 89 | 71 | 53 | 36 | 19 | 489 | 58 | 184 | 0.53 |
| 2013 (October) | Slow Lane BWP | 4300 | 37.4 | 529 | 361 | 207 | 118 | 60 | 36 | 28 | 20 | 15 | 10 | 386 | 21 | 165 | 0.45 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane BWP | 4350 | 37.4 | 529 | 437 | 284 | 202 | 127 | 87 | 68 | 49 | 35 | 21 | 467 | 52 | 164 | 0.56 |
| 2013 (October) | Slow Lane BWP | 4400 | 37.3 | 527 | 402 | 244 | 160 | 89 | 57 | 44 | 30 | 21 | 12 | 432 | 32 | 170 | 0.50 |
| 2013 (October) | Slow Lane BWP | 4450 | 37.4 | 529 | 418 | 260 | 176 | 97 | 61 | 46 | 31 | 22 | 12 | 447 | 33 | 169 | 0.52 |
| 2013 (October) | Slow Lane BWP | 4500 | 36.9 | 522 | 310 | 183 | 116 | 70 | 48 | 38 | 28 | 20 | 12 | 336 | 30 | 138 | 0.48 |
| 2013 (October) | Slow Lane BWP | 4549 | 37.3 | 528 | 395 | 244 | 155 | 91 | 58 | 44 | 30 | 22 | 14 | 423 | 32 | 162 | 0.51 |
| 2013 (October) | Slow Lane BWP | 4600 | 37.5 | 530 | 378 | 218 | 147 | 85 | 56 | 44 | 31 | 23 | 14 | 404 | 33 | 171 | 0.48 |
| 2013 (October) | Slow Lane BWP | 4650 | 37.5 | 531 | 316 | 189 | 127 | 81 | 54 | 42 | 29 | 20 | 11 | 337 | 31 | 135 | 0.50 |
| 2013 (October) | Slow Lane BWP | 5650 | 39.1 | 553 | 333 | 189 | 126 | 79 | 55 | 43 | 30 | 24 | 17 | 341 | 31 | 147 | 0.47 |
| 2013 (October) | Slow Lane BWP | 5700 | 38.8 | 549 | 279 | 169 | 110 | 75 | 54 | 46 | 37 | 28 | 19 | 288 | 38 | 113 | 0.50 |
| 2013 (October) | Slow Lane BWP | 5750 | 39.2 | 555 | 343 | 203 | 134 | 85 | 62 | 50 | 37 | 28 | 19 | 350 | 38 | 143 | 0.49 |
| 2013 (October) | Slow Lane BWP | 5800 | 38.7 | 547 | 281 | 152 | 97 | 66 | 52 | 44 | 36 | 30 | 24 | 291 | 37 | 133 | 0.44 |
| 2013 (October) | Slow Lane BWP | 5850 | 39.5 | 559 | 264 | 129 | 76 | 43 | 35 | 26 | 16 | 13 | 10 | 267 | 16 | 137 | 0.39 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane BWP | 5900 | 39.2 | 555 | 324 | 178 | 116 | 67 | 47 | 36 | 25 | 19 | 12 | 330 | 25 | 149 | 0.45 |
| 2013 (October) | Slow Lane OWP | 2025 | 40.4 | 572 | 414 | 256 | 175 | 108 | 75 | 59 | 43 | 32 | 21 | 410 | 43 | 156 | 0.52 |
| 2013 (October) | Slow Lane OWP | 2075 | 40.8 | 577 | 410 | 250 | 175 | 118 | 84 | 70 | 55 | 40 | 24 | 402 | 54 | 157 | 0.52 |
| 2013 (October) | Slow Lane OWP | 2125 | 40.1 | 568 | 369 | 216 | 155 | 106 | 80 | 67 | 54 | 42 | 30 | 368 | 54 | 152 | 0.50 |
| 2013 (October) | Slow Lane OWP | 2475 | 38.0 | 538 | 284 | 147 | 94 | 55 | 41 | 33 | 24 | 18 | 11 | 299 | 25 | 144 | 0.42 |
| 2013 (October) | Slow Lane OWP | 2525 | 37.9 | 536 | 252 | 145 | 95 | 65 | 46 | 36 | 25 | 20 | 14 | 266 | 26 | 113 | 0.48 |
| 2013 (October) | Slow Lane OWP | 2575 | 37.5 | 531 | 299 | 157 | 100 | 64 | 43 | 35 | 27 | 20 | 13 | 319 | 29 | 151 | 0.43 |
| 2013 (October) | Slow Lane OWP | 2625 | 37.5 | 530 | 266 | 156 | 98 | 62 | 44 | 37 | 29 | 20 | 11 | 284 | 31 | 117 | 0.48 |
| 2013 (October) | Slow Lane OWP | 2675 | 38.1 | 539 | 291 | 157 | 93 | 54 | 38 | 31 | 23 | 17 | 11 | 306 | 24 | 141 | 0.43 |
| 2013 (October) | Slow Lane OWP | 2725 | 37.5 | 530 | 231 | 101 | 49 | 22 | 13 | 11 | 9 | 8 | 7 | 247 | 10 | 139 | 0.32 |
| 2013 (October) | Slow Lane OWP | 2775 | 38.1 | 539 | 306 | 163 | 100 | 56 | 41 | 33 | 24 | 17 | 10 | 321 | 25 | 150 | 0.43 |
| 2013 (October) | Slow Lane OWP | 2825 | 37.5 | 531 | 238 | 109 | 64 | 34 | 22 | 20 | 17 | 14 | 11 | 254 | 18 | 137 | 0.36 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane OWP | 2875 | 37.7 | 533 | 256 | 120 | 75 | 47 | 35 | 30 | 25 | 18 | 11 | 272 | 27 | 144 | 0.38 |
| 2013 (October) | Slow Lane OWP | 2925 | 37.4 | 529 | 266 | 138 | 91 | 56 | 39 | 32 | 24 | 17 | 9 | 285 | 26 | 137 | 0.43 |
| 2013 (October) | Slow Lane OWP | 2975 | 37.9 | 536 | 302 | 191 | 129 | 82 | 58 | 45 | 32 | 25 | 17 | 319 | 34 | 117 | 0.53 |
| 2013 (October) | Slow Lane OWP | 3025 | 37.9 | 536 | 300 | 175 | 112 | 66 | 50 | 40 | 29 | 21 | 13 | 317 | 31 | 132 | 0.48 |
| 2013 (October) | Slow Lane OWP | 3075 | 38.3 | 542 | 335 | 198 | 124 | 66 | 45 | 36 | 27 | 21 | 15 | 350 | 28 | 143 | 0.48 |
| 2013 (October) | Slow Lane OWP | 3125 | 38.4 | 543 | 329 | 189 | 116 | 67 | 45 | 38 | 30 | 22 | 13 | 343 | 31 | 146 | 0.46 |
| 2013 (October) | Slow Lane OWP | 3175 | 37.8 | 535 | 336 | 193 | 133 | 76 | 54 | 46 | 38 | 30 | 21 | 355 | 40 | 151 | 0.49 |
| 2013 (October) | Slow Lane OWP | 3225 | 38.3 | 542 | 266 | 175 | 125 | 80 | 52 | 43 | 33 | 24 | 15 | 278 | 34 | 95 | 0.56 |
| 2013 (October) | Slow Lane OWP | 3275 | 38.7 | 547 | 249 | 147 | 81 | 44 | 29 | 26 | 23 | 17 | 11 | 258 | 24 | 106 | 0.46 |
| 2013 (October) | Slow Lane OWP | 3325 | 39.5 | 559 | 343 | 219 | 138 | 75 | 50 | 36 | 21 | 15 | 9 | 347 | 21 | 126 | 0.52 |
| 2013 (October) | Slow Lane OWP | 3375 | 39.2 | 554 | 251 | 132 | 74 | 41 | 18 | 15 | 11 | 9 | 6 | 256 | 11 | 122 | 0.41 |
| 2013 (October) | Slow Lane OWP | 3425 | 39.1 | 553 | 293 | 174 | 110 | 62 | 39 | 32 | 24 | 18 | 12 | 300 | 25 | 122 | 0.48 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane OWP | 3475 | 38.5 | 545 | 356 | 197 | 128 | 78 | 49 | 38 | 27 | 20 | 12 | 370 | 28 | 165 | 0.46 |
| 2013 (October) | Slow Lane OWP | 3525 | 39.3 | 556 | 366 | 220 | 153 | 93 | 62 | 50 | 37 | 28 | 18 | 373 | 38 | 149 | 0.51 |
| 2013 (October) | Slow Lane OWP | 3575 | 39.5 | 559 | 279 | 148 | 87 | 43 | 27 | 19 | 11 | 8 | 5 | 282 | 11 | 133 | 0.42 |
| 2013 (October) | Slow Lane OWP | 3625 | 38.4 | 543 | 246 | 150 | 108 | 71 | 52 | 42 | 32 | 23 | 14 | 256 | 33 | 100 | 0.52 |
| 2013 (October) | Slow Lane OWP | 3674 | 38.8 | 549 | 351 | 213 | 135 | 88 | 59 | 45 | 31 | 24 | 17 | 362 | 32 | 142 | 0.50 |
| 2013 (October) | Slow Lane OWP | 3725 | 38.7 | 548 | 278 | 167 | 104 | 57 | 39 | 30 | 20 | 15 | 9 | 287 | 21 | 115 | 0.49 |
| 2013 (October) | Slow Lane OWP | 3775 | 38.9 | 550 | 341 | 198 | 135 | 85 | 62 | 51 | 39 | 30 | 20 | 351 | 40 | 147 | 0.49 |
| 2013 (October) | Slow Lane OWP | 3825 | 37.7 | 534 | 252 | 145 | 106 | 72 | 48 | 40 | 32 | 24 | 16 | 267 | 34 | 113 | 0.50 |
| 2013 (October) | Slow Lane OWP | 3875 | 37.8 | 535 | 247 | 129 | 79 | 47 | 30 | 23 | 16 | 12 | 7 | 261 | 17 | 125 | 0.42 |
| 2013 (October) | Slow Lane OWP | 3925 | 39.0 | 552 | 362 | 222 | 132 | 74 | 46 | 36 | 25 | 19 | 13 | 371 | 26 | 144 | 0.49 |
| 2013 (October) | Slow Lane OWP | 3975 | 40.0 | 566 | 379 | 236 | 164 | 90 | 50 | 38 | 25 | 22 | 19 | 379 | 25 | 143 | 0.53 |
| 2013 (October) | Slow Lane OWP | 4025 | 38.5 | 545 | 368 | 233 | 167 | 105 | 72 | 56 | 40 | 30 | 20 | 382 | 42 | 140 | 0.54 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane OWP | 4090 | 38.5 | 545 | 264 | 165 | 115 | 71 | 49 | 38 | 26 | 19 | 12 | 274 | 27 | 103 | 0.53 |
| 2013 (October) | Slow Lane OWP | 4125 | 39.0 | 552 | 385 | 248 | 162 | 97 | 61 | 48 | 34 | 24 | 14 | 395 | 35 | 140 | 0.53 |
| 2013 (October) | Slow Lane OWP | 4175 | 38.5 | 545 | 356 | 215 | 137 | 73 | 49 | 37 | 25 | 19 | 12 | 370 | 26 | 146 | 0.49 |
| 2013 (October) | Slow Lane OWP | 4225 | 38.9 | 550 | 608 | 404 | 260 | 149 | 88 | 65 | 41 | 29 | 16 | 626 | 42 | 210 | 0.55 |
| 2013 (October) | Slow Lane OWP | 4275 | 39.1 | 553 | 629 | 427 | 301 | 177 | 111 | 81 | 50 | 37 | 24 | 644 | 51 | 207 | 0.58 |
| 2013 (October) | Slow Lane OWP | 4325 | 38.5 | 545 | 370 | 235 | 161 | 101 | 72 | 55 | 37 | 27 | 16 | 384 | 38 | 140 | 0.54 |
| 2013 (October) | Slow Lane OWP | 4375 | 39.1 | 553 | 449 | 285 | 188 | 105 | 64 | 48 | 31 | 24 | 16 | 459 | 32 | 168 | 0.53 |
| 2013 (October) | Slow Lane OWP | 4425 | 38.9 | 551 | 482 | 316 | 210 | 127 | 84 | 66 | 47 | 36 | 24 | 495 | 48 | 170 | 0.55 |
| 2013 (October) | Slow Lane OWP | 4475 | 38.8 | 549 | 417 | 259 | 168 | 93 | 56 | 42 | 28 | 20 | 11 | 430 | 29 | 163 | 0.51 |
| 2013 (October) | Slow Lane OWP | 4525 | 38.7 | 547 | 460 | 282 | 198 | 129 | 88 | 68 | 47 | 31 | 15 | 476 | 49 | 184 | 0.52 |
| 2013 (October) | Slow Lane OWP | 4575 | 39.0 | 552 | 368 | 225 | 146 | 83 | 56 | 44 | 32 | 24 | 16 | 377 | 33 | 147 | 0.50 |
| 2013 (October) | Slow Lane OWP | 4625 | 38.8 | 549 | 379 | 222 | 149 | 86 | 53 | 40 | 27 | 19 | 11 | 391 | 28 | 162 | 0.49 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane OWP | 5205 | 39.9 | 564 | 336 | 208 | 140 | 95 | 71 | 61 | 50 | 40 | 30 | 337 | 50 | 128 | 0.52 |
| 2013 (October) | Slow Lane OWP | 5225 | 39.2 | 554 | 355 | 212 | 160 | 99 | 65 | 51 | 37 | 30 | 23 | 363 | 38 | 146 | 0.52 |
| 2013 (October) | Slow Lane OWP | 5275 | 38.6 | 546 | 312 | 182 | 137 | 98 | 75 | 65 | 55 | 42 | 29 | 323 | 57 | 135 | 0.51 |
| 2013 (October) | Slow Lane OWP | 5325 | 39.2 | 554 | 327 | 178 | 115 | 65 | 42 | 33 | 23 | 18 | 12 | 334 | 23 | 152 | 0.45 |
| 2013 (October) | Slow Lane OWP | 5375 | 38.9 | 550 | 351 | 206 | 131 | 76 | 51 | 42 | 32 | 26 | 19 | 361 | 33 | 149 | 0.48 |
| 2013 (October) | Slow Lane OWP | 5425 | 39.3 | 556 | 365 | 207 | 137 | 73 | 49 | 39 | 28 | 23 | 17 | 371 | 28 | 161 | 0.47 |
| 2013 (October) | Slow Lane OWP | 5475 | 39.2 | 554 | 331 | 192 | 128 | 76 | 53 | 44 | 35 | 28 | 20 | 338 | 36 | 142 | 0.48 |
| 2013 (October) | Slow Lane OWP | 5525 | 39.3 | 556 | 354 | 211 | 140 | 83 | 57 | 45 | 33 | 26 | 18 | 360 | 34 | 146 | 0.50 |
| 2013 (October) | Slow Lane OWP | 5575 | 39.2 | 555 | 340 | 201 | 143 | 97 | 71 | 58 | 44 | 34 | 23 | 347 | 45 | 142 | 0.51 |
| 2013 (October) | Slow Lane OWP | 5625 | 39.4 | 558 | 349 | 196 | 133 | 83 | 60 | 49 | 38 | 29 | 19 | 354 | 39 | 155 | 0.47 |
| 2013 (October) | Slow Lane OWP | 5675 | 40.5 | 573 | 358 | 220 | 143 | 88 | 60 | 48 | 35 | 26 | 17 | 354 | 35 | 136 | 0.51 |
| 2013 (October) | Slow Lane OWP | 5725 | 39.5 | 559 | 310 | 176 | 114 | 68 | 48 | 40 | 31 | 24 | 17 | 314 | 31 | 136 | 0.47 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 (October) | Slow Lane OWP | 5775 | 40.0 | 566 | 307 | 176 | 112 | 70 | 52 | 43 | 34 | 26 | 18 | 307 | 34 | 131 | 0.47 |
| 2013 (October) | Slow Lane OWP | 5825 | 40.1 | 568 | 292 | 164 | 111 | 71 | 50 | 39 | 28 | 21 | 13 | 291 | 28 | 128 | 0.47 |
| 2013 (October) | Slow Lane OWP | 5875 | 40.4 | 571 | 304 | 164 | 112 | 68 | 52 | 42 | 31 | 25 | 18 | 301 | 31 | 139 | 0.45 |

| Year (Month) | Testing Control Line | Measured Chainage (m) | Load (kN) | Stress (kPa) | Deflection in microns at distance from load in mm | | | | | | | | | | Normalised to 566 kPa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0 | 200 | 250 | 300 | 450 | 600 | 750 | 900 | 1200 | 1500 | D0 | D900 | Curvature | Deflection Ratio |
| 2017 (May) | Fast Lane BWP | 2000 | 40.1 | 568 | 582 | 373 | 315 | 256 | 160 | 108 | 76 | 58 | 39 | 29 | 580 | 58 | 208 | 0.54 |
| 2017 (May) | Fast Lane BWP | 2100 | 39.8 | 563 | 573 | 385 | 328 | 270 | 178 | 121 | 91 | 71 | 56 | 42 | 576 | 72 | 189 | 0.58 |
| 2017 (May) | Fast Lane BWP | 2200 | 40.1 | 567 | 485 | 323 | 280 | 238 | 157 | 109 | 83 | 66 | 48 | 39 | 484 | 66 | 162 | 0.58 |
| 2017 (May) | Fast Lane BWP | 2300 | 40.5 | 573 | 441 | 306 | 265 | 224 | 156 | 119 | 95 | 76 | 57 | 45 | 436 | 75 | 134 | 0.59 |
| 2017 (May) | Fast Lane BWP | 2400 | 40.9 | 579 | 540 | 338 | 292 | 245 | 161 | 113 | 84 | 62 | 42 | 26 | 528 | 61 | 198 | 0.53 |
| 2017 (May) | Fast Lane BWP | 2500 | 40.2 | 569 | 493 | 304 | 253 | 201 | 124 | 77 | 52 | 37 | 25 | 19 | 491 | 36 | 188 | 0.51 |
| 2017 (May) | Fast Lane BWP | 2600 | 40.6 | 574 | 443 | 273 | 230 | 187 | 124 | 86 | 65 | 49 | 32 | 23 | 437 | 49 | 168 | 0.51 |
| 2017 (May) | Fast Lane BWP | 2700 | 39.9 | 565 | 475 | 316 | 271 | 226 | 152 | 97 | 72 | 56 | 38 | 28 | 475 | 56 | 159 | 0.57 |
| 2017 (May) | Fast Lane BWP | 2800 | 39.6 | 560 | 377 | 205 | 160 | 116 | 61 | 37 | 29 | 22 | 19 | 12 | 381 | 22 | 174 | 0.43 |
| 2017 (May) | Fast Lane BWP | 2900 | 40.2 | 569 | 536 | 339 | 284 | 230 | 150 | 101 | 69 | 50 | 29 | 20 | 533 | 50 | 196 | 0.53 |
| 2017 (May) | Fast Lane BWP | 3000 | 39.7 | 562 | 649 | 434 | 378 | 322 | 205 | 130 | 88 | 64 | 39 | 28 | 653 | 65 | 216 | 0.59 |
| 2017 (May) | Fast Lane BWP | 3100 | 40.1 | 568 | 482 | 298 | 251 | 204 | 129 | 82 | 56 | 45 | 34 | 19 | 481 | 45 | 183 | 0.52 |
| 2017 (May) | Fast Lane BWP | 3200 | 40.1 | 567 | 692 | 461 | 397 | 334 | 218 | 139 | 89 | 57 | 32 | 23 | 691 | 57 | 231 | 0.57 |
| 2017 (May) | Fast Lane BWP | 3300 | 40.0 | 566 | 492 | 305 | 255 | 204 | 113 | 63 | 38 | 25 | 15 | 11 | 492 | 25 | 187 | 0.52 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Fast Lane BWP | 3400 | 40.1 | 568 | 463 | 277 | 228 | 178 | 102 | 61 | 40 | 27 | 16 | 11 | 462 | 27 | 185 | 0.49 |
| 2017 (May) | Fast Lane BWP | 3500 | 40.5 | 573 | 430 | 260 | 216 | 173 | 106 | 68 | 44 | 31 | 18 | 12 | 425 | 31 | 168 | 0.50 |
| 2017 (May) | Fast Lane BWP | 3600 | 40.1 | 568 | 556 | 354 | 305 | 256 | 170 | 113 | 76 | 55 | 31 | 20 | 554 | 55 | 201 | 0.55 |
| 2017 (May) | Fast Lane BWP | 3700 | 40.2 | 569 | 404 | 244 | 200 | 157 | 89 | 56 | 38 | 29 | 20 | 14 | 402 | 29 | 160 | 0.49 |
| 2017 (May) | Fast Lane BWP | 3800 | 40.0 | 566 | 429 | 267 | 232 | 197 | 130 | 91 | 70 | 55 | 40 | 31 | 429 | 55 | 162 | 0.54 |
| 2017 (May) | Fast Lane BWP | 3900 | 40.1 | 568 | 421 | 254 | 203 | 152 | 84 | 53 | 36 | 28 | 18 | 13 | 419 | 27 | 166 | 0.48 |
| 2017 (May) | Fast Lane BWP | 4000 | 40.3 | 570 | 515 | 332 | 285 | 238 | 154 | 104 | 75 | 58 | 38 | 27 | 511 | 57 | 182 | 0.55 |
| 2017 (May) | Fast Lane BWP | 4100 | 40.4 | 571 | 459 | 300 | 257 | 213 | 136 | 89 | 62 | 49 | 30 | 22 | 454 | 48 | 157 | 0.56 |
| 2017 (May) | Fast Lane BWP | 4200 | 40.5 | 573 | 507 | 343 | 288 | 233 | 148 | 101 | 73 | 51 | 34 | 23 | 501 | 50 | 162 | 0.56 |
| 2017 (May) | Fast Lane BWP | 4300 | 39.9 | 564 | 498 | 304 | 255 | 206 | 126 | 78 | 51 | 41 | 23 | 34 | 500 | 41 | 195 | 0.51 |
| 2017 (May) | Fast Lane BWP | 4400 | 40.4 | 571 | 535 | 342 | 286 | 231 | 140 | 85 | 52 | 36 | 21 | 16 | 531 | 36 | 192 | 0.53 |
| 2017 (May) | Fast Lane BWP | 4500 | 39.9 | 565 | 490 | 307 | 256 | 204 | 124 | 77 | 53 | 40 | 26 | 19 | 491 | 40 | 183 | 0.52 |
| 2017 (May) | Fast Lane BWP | 4600 | 39.9 | 565 | 440 | 279 | 232 | 186 | 115 | 78 | 53 | 40 | 26 | 17 | 440 | 40 | 161 | 0.53 |
| 2017 (May) | Fast Lane BWP | 4700 | 39.8 | 563 | 458 | 291 | 247 | 204 | 131 | 81 | 55 | 37 | 24 | 15 | 461 | 37 | 168 | 0.54 |
| 2017 (May) | Fast Lane BWP | 4800 | 40.0 | 566 | 506 | 319 | 265 | 211 | 131 | 85 | 61 | 50 | 29 | 27 | 506 | 50 | 188 | 0.52 |
| 2017 (May) | Fast Lane BWP | 4900 | 39.9 | 565 | 511 | 337 | 282 | 227 | 142 | 91 | 62 | 44 | 27 | 19 | 511 | 44 | 174 | 0.55 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Fast Lane BWP | 5000 | 40.2 | 569 | 425 | 259 | 213 | 166 | 102 | 64 | 47 | 36 | 25 | 20 | 423 | 36 | 166 | 0.50 |
| 2017 (May) | Fast Lane BWP | 5100 | 39.9 | 564 | 569 | 380 | 325 | 269 | 177 | 112 | 73 | 50 | 29 | 20 | 571 | 50 | 189 | 0.57 |
| 2017 (May) | Fast Lane BWP | 5200 | 40.0 | 566 | 471 | 296 | 253 | 211 | 143 | 105 | 79 | 62 | 47 | 34 | 471 | 62 | 175 | 0.54 |
| 2017 (May) | Fast Lane BWP | 5300 | 40.6 | 575 | 518 | 314 | 262 | 210 | 132 | 94 | 66 | 51 | 33 | 25 | 510 | 50 | 201 | 0.50 |
| 2017 (May) | Fast Lane BWP | 5400 | 39.9 | 564 | 585 | 380 | 327 | 274 | 186 | 130 | 94 | 71 | 43 | 32 | 587 | 71 | 205 | 0.56 |
| 2017 (May) | Fast Lane BWP | 5500 | 40.6 | 575 | 598 | 386 | 329 | 273 | 182 | 118 | 83 | 59 | 40 | 25 | 588 | 58 | 209 | 0.54 |
| 2017 (May) | Fast Lane BWP | 5600 | 40.3 | 570 | 584 | 384 | 327 | 269 | 179 | 117 | 81 | 59 | 38 | 26 | 580 | 58 | 198 | 0.56 |
| 2017 (May) | Fast Lane BWP | 5700 | 40.7 | 576 | 577 | 377 | 324 | 271 | 183 | 125 | 90 | 67 | 43 | 30 | 567 | 66 | 197 | 0.55 |
| 2017 (May) | Fast Lane BWP | 5800 | 39.7 | 561 | 546 | 347 | 296 | 245 | 162 | 107 | 76 | 59 | 39 | 29 | 551 | 59 | 201 | 0.55 |
| 2017 (May) | Fast Lane BWP | 5900 | 40.6 | 574 | 610 | 396 | 332 | 268 | 164 | 101 | 61 | 47 | 25 | 22 | 602 | 46 | 211 | 0.54 |
| 2017 (May) | Fast Lane BWP | 5950 | 40.5 | 573 | 799 | 526 | 450 | 374 | 230 | 136 | 86 | 59 | 33 | 23 | 789 | 59 | 270 | 0.56 |
| 2017 (May) | Fast Lane BWP | 2000 | 40.0 | 566 | 583 | 394 | 335 | 277 | 171 | 110 | 78 | 59 | 39 | 29 | 583 | 59 | 189 | 0.58 |
| 2017 (May) | Fast Lane BWP | 2050 | 39.9 | 565 | 502 | 308 | 255 | 203 | 119 | 76 | 52 | 41 | 24 | 17 | 503 | 41 | 195 | 0.51 |
| 2017 (May) | Fast Lane BWP | 2150 | 40.1 | 568 | 602 | 396 | 341 | 286 | 178 | 120 | 88 | 72 | 52 | 42 | 600 | 71 | 205 | 0.56 |
| 2017 (May) | Fast Lane BWP | 2250 | 40.1 | 568 | 576 | 377 | 325 | 273 | 183 | 125 | 89 | 70 | 49 | 39 | 574 | 70 | 199 | 0.56 |
| 2017 (May) | Fast Lane BWP | 2350 | 40.1 | 567 | 569 | 395 | 340 | 286 | 198 | 147 | 119 | 97 | 72 | 53 | 567 | 97 | 173 | 0.60 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Fast Lane BWP | 2450 | 40.3 | 570 | 578 | 364 | 302 | 239 | 139 | 77 | 44 | 28 | 16 | 4 | 574 | 28 | 212 | 0.52 |
| 2017 (May) | Fast Lane BWP | 2550 | 40.1 | 568 | 448 | 288 | 235 | 183 | 109 | 67 | 43 | 33 | 20 | 18 | 446 | 33 | 159 | 0.52 |
| 2017 (May) | Fast Lane BWP | 2650 | 40.1 | 568 | 380 | 215 | 174 | 133 | 71 | 39 | 26 | 19 | 13 | 10 | 379 | 19 | 165 | 0.46 |
| 2017 (May) | Fast Lane BWP | 2650 | 40.1 | 568 | 377 | 212 | 171 | 130 | 70 | 39 | 26 | 20 | 13 | 11 | 375 | 19 | 164 | 0.45 |
| 2017 (May) | Fast Lane BWP | 2750 | 40.4 | 572 | 340 | 188 | 155 | 121 | 64 | 38 | 25 | 18 | 13 | 10 | 336 | 18 | 150 | 0.45 |
| 2017 (May) | Fast Lane BWP | 2850 | 40.7 | 576 | 419 | 242 | 194 | 146 | 80 | 51 | 38 | 30 | 22 | 15 | 412 | 29 | 174 | 0.46 |
| 2017 (May) | Fast Lane BWP | 2950 | 40.6 | 574 | 760 | 527 | 457 | 387 | 243 | 148 | 93 | 63 | 37 | 27 | 749 | 62 | 230 | 0.59 |
| 2017 (May) | Fast Lane BWP | 3050 | 39.9 | 564 | 797 | 552 | 475 | 397 | 253 | 154 | 100 | 71 | 40 | 29 | 800 | 71 | 246 | 0.60 |
| 2017 (May) | Fast Lane BWP | 3150 | 40.6 | 574 | 773 | 540 | 465 | 391 | 244 | 157 | 102 | 76 | 47 | 34 | 762 | 74 | 230 | 0.59 |
| 2017 (May) | Fast Lane BWP | 3250 | 40.3 | 570 | 580 | 388 | 331 | 275 | 165 | 97 | 59 | 39 | 16 | 19 | 576 | 39 | 191 | 0.57 |
| 2017 (May) | Fast Lane BWP | 3350 | 40.4 | 572 | 414 | 230 | 182 | 135 | 59 | 26 | 14 | 9 | 5 | 4 | 409 | 9 | 182 | 0.44 |
| 2017 (May) | Fast Lane BWP | 3450 | 39.9 | 564 | 641 | 416 | 351 | 286 | 174 | 99 | 60 | 39 | 21 | 18 | 643 | 39 | 225 | 0.55 |
| 2017 (May) | Fast Lane BWP | 3550 | 40.6 | 574 | 445 | 289 | 244 | 200 | 130 | 88 | 64 | 49 | 32 | 22 | 439 | 48 | 154 | 0.54 |
| 2017 (May) | Fast Lane BWP | 3650 | 39.9 | 565 | 661 | 455 | 394 | 332 | 219 | 142 | 92 | 65 | 39 | 28 | 662 | 66 | 207 | 0.60 |
| 2017 (May) | Fast Lane BWP | 3750 | 40.1 | 568 | 636 | 407 | 347 | 288 | 169 | 93 | 50 | 30 | 16 | 12 | 633 | 29 | 227 | 0.54 |
| 2017 (May) | Fast Lane BWP | 3850 | 40.1 | 568 | 499 | 298 | 247 | 197 | 105 | 55 | 34 | 26 | 17 | 13 | 497 | 25 | 200 | 0.49 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Fast Lane BWP | 3950 | 40.1 | 567 | 487 | 291 | 241 | 191 | 98 | 65 | 40 | 31 | 31 | 24 | 487 | 31 | 196 | 0.49 |
| 2017 (May) | Fast Lane BWP | 4048 | 40.4 | 571 | 232 | 205 | 179 | 152 | 100 | 67 | 49 | 38 | 28 | 22 | 230 | 38 | 26 | 0.76 |
| 2017 (May) | Fast Lane BWP | 4150 | 39.7 | 561 | 698 | 408 | 344 | 280 | 152 | 84 | 46 | 27 | 17 | 13 | 704 | 28 | 293 | 0.50 |
| 2017 (May) | Fast Lane BWP | 4250 | 40.1 | 568 | 606 | 433 | 366 | 300 | 192 | 124 | 82 | 59 | 37 | 25 | 604 | 58 | 173 | 0.60 |
| 2017 (May) | Fast Lane BWP | 4350 | 40.2 | 569 | 459 | 276 | 231 | 187 | 117 | 84 | 64 | 49 | 36 | 29 | 457 | 49 | 182 | 0.50 |
| 2017 (May) | Fast Lane BWP | 4450 | 39.9 | 565 | 542 | 336 | 279 | 223 | 120 | 60 | 35 | 23 | 15 | 7 | 543 | 23 | 206 | 0.52 |
| 2017 (May) | Fast Lane BWP | 4550 | 40.5 | 573 | 481 | 300 | 250 | 200 | 121 | 75 | 46 | 37 | 22 | 18 | 475 | 37 | 179 | 0.51 |
| 2017 (May) | Fast Lane BWP | 4650 | 40.1 | 568 | 504 | 347 | 291 | 236 | 144 | 83 | 50 | 34 | 16 | 13 | 502 | 34 | 157 | 0.58 |
| 2017 (May) | Fast Lane BWP | 4750 | 39.9 | 564 | 529 | 345 | 287 | 229 | 128 | 73 | 44 | 31 | 16 | 12 | 531 | 31 | 185 | 0.54 |
| 2017 (May) | Fast Lane BWP | 4850 | 40.0 | 566 | 506 | 339 | 279 | 219 | 132 | 79 | 52 | 38 | 24 | 15 | 506 | 38 | 167 | 0.55 |
| 2017 (May) | Fast Lane BWP | 4950 | 40.4 | 572 | 452 | 279 | 224 | 168 | 96 | 60 | 40 | 30 | 22 | 23 | 447 | 29 | 170 | 0.49 |
| 2017 (May) | Fast Lane BWP | 5050 | 40.4 | 571 | 550 | 341 | 285 | 229 | 133 | 77 | 59 | 41 | 24 | 17 | 545 | 41 | 207 | 0.51 |
| 2017 (May) | Fast Lane BWP | 5150 | 40.4 | 572 | 502 | 317 | 273 | 229 | 156 | 113 | 80 | 65 | 46 | 36 | 497 | 64 | 183 | 0.54 |
| 2017 (May) | Fast Lane BWP | 5250 | 39.6 | 560 | 627 | 385 | 330 | 275 | 184 | 130 | 90 | 66 | 37 | 31 | 634 | 67 | 245 | 0.53 |
| 2017 (May) | Fast Lane BWP | 5350 | 40.1 | 568 | 792 | 507 | 433 | 358 | 227 | 146 | 101 | 73 | 45 | 36 | 789 | 73 | 283 | 0.54 |
| 2017 (May) | Fast Lane BWP | 5450 | 40.0 | 566 | 624 | 421 | 365 | 309 | 209 | 143 | 100 | 74 | 44 | 33 | 624 | 74 | 203 | 0.59 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Fast Lane BWP | 5550 | 40.1 | 567 | 550 | 362 | 307 | 251 | 168 | 110 | 77 | 56 | 35 | 24 | 549 | 56 | 187 | 0.56 |
| 2017 (May) | Fast Lane BWP | 5650 | 40.3 | 570 | 622 | 417 | 357 | 298 | 201 | 131 | 90 | 65 | 41 | 28 | 618 | 65 | 204 | 0.57 |
| 2017 (May) | Fast Lane BWP | 5750 | 40.5 | 573 | 674 | 442 | 375 | 308 | 192 | 120 | 86 | 63 | 41 | 31 | 666 | 62 | 229 | 0.55 |
| 2017 (May) | Fast Lane BWP | 5850 | 39.8 | 563 | 544 | 333 | 275 | 217 | 130 | 76 | 49 | 33 | 21 | 14 | 547 | 34 | 212 | 0.51 |
| 2017 (May) | Fast Lane BWP | 5950 | 39.5 | 559 | 821 | 540 | 465 | 390 | 228 | 137 | 76 | 50 | 32 | 24 | 831 | 51 | 284 | 0.57 |
| 2017 (May) | Slow Lane BWP | 2100 | 40.3 | 570 | 586 | 391 | 331 | 272 | 178 | 130 | 96 | 76 | 53 | 39 | 582 | 76 | 194 | 0.56 |
| 2017 (May) | Slow Lane BWP | 2150 | 40.1 | 567 | 646 | 454 | 388 | 322 | 214 | 146 | 110 | 87 | 61 | 50 | 645 | 87 | 192 | 0.60 |
| 2017 (May) | Slow Lane BWP | 2250 | 40.4 | 571 | 492 | 322 | 277 | 232 | 147 | 99 | 76 | 60 | 43 | 34 | 488 | 60 | 169 | 0.56 |
| 2017 (May) | Slow Lane BWP | 2350 | 39.9 | 564 | 549 | 353 | 308 | 263 | 181 | 136 | 111 | 95 | 68 | 49 | 551 | 95 | 196 | 0.56 |
| 2017 (May) | Slow Lane BWP | 2450 | 40.1 | 568 | 481 | 279 | 230 | 181 | 100 | 61 | 41 | 32 | 20 | 15 | 479 | 31 | 201 | 0.48 |
| 2017 (May) | Slow Lane BWP | 2550 | 40.6 | 574 | 430 | 261 | 215 | 168 | 101 | 60 | 46 | 37 | 28 | 19 | 424 | 36 | 166 | 0.49 |
| 2017 (May) | Slow Lane BWP | 2650 | 40.0 | 566 | 359 | 219 | 180 | 141 | 81 | 49 | 36 | 25 | 16 | 11 | 359 | 25 | 140 | 0.50 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane BWP | 2650 | 40.4 | 572 | 354 | 216 | 178 | 141 | 84 | 47 | 35 | 21 | 16 | 5 | 350 | 21 | 137 | 0.50 |
| 2017 (May) | Slow Lane BWP | 2750 | 40.1 | 567 | 253 | 145 | 112 | 80 | 40 | 23 | 16 | 13 | 10 | 7 | 253 | 13 | 108 | 0.44 |
| 2017 (May) | Slow Lane BWP | 2850 | 39.8 | 563 | 375 | 235 | 192 | 150 | 88 | 60 | 44 | 34 | 19 | 18 | 377 | 34 | 141 | 0.52 |
| 2017 (May) | Slow Lane BWP | 2950 | 39.4 | 558 | 344 | 236 | 201 | 166 | 107 | 70 | 53 | 38 | 27 | 15 | 349 | 38 | 110 | 0.59 |
| 2017 (May) | Slow Lane BWP | 3050 | 39.9 | 564 | 621 | 416 | 355 | 295 | 185 | 117 | 80 | 60 | 36 | 26 | 623 | 60 | 206 | 0.57 |
| 2017 (May) | Slow Lane BWP | 3150 | 39.6 | 560 | 417 | 265 | 227 | 189 | 125 | 85 | 63 | 52 | 36 | 28 | 422 | 53 | 154 | 0.55 |
| 2017 (May) | Slow Lane BWP | 3250 | 40.4 | 572 | 619 | 395 | 332 | 268 | 162 | 94 | 54 | 33 | 18 | 13 | 613 | 33 | 222 | 0.53 |
| 2017 (May) | Slow Lane BWP | 3350 | 40.6 | 575 | 441 | 287 | 237 | 187 | 106 | 64 | 42 | 31 | 18 | 12 | 434 | 31 | 151 | 0.53 |
| 2017 (May) | Slow Lane BWP | 3350 | 40.4 | 572 | 434 | 281 | 234 | 186 | 107 | 65 | 41 | 32 | 18 | 12 | 429 | 31 | 152 | 0.53 |
| 2017 (May) | Slow Lane BWP | 3450 | 40.1 | 567 | 373 | 246 | 203 | 161 | 101 | 69 | 50 | 38 | 24 | 17 | 373 | 38 | 127 | 0.54 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane BWP | 3550 | 40.6 | 574 | 381 | 240 | 201 | 162 | 101 | 68 | 48 | 40 | 27 | 20 | 376 | 39 | 139 | 0.52 |
| 2017 (May) | Slow Lane BWP | 3650 | 40.6 | 575 | 318 | 209 | 178 | 147 | 92 | 65 | 48 | 39 | 26 | 20 | 313 | 38 | 107 | 0.55 |
| 2017 (May) | Slow Lane BWP | 3750 | 40.1 | 568 | 466 | 300 | 249 | 198 | 112 | 63 | 40 | 28 | 19 | 15 | 464 | 28 | 166 | 0.53 |
| 2017 (May) | Slow Lane BWP | 3850 | 39.9 | 565 | 379 | 231 | 192 | 153 | 86 | 50 | 33 | 25 | 17 | 14 | 380 | 25 | 149 | 0.51 |
| 2017 (May) | Slow Lane BWP | 3950 | 40.4 | 571 | 374 | 195 | 160 | 125 | 71 | 45 | 35 | 28 | 20 | 16 | 370 | 28 | 177 | 0.42 |
| 2017 (May) | Slow Lane BWP | 4046 | 40.8 | 577 | 408 | 317 | 282 | 248 | 179 | 130 | 97 | 76 | 50 | 35 | 400 | 74 | 89 | 0.68 |
| 2017 (May) | Slow Lane BWP | 4150 | 40.0 | 566 | 609 | 389 | 322 | 255 | 141 | 73 | 41 | 28 | 17 | 13 | 609 | 28 | 220 | 0.53 |
| 2017 (May) | Slow Lane BWP | 4250 | 39.9 | 564 | 553 | 392 | 326 | 261 | 169 | 113 | 70 | 56 | 39 | 25 | 555 | 56 | 162 | 0.59 |
| 2017 (May) | Slow Lane BWP | 4350 | 39.9 | 565 | 339 | 195 | 161 | 127 | 77 | 51 | 38 | 31 | 22 | 18 | 339 | 31 | 144 | 0.48 |
| 2017 (May) | Slow Lane BWP | 4450 | 39.9 | 565 | 590 | 367 | 302 | 237 | 122 | 60 | 34 | 23 | 14 | 11 | 591 | 23 | 224 | 0.51 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane BWP | 4550 | 39.7 | 562 | 461 | 293 | 244 | 196 | 119 | 79 | 53 | 42 | 26 | 18 | 464 | 43 | 169 | 0.53 |
| 2017 (May) | Slow Lane BWP | 4650 | 40.0 | 566 | 403 | 267 | 228 | 189 | 122 | 79 | 56 | 41 | 25 | 17 | 403 | 41 | 136 | 0.57 |
| 2017 (May) | Slow Lane BWP | 4750 | 40.1 | 568 | 405 | 251 | 209 | 168 | 102 | 66 | 45 | 33 | 22 | 16 | 404 | 33 | 154 | 0.51 |
| 2017 (May) | Slow Lane BWP | 4850 | 40.2 | 569 | 455 | 300 | 247 | 195 | 115 | 75 | 53 | 40 | 26 | 18 | 453 | 40 | 155 | 0.54 |
| 2017 (May) | Slow Lane BWP | 4950 | 40.1 | 568 | 424 | 260 | 214 | 167 | 103 | 65 | 47 | 39 | 24 | 18 | 422 | 39 | 163 | 0.50 |
| 2017 (May) | Slow Lane BWP | 5050 | 40.0 | 566 | 431 | 251 | 204 | 157 | 85 | 50 | 34 | 25 | 16 | 11 | 431 | 25 | 180 | 0.47 |
| 2017 (May) | Slow Lane BWP | 5150 | 40.4 | 571 | 496 | 323 | 273 | 224 | 148 | 107 | 81 | 64 | 44 | 34 | 491 | 64 | 171 | 0.55 |
| 2017 (May) | Slow Lane BWP | 5250 | 40.1 | 567 | 451 | 289 | 246 | 202 | 129 | 90 | 66 | 51 | 39 | 23 | 450 | 50 | 161 | 0.54 |
| 2017 (May) | Slow Lane BWP | 5350 | 40.1 | 567 | 701 | 429 | 368 | 306 | 190 | 121 | 85 | 65 | 42 | 30 | 700 | 64 | 271 | 0.52 |
| 2017 (May) | Slow Lane BWP | 5450 | 39.7 | 561 | 413 | 242 | 205 | 168 | 113 | 80 | 62 | 49 | 34 | 26 | 417 | 50 | 173 | 0.50 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane BWP | 5550 | 40.1 | 567 | 587 | 373 | 320 | 266 | 177 | 116 | 83 | 60 | 39 | 26 | 586 | 59 | 214 | 0.54 |
| 2017 (May) | Slow Lane BWP | 5650 | 40.1 | 567 | 595 | 428 | 369 | 309 | 200 | 132 | 92 | 68 | 38 | 27 | 594 | 67 | 167 | 0.62 |
| 2017 (May) | Slow Lane BWP | 5750 | 40.7 | 576 | 501 | 305 | 260 | 215 | 135 | 91 | 66 | 52 | 35 | 25 | 492 | 51 | 193 | 0.51 |
| 2017 (May) | Slow Lane BWP | 5850 | 40.1 | 568 | 473 | 287 | 244 | 200 | 123 | 74 | 50 | 35 | 20 | 14 | 471 | 34 | 185 | 0.51 |
| 2017 (May) | Slow Lane BWP | 5950 | 40.5 | 573 | 705 | 462 | 398 | 334 | 211 | 133 | 89 | 64 | 39 | 28 | 696 | 64 | 240 | 0.56 |
| 2017 (May) | Slow Lane LWP | 2100 | 39.9 | 565 | 602 | 371 | 312 | 253 | 169 | 117 | 91 | 75 | 50 | 40 | 603 | 75 | 232 | 0.52 |
| 2017 (May) | Slow Lane LWP | 2200 | 40.1 | 567 | 569 | 395 | 336 | 278 | 185 | 129 | 96 | 76 | 53 | 40 | 568 | 76 | 174 | 0.59 |
| 2017 (May) | Slow Lane LWP | 2300 | 39.5 | 559 | 523 | 353 | 309 | 265 | 187 | 133 | 104 | 84 | 62 | 50 | 529 | 85 | 172 | 0.60 |
| 2017 (May) | Slow Lane LWP | 2400 | 39.6 | 560 | 553 | 363 | 305 | 248 | 151 | 90 | 58 | 39 | 22 | 17 | 558 | 39 | 191 | 0.56 |
| 2017 (May) | Slow Lane LWP | 2500 | 40.2 | 569 | 415 | 238 | 191 | 145 | 76 | 39 | 24 | 19 | 13 | 11 | 413 | 19 | 176 | 0.46 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane LWP | 2600 | 40.4 | 572 | 446 | 286 | 243 | 201 | 128 | 90 | 67 | 49 | 32 | 23 | 441 | 49 | 158 | 0.54 |
| 2017 (May) | Slow Lane LWP | 2700 | 40.4 | 571 | 386 | 254 | 214 | 174 | 118 | 85 | 64 | 52 | 36 | 27 | 383 | 51 | 132 | 0.55 |
| 2017 (May) | Slow Lane LWP | 2800 | 40.6 | 574 | 319 | 170 | 134 | 98 | 45 | 29 | 23 | 19 | 16 | 14 | 315 | 19 | 147 | 0.41 |
| 2017 (May) | Slow Lane LWP | 2900 | 39.8 | 563 | 268 | 165 | 135 | 105 | 64 | 45 | 33 | 27 | 19 | 13 | 269 | 27 | 103 | 0.51 |
| 2017 (May) | Slow Lane LWP | 3000 | 39.7 | 562 | 581 | 387 | 333 | 279 | 180 | 110 | 75 | 56 | 35 | 23 | 585 | 56 | 196 | 0.58 |
| 2017 (May) | Slow Lane LWP | 3100 | 39.7 | 562 | 434 | 286 | 241 | 196 | 115 | 72 | 53 | 41 | 29 | 20 | 437 | 41 | 149 | 0.56 |
| 2017 (May) | Slow Lane LWP | 3200 | 40.1 | 568 | 591 | 411 | 352 | 293 | 180 | 107 | 65 | 45 | 25 | 20 | 589 | 45 | 179 | 0.59 |
| 2017 (May) | Slow Lane LWP | 3300 | 40.1 | 567 | 554 | 349 | 294 | 239 | 138 | 83 | 54 | 40 | 25 | 17 | 553 | 40 | 205 | 0.53 |
| 2017 (May) | Slow Lane LWP | 3400 | 39.9 | 564 | 415 | 261 | 216 | 171 | 95 | 56 | 34 | 24 | 14 | 8 | 416 | 24 | 155 | 0.52 |
| 2017 (May) | Slow Lane LWP | 3500 | 40.0 | 566 | 466 | 301 | 252 | 203 | 109 | 61 | 38 | 27 | 17 | 12 | 466 | 27 | 165 | 0.54 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane LWP | 3600 | 39.9 | 565 | 394 | 270 | 229 | 189 | 118 | 72 | 47 | 32 | 19 | 13 | 394 | 32 | 124 | 0.58 |
| 2017 (May) | Slow Lane LWP | 3700 | 39.9 | 565 | 286 | 177 | 145 | 113 | 66 | 42 | 29 | 21 | 22 | 8 | 287 | 21 | 109 | 0.51 |
| 2017 (May) | Slow Lane LWP | 3800 | 40.1 | 568 | 481 | 334 | 283 | 232 | 140 | 90 | 64 | 51 | 34 | 27 | 479 | 50 | 146 | 0.59 |
| 2017 (May) | Slow Lane LWP | 3900 | 39.8 | 563 | 518 | 321 | 261 | 201 | 105 | 60 | 37 | 27 | 17 | 13 | 520 | 27 | 198 | 0.51 |
| 2017 (May) | Slow Lane LWP | 4000 | 40.0 | 566 | 523 | 375 | 324 | 273 | 177 | 115 | 78 | 58 | 36 | 26 | 523 | 58 | 148 | 0.62 |
| 2017 (May) | Slow Lane LWP | 4100 | 40.2 | 569 | 616 | 407 | 349 | 290 | 175 | 102 | 68 | 49 | 31 | 23 | 613 | 49 | 208 | 0.56 |
| 2017 (May) | Slow Lane LWP | 4200 | 40.3 | 570 | 458 | 315 | 270 | 225 | 150 | 107 | 79 | 60 | 38 | 28 | 455 | 59 | 142 | 0.59 |
| 2017 (May) | Slow Lane LWP | 4300 | 40.4 | 571 | 470 | 308 | 247 | 187 | 97 | 55 | 37 | 29 | 18 | 15 | 466 | 29 | 161 | 0.52 |
| 2017 (May) | Slow Lane LWP | 4400 | 40.1 | 568 | 560 | 372 | 311 | 251 | 137 | 73 | 44 | 31 | 19 | 15 | 558 | 30 | 187 | 0.55 |
| 2017 (May) | Slow Lane LWP | 4500 | 40.4 | 572 | 613 | 402 | 338 | 274 | 153 | 93 | 57 | 41 | 22 | 17 | 606 | 40 | 209 | 0.55 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane LWP | 4600 | 39.9 | 565 | 481 | 317 | 263 | 209 | 126 | 75 | 51 | 39 | 24 | 18 | 482 | 39 | 164 | 0.55 |
| 2017 (May) | Slow Lane LWP | 4700 | 39.9 | 565 | 538 | 354 | 297 | 239 | 139 | 84 | 53 | 38 | 23 | 16 | 539 | 38 | 184 | 0.55 |
| 2017 (May) | Slow Lane LWP | 4800 | 40.3 | 570 | 480 | 315 | 261 | 206 | 125 | 80 | 58 | 46 | 32 | 24 | 477 | 46 | 164 | 0.54 |
| 2017 (May) | Slow Lane LWP | 4900 | 39.8 | 563 | 470 | 316 | 265 | 215 | 128 | 82 | 56 | 41 | 24 | 16 | 472 | 41 | 155 | 0.57 |
| 2017 (May) | Slow Lane LWP | 5000 | 40.1 | 568 | 401 | 243 | 196 | 149 | 84 | 54 | 41 | 33 | 23 | 17 | 400 | 33 | 157 | 0.49 |
| 2017 (May) | Slow Lane LWP | 5100 | 40.1 | 567 | 483 | 318 | 272 | 226 | 145 | 101 | 75 | 60 | 40 | 29 | 482 | 59 | 165 | 0.56 |
| 2017 (May) | Slow Lane LWP | 5200 | 40.1 | 567 | 602 | 409 | 354 | 299 | 197 | 131 | 93 | 71 | 48 | 38 | 601 | 71 | 193 | 0.59 |
| 2017 (May) | Slow Lane LWP | 5300 | 40.3 | 570 | 379 | 244 | 209 | 174 | 109 | 73 | 55 | 41 | 30 | 23 | 376 | 40 | 133 | 0.55 |
| 2017 (May) | Slow Lane LWP | 5400 | 40.2 | 569 | 611 | 399 | 339 | 279 | 174 | 113 | 77 | 56 | 38 | 27 | 607 | 56 | 210 | 0.55 |
| 2017 (May) | Slow Lane LWP | 5500 | 40.4 | 572 | 533 | 366 | 314 | 263 | 173 | 115 | 80 | 60 | 39 | 26 | 528 | 59 | 166 | 0.58 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 (May) | Slow Lane LWP | 5600 | 40.5 | 573 | 649 | 411 | 360 | 309 | 204 | 137 | 93 | 66 | 38 | 28 | 641 | 65 | 235 | 0.55 |
| 2017 (May) | Slow Lane LWP | 5700 | 39.9 | 565 | 532 | 356 | 306 | 255 | 166 | 110 | 79 | 58 | 37 | 26 | 533 | 59 | 176 | 0.58 |
| 2017 (May) | Slow Lane LWP | 5800 | 40.0 | 566 | 336 | 220 | 190 | 160 | 106 | 68 | 51 | 39 | 30 | 23 | 336 | 39 | 116 | 0.56 |
| 2017 (May) | Slow Lane LWP | 5900 | 40.4 | 572 | 489 | 294 | 241 | 189 | 96 | 48 | 27 | 15 | 7 | 6 | 484 | 14 | 193 | 0.49 |
| 2017 (May) | Slow Lane LWP | 5950 | 40.4 | 571 | 633 | 438 | 378 | 318 | 202 | 129 | 83 | 58 | 34 | 22 | 627 | 58 | 193 | 0.59 |

# APPENDIX B SUMMARY OF EFROMD3 BACK CALCULATION RESULTS

| Layer | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Material | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | (%) |
| 2013 - Site 1 | 805 | 333 | 230 | 163 | 111 | 80 | 60 | 48 | 34 | 27 | 1316 | 154 | 250 | 271 | 296 | 1.8 |
| 2013 - Site 1 | 855 | 572 | 362 | 227 | 132 | 80 | 56 | 51 | 45 | 37 | 633 | 50 | 596 | 1000 | 218 | 3.8 |
| 2013 - Site 1 | 905 | 478 | 322 | 209 | 117 | 76 | 55 | 43 | 31 | 24 | 775 | 58 | 1000 | 253 | 329 | 3.6 |
| 2013 - Site 1 | 955 | 501 | 316 | 207 | 120 | 81 | 59 | 46 | 34 | 31 | 711 | 75 | 266 | 435 | 269 | 2.9 |
| 2013 - Site 1 | 1005 | 304 | 182 | 103 | 59 | 42 | 32 | 27 | 21 | 17 | 867 | 148 | 1000 | 670 | 470 | 4.3 |
| 2013 - Site 1 | 1055 | 434 | 252 | 150 | 88 | 65 | 51 | 44 | 36 | 30 | 622 | 101 | 999 | 561 | 271 | 3.2 |
| 2013 - Site 1 | 1105 | 569 | 349 | 230 | 121 | 78 | 56 | 42 | 26 | 17 | 509 | 101 | 202 | 150 | 433 | 4.6 |
| 2013 - Site 1 | 1105 | 411 | 259 | 168 | 105 | 68 | 48 | 39 | 29 | 20 | 800 | 116 | 322 | 250 | 382 | 3.7 |
| 2013 - Site 1 | 1154 | 501 | 314 | 184 | 116 | 78 | 60 | 57 | 48 | 31 | 563 | 88 | 576 | 355 | 236 | 7.2 |
| 2013 - Site 1 | 1155 | 455 | 324 | 202 | 131 | 96 | 74 | 62 | 46 | 36 | 797 | 88 | 473 | 221 | 222 | 4.4 |
| 2013 - Site 1 | 1204 | 568 | 388 | 260 | 166 | 122 | 96 | 80 | 60 | 46 | 666 | 61 | 1000 | 134 | 179 | 3.0 |
| 2013 - Site 1 | 1205 | 456 | 311 | 204 | 122 | 90 | 70 | 56 | 40 | 32 | 753 | 100 | 342 | 219 | 251 | 4.2 |
| 2013 - Site 1 | 1255 | 425 | 262 | 174 | 122 | 95 | 77 | 66 | 50 | 38 | 681 | 165 | 547 | 180 | 215 | 2.8 |
| 2013 - Site 1 | 1255 | 477 | 310 | 217 | 141 | 104 | 79 | 62 | 44 | 37 | 772 | 128 | 189 | 218 | 220 | 2.3 |
| 2013 - Site 1 | 1305 | 454 | 288 | 185 | 117 | 85 | 67 | 57 | 44 | 35 | 721 | 87 | 1000 | 256 | 234 | 2.6 |
| 2013 - Site 1 | 1305 | 534 | 350 | 235 | 151 | 109 | 84 | 70 | 51 | 36 | 670 | 71 | 994 | 112 | 231 | 2.7 |
| 2013 - Site 1 | 1355 | 681 | 432 | 285 | 191 | 144 | 113 | 95 | 70 | 52 | 462 | 86 | 303 | 110 | 156 | 2.8 |
| 2013 - Site 1 | 1355 | 453 | 292 | 198 | 134 | 87 | 65 | 60 | 51 | 36 | 809 | 88 | 358 | 396 | 211 | 5.2 |
| 2013 - Site 1 | 1405 | 447 | 268 | 178 | 119 | 89 | 73 | 66 | 55 | 44 | 676 | 118 | 469 | 514 | 178 | 2.3 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 - Site 1** | 1405 | 502 | 308 | 209 | 140 | 109 | 90 | 77 | 60 | 49 | 628 | 98 | 1000 | 186 | 171 | 1.8 |
| **2013 - Site 1** | 1455 | 588 | 354 | 234 | 161 | 116 | 90 | 78 | 60 | 43 | 524 | 98 | 421 | 136 | 188 | 3.1 |
| **2013 - Site 1** | 1455 | 441 | 275 | 190 | 134 | 103 | 83 | 72 | 55 | 42 | 722 | 153 | 433 | 184 | 193 | 2.2 |
| **2013 - Site 1** | 1504 | 379 | 245 | 168 | 107 | 78 | 59 | 46 | 32 | 25 | 910 | 180 | 225 | 248 | 316 | 2.5 |
| **2013 - Site 1** | 1505 | 449 | 279 | 184 | 111 | 75 | 54 | 43 | 29 | 20 | 675 | 135 | 276 | 170 | 392 | 3.5 |
| **2013 - Site 1** | 1555 | 446 | 263 | 147 | 78 | 51 | 36 | 28 | 18 | 11 | 518 | 145 | 412 | 189 | 694 | 6.5 |
| **2013 - Site 1** | 1555 | 354 | 212 | 125 | 63 | 43 | 31 | 22 | 14 | 11 | 694 | 180 | 337 | 348 | 701 | 6.0 |
| **2013 - Site 1** | 1605 | 419 | 255 | 146 | 82 | 49 | 33 | 28 | 21 | 13 | 658 | 104 | 539 | 281 | 570 | 7.2 |
| **2013 - Site 1** | 1605 | 475 | 264 | 152 | 81 | 52 | 37 | 30 | 21 | 15 | 500 | 116 | 433 | 285 | 509 | 3.9 |
| **2013 - Site 1** | 1705 | 394 | 220 | 128 | 76 | 51 | 37 | 31 | 23 | 15 | 614 | 143 | 762 | 252 | 511 | 4.5 |
| **2013 - Site 1** | 1705 | 382 | 232 | 132 | 69 | 45 | 33 | 27 | 20 | 14 | 687 | 107 | 1000 | 360 | 549 | 4.9 |
| **2013 - Site 1** | 1755 | 438 | 247 | 135 | 64 | 36 | 22 | 16 | 12 | 12 | 641 | 85 | 418 | 1000 | 726 | 5.6 |
| **2013 - Site 1** | 1755 | 301 | 168 | 95 | 47 | 31 | 23 | 20 | 15 | 10 | 758 | 167 | 1000 | 517 | 767 | 5.9 |
| **2013 - Site 1** | 1805 | 355 | 185 | 98 | 44 | 27 | 19 | 16 | 13 | 11 | 615 | 128 | 1000 | 1000 | 779 | 4.5 |
| **2013 - Site 1** | 1805 | 341 | 174 | 90 | 41 | 26 | 20 | 17 | 14 | 11 | 593 | 154 | 1000 | 1000 | 746 | 4.7 |
| **2013 - Site 1** | 1855 | 436 | 258 | 146 | 66 | 35 | 25 | 24 | 21 | 13 | 547 | 83 | 1000 | 725 | 575 | 9.4 |
| **2013 - Site 1** | 1855 | 318 | 176 | 91 | 43 | 25 | 17 | 15 | 12 | 7 | 704 | 148 | 1000 | 667 | 999 | 9.2 |
| **2013 - Site 1** | 2005 | 382 | 241 | 153 | 94 | 63 | 45 | 36 | 24 | 17 | 750 | 169 | 299 | 209 | 469 | 3.8 |
| **2013 - Site 1** | 2005 | 384 | 214 | 128 | 73 | 48 | 35 | 28 | 21 | 16 | 679 | 139 | 461 | 414 | 493 | 2.5 |
| **2013 - Site 1** | 2055 | 474 | 304 | 193 | 119 | 80 | 58 | 47 | 34 | 24 | 704 | 102 | 302 | 199 | 323 | 3.9 |
| **2013 - Site 1** | 2055 | 391 | 253 | 163 | 93 | 59 | 41 | 33 | 24 | 18 | 880 | 90 | 466 | 335 | 438 | 3.2 |
| **2013 - Site 1** | 2105 | 512 | 338 | 216 | 123 | 78 | 56 | 46 | 33 | 23 | 622 | 78 | 342 | 211 | 328 | 4.8 |
| **2013 - Site 1** | 2105 | 444 | 281 | 165 | 89 | 57 | 41 | 35 | 27 | 19 | 640 | 88 | 550 | 355 | 407 | 5.3 |
| **2013 - Site 1** | 2155 | 588 | 392 | 237 | 126 | 72 | 47 | 41 | 33 | 24 | 544 | 50 | 413 | 425 | 320 | 6.0 |
| **2013 - Site 1** | 2155 | 355 | 219 | 129 | 70 | 46 | 34 | 28 | 21 | 15 | 800 | 110 | 999 | 383 | 513 | 4.3 |
| **2013 - Site 1** | 2205 | 446 | 279 | 165 | 96 | 67 | 52 | 46 | 37 | 27 | 615 | 99 | 691 | 374 | 288 | 5.2 |
| **2013 - Site 1** | 2205 | 468 | 290 | 179 | 108 | 77 | 61 | 54 | 43 | 33 | 645 | 84 | 1000 | 364 | 238 | 3.4 |
| **2013 - Site 1** | 2255 | 550 | 352 | 214 | 118 | 70 | 48 | 43 | 34 | 23 | 550 | 65 | 360 | 344 | 323 | 6.1 |
| **2013 - Site 1** | 2255 | 380 | 250 | 158 | 93 | 59 | 41 | 33 | 24 | 18 | 902 | 102 | 360 | 352 | 430 | 3.4 |
| **2013 - Site 1** | 2304 | 459 | 266 | 166 | 94 | 61 | 43 | 35 | 25 | 18 | 604 | 110 | 357 | 274 | 425 | 2.7 |
| **2013 - Site 1** | 2305 | 407 | 254 | 148 | 76 | 52 | 36 | 26 | 18 | 19 | 710 | 124 | 221 | 782 | 472 | 7.6 |
| **2013 - Site 1** | 2355 | 438 | 264 | 152 | 84 | 53 | 37 | 31 | 24 | 20 | 666 | 91 | 382 | 760 | 397 | 3.5 |
| **2013 - Site 1** | 2355 | 340 | 209 | 142 | 83 | 56 | 40 | 30 | 20 | 16 | 990 | 169 | 241 | 360 | 489 | 2.7 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 - Site 1** | 2405 | 312 | 179 | 83 | 35 | 21 | 15 | 14 | 11 | 6 | 617 | 162 | 1000 | 1000 | 1000 | 15.5 |
| **2013 - Site 1** | 2405 | 341 | 171 | 83 | 37 | 21 | 14 | 12 | 10 | 8 | 579 | 151 | 1000 | 1000 | 1000 | 7.7 |
| **2013 - Site 1** | 2455 | 419 | 208 | 115 | 52 | 34 | 26 | 21 | 15 | 12 | 485 | 131 | 888 | 526 | 660 | 4.5 |
| **2013 - Site 1** | 2455 | 313 | 195 | 116 | 62 | 38 | 23 | 15 | 9 | 9 | 990 | 196 | 177 | 913 | 919 | 6.6 |
| **2013 - Site 1** | 2505 | 497 | 317 | 186 | 101 | 64 | 46 | 38 | 27 | 19 | 594 | 80 | 460 | 254 | 399 | 5.2 |
| **2013 - Site 1** | 2505 | 406 | 258 | 159 | 81 | 45 | 29 | 24 | 17 | 10 | 695 | 91 | 570 | 280 | 709 | 6.7 |
| **2013 - Site 1** | 2555 | 476 | 304 | 189 | 105 | 69 | 49 | 38 | 24 | 16 | 663 | 97 | 338 | 167 | 482 | 4.9 |
| **2013 - Site 1** | 2555 | 566 | 370 | 239 | 133 | 86 | 60 | 46 | 30 | 20 | 593 | 81 | 233 | 139 | 386 | 4.8 |
| **2013 - Site 1** | 2605 | 364 | 236 | 153 | 85 | 52 | 34 | 23 | 14 | 11 | 932 | 150 | 171 | 395 | 670 | 3.6 |
| **2013 - Site 1** | 2605 | 523 | 333 | 209 | 119 | 77 | 54 | 43 | 29 | 19 | 594 | 84 | 380 | 147 | 413 | 4.3 |
| **2013 - Site 1** | 2655 | 428 | 256 | 172 | 98 | 61 | 42 | 32 | 21 | 16 | 765 | 108 | 267 | 281 | 478 | 1.7 |
| **2013 - Site 1** | 2655 | 339 | 204 | 132 | 80 | 50 | 33 | 26 | 17 | 10 | 980 | 159 | 355 | 227 | 729 | 4.5 |
| **2013 - Site 1** | 2705 | 435 | 289 | 177 | 101 | 65 | 44 | 34 | 23 | 17 | 709 | 111 | 253 | 246 | 454 | 4.5 |
| **2013 - Site 1** | 2705 | 451 | 295 | 188 | 110 | 69 | 47 | 36 | 24 | 17 | 759 | 90 | 330 | 197 | 456 | 3.3 |
| **2013 - Site 1** | 2755 | 319 | 187 | 117 | 65 | 40 | 27 | 22 | 17 | 13 | 941 | 124 | 600 | 554 | 614 | 2.9 |
| **2013 - Site 1** | 2755 | 496 | 286 | 163 | 85 | 51 | 36 | 33 | 26 | 17 | 520 | 82 | 658 | 390 | 439 | 6.8 |
| **2013 - Site 1** | 2805 | 419 | 233 | 132 | 69 | 41 | 28 | 22 | 16 | 12 | 608 | 107 | 557 | 415 | 644 | 3.3 |
| **2013 - Site 1** | 2805 | 486 | 280 | 169 | 93 | 58 | 40 | 32 | 22 | 15 | 537 | 107 | 349 | 240 | 501 | 3.6 |
| **2013 - Site 1** | 2855 | 431 | 251 | 160 | 92 | 65 | 50 | 40 | 29 | 24 | 648 | 122 | 424 | 313 | 341 | 2.9 |
| **2013 - Site 1** | 2855 | 493 | 303 | 195 | 115 | 81 | 63 | 53 | 40 | 31 | 640 | 77 | 1000 | 245 | 261 | 2.6 |
| **2013 - Site 1** | 2905 | 418 | 239 | 139 | 74 | 48 | 34 | 28 | 21 | 16 | 623 | 108 | 571 | 425 | 493 | 3.3 |
| **2013 - Site 1** | 2905 | 411 | 245 | 150 | 82 | 56 | 42 | 34 | 25 | 20 | 697 | 95 | 999 | 332 | 412 | 3.2 |
| **2013 - Site 1** | 2955 | 333 | 177 | 112 | 61 | 36 | 24 | 18 | 12 | 7 | 752 | 184 | 440 | 303 | 999 | 4.3 |
| **2013 - Site 1** | 2955 | 494 | 285 | 178 | 98 | 59 | 40 | 31 | 18 | 7 | 1032 | 118 | 230 | 143 | 890 | 14.6 |
| **2013 - Site 1** | 3005 | 575 | 345 | 215 | 120 | 81 | 59 | 46 | 31 | 23 | 482 | 96 | 247 | 189 | 338 | 3.5 |
| **2013 - Site 1** | 3005 | 476 | 281 | 186 | 118 | 84 | 62 | 50 | 34 | 26 | 582 | 181 | 200 | 204 | 306 | 2.2 |
| **2013 - Site 1** | 3055 | 403 | 268 | 172 | 99 | 69 | 50 | 38 | 24 | 18 | 798 | 141 | 241 | 221 | 427 | 4.4 |
| **2013 - Site 1** | 3055 | 452 | 273 | 162 | 91 | 64 | 49 | 40 | 29 | 21 | 589 | 100 | 1000 | 206 | 389 | 4.3 |
| **2013 - Site 1** | 3105 | 551 | 355 | 249 | 149 | 102 | 74 | 55 | 34 | 24 | 584 | 154 | 118 | 145 | 310 | 3.3 |
| **2013 - Site 1** | 3105 | 376 | 235 | 158 | 94 | 63 | 47 | 38 | 28 | 20 | 916 | 97 | 989 | 231 | 400 | 2.3 |
| **2013 - Site 1** | 3155 | 365 | 206 | 124 | 75 | 57 | 41 | 27 | 15 | 14 | 601 | 523 | 158 | 352 | 605 | 7.8 |
| **2013 - Site 1** | 3155 | 382 | 214 | 121 | 74 | 56 | 44 | 37 | 27 | 19 | 597 | 165 | 1000 | 258 | 419 | 4.2 |
| **2013 - Site 1** | 3205 | 568 | 382 | 235 | 127 | 79 | 53 | 40 | 26 | 19 | 554 | 74 | 214 | 196 | 392 | 4.7 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 - Site 1** | 3205 | 455 | 305 | 192 | 106 | 66 | 45 | 35 | 25 | 19 | 754 | 76 | 344 | 296 | 414 | 3.9 |
| **2013 - Site 1** | 3255 | 561 | 382 | 276 | 174 | 112 | 78 | 61 | 39 | 24 | 752 | 70 | 249 | 93 | 324 | 4.0 |
| **2013 - Site 1** | 3255 | 574 | 379 | 238 | 137 | 91 | 66 | 54 | 38 | 24 | 596 | 73 | 369 | 136 | 315 | 5.6 |
| **2013 - Site 1** | 3305 | 584 | 382 | 249 | 150 | 100 | 69 | 53 | 35 | 27 | 599 | 88 | 148 | 190 | 284 | 2.8 |
| **2013 - Site 1** | 3305 | 400 | 297 | 195 | 120 | 82 | 60 | 47 | 31 | 20 | 1173 | 106 | 256 | 156 | 378 | 6.5 |
| **2013 - Site 1** | 3354 | 487 | 308 | 177 | 88 | 47 | 29 | 24 | 19 | 11 | 551 | 68 | 936 | 270 | 682 | 8.4 |
| **2013 - Site 1** | 3355 | 526 | 327 | 190 | 96 | 54 | 32 | 21 | 11 | 8 | 507 | 104 | 174 | 240 | 842 | 4.6 |
| **2013 - Site 1** | 3404 | 565 | 346 | 228 | 127 | 86 | 63 | 46 | 30 | 25 | 542 | 103 | 165 | 214 | 320 | 3.6 |
| **2013 - Site 1** | 3405 | 449 | 285 | 198 | 126 | 89 | 67 | 53 | 37 | 27 | 743 | 158 | 206 | 182 | 290 | 2.4 |
| **2013 - Site 1** | 3455 | 440 | 273 | 160 | 79 | 49 | 34 | 26 | 18 | 15 | 642 | 88 | 437 | 417 | 529 | 4.7 |
| **2013 - Site 1** | 3455 | 503 | 290 | 185 | 101 | 65 | 45 | 34 | 22 | 17 | 543 | 127 | 198 | 254 | 457 | 2.8 |
| **2013 - Site 1** | 3505 | 507 | 326 | 199 | 106 | 57 | 35 | 29 | 23 | 17 | 626 | 58 | 438 | 499 | 446 | 5.4 |
| **2013 - Site 1** | 3505 | 382 | 227 | 134 | 69 | 43 | 31 | 25 | 19 | 15 | 739 | 95 | 1000 | 478 | 543 | 3.4 |
| **2013 - Site 1** | 3555 | 472 | 280 | 180 | 119 | 74 | 50 | 42 | 33 | 26 | 730 | 90 | 270 | 410 | 304 | 3.5 |
| **2013 - Site 1** | 3555 | 375 | 247 | 143 | 79 | 51 | 35 | 27 | 19 | 17 | 863 | 98 | 376 | 548 | 491 | 4.8 |
| **2013 - Site 1** | 3605 | 519 | 327 | 203 | 110 | 80 | 57 | 37 | 19 | 19 | 496 | 288 | 77 | 461 | 426 | 8.9 |
| **2013 - Site 1** | 3605 | 381 | 233 | 146 | 81 | 55 | 40 | 30 | 20 | 18 | 791 | 135 | 287 | 399 | 464 | 4.3 |
| **2013 - Site 1** | 3655 | 450 | 282 | 183 | 110 | 73 | 50 | 36 | 23 | 20 | 748 | 130 | 160 | 299 | 403 | 3.1 |
| **2013 - Site 1** | 3655 | 457 | 316 | 180 | 98 | 60 | 40 | 32 | 24 | 17 | 663 | 77 | 423 | 303 | 451 | 6.1 |
| **2013 - Site 1** | 3705 | 419 | 271 | 171 | 105 | 68 | 45 | 33 | 22 | 18 | 834 | 126 | 177 | 322 | 436 | 3.2 |
| **2013 - Site 1** | 3705 | 266 | 178 | 121 | 78 | 53 | 37 | 28 | 18 | 13 | 1400 | 253 | 283 | 253 | 615 | 3.1 |
| **2013 - Site 1** | 3755 | 330 | 177 | 129 | 89 | 60 | 43 | 34 | 24 | 18 | 828 | 376 | 234 | 304 | 432 | 1.8 |
| **2013 - Site 1** | 3755 | 382 | 229 | 139 | 73 | 41 | 29 | 27 | 22 | 13 | 696 | 95 | 997 | 449 | 550 | 9.1 |
| **2013 - Site 1** | 3805 | 344 | 205 | 127 | 73 | 50 | 37 | 30 | 22 | 16 | 801 | 155 | 507 | 331 | 494 | 3.7 |
| **2013 - Site 1** | 3805 | 452 | 299 | 178 | 101 | 67 | 46 | 34 | 23 | 19 | 714 | 101 | 222 | 329 | 413 | 4.6 |
| **2013 - Site 1** | 3855 | 437 | 264 | 168 | 98 | 62 | 44 | 36 | 26 | 18 | 686 | 107 | 370 | 253 | 428 | 3.5 |
| **2013 - Site 1** | 3855 | 518 | 319 | 212 | 123 | 78 | 53 | 39 | 27 | 22 | 667 | 87 | 183 | 285 | 358 | 1.8 |
| **2013 - Site 1** | 3905 | 437 | 276 | 175 | 113 | 78 | 57 | 47 | 34 | 22 | 774 | 132 | 331 | 163 | 355 | 4.8 |
| **2013 - Site 1** | 3905 | 522 | 330 | 211 | 127 | 84 | 60 | 48 | 34 | 25 | 621 | 93 | 236 | 212 | 309 | 3.0 |
| **2013 - Site 1** | 3955 | 468 | 303 | 201 | 116 | 73 | 46 | 29 | 13 | 8 | 617 | 304 | 77 | 247 | 742 | 4.3 |
| **2013 - Site 1** | 3955 | 559 | 348 | 219 | 135 | 85 | 57 | 45 | 31 | 23 | 591 | 84 | 205 | 207 | 334 | 3.0 |
| **2013 - Site 1** | 4005 | 440 | 278 | 179 | 105 | 72 | 51 | 37 | 23 | 19 | 663 | 210 | 132 | 288 | 417 | 4.0 |
| **2013 - Site 1** | 4005 | 512 | 309 | 193 | 108 | 71 | 51 | 41 | 29 | 23 | 576 | 88 | 320 | 280 | 345 | 2.8 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 - Site 1** | 4055 | 446 | 302 | 185 | 108 | 82 | 63 | 47 | 30 | 25 | 665 | 162 | 196 | 222 | 324 | 6.3 |
| **2013 - Site 1** | 4055 | 367 | 238 | 139 | 81 | 57 | 43 | 36 | 26 | 18 | 762 | 121 | 1000 | 221 | 450 | 5.5 |
| **2013 - Site 1** | 4104 | 446 | 272 | 176 | 108 | 74 | 52 | 40 | 25 | 17 | 564 | 237 | 172 | 186 | 438 | 3.9 |
| **2013 - Site 1** | 4105 | 487 | 291 | 174 | 98 | 56 | 31 | 19 | 12 | 15 | 753 | 80 | 146 | 999 | 615 | 8.5 |
| **2013 - Site 1** | 4155 | 366 | 236 | 154 | 95 | 64 | 46 | 36 | 25 | 17 | 876 | 157 | 280 | 243 | 440 | 3.7 |
| **2013 - Site 1** | 4155 | 475 | 318 | 203 | 128 | 89 | 67 | 56 | 41 | 29 | 705 | 102 | 310 | 189 | 270 | 4.4 |
| **2013 - Site 1** | 4405 | 419 | 257 | 148 | 81 | 56 | 42 | 34 | 26 | 23 | 678 | 93 | 670 | 563 | 363 | 4.5 |
| **2013 - Site 1** | 4455 | 343 | 199 | 118 | 66 | 43 | 33 | 31 | 26 | 20 | 787 | 118 | 893 | 997 | 399 | 3.9 |
| **2013 - Site 1** | 4455 | 484 | 310 | 181 | 100 | 70 | 53 | 43 | 31 | 25 | 593 | 79 | 999 | 244 | 335 | 4.7 |
| **2013 - Site 1** | 4505 | 355 | 212 | 128 | 73 | 54 | 41 | 32 | 23 | 21 | 762 | 165 | 385 | 457 | 413 | 5.0 |
| **2013 - Site 1** | 4505 | 426 | 247 | 148 | 84 | 56 | 41 | 35 | 26 | 21 | 658 | 97 | 785 | 381 | 391 | 2.7 |
| **2013 - Site 1** | 4555 | 557 | 355 | 219 | 129 | 81 | 58 | 50 | 39 | 27 | 554 | 72 | 362 | 238 | 286 | 5.4 |
| **2013 - Site 1** | 4555 | 375 | 239 | 154 | 95 | 62 | 45 | 39 | 30 | 21 | 891 | 109 | 503 | 331 | 363 | 4.4 |
| **2013 - Site 1** | 4705 | 423 | 251 | 151 | 93 | 65 | 49 | 40 | 30 | 24 | 661 | 122 | 487 | 306 | 342 | 3.0 |
| **2013 - Site 1** | 4705 | 463 | 305 | 192 | 107 | 67 | 47 | 37 | 27 | 20 | 697 | 80 | 366 | 277 | 386 | 4.0 |
| **2013 - Site 1** | 4755 | 326 | 205 | 129 | 80 | 57 | 43 | 37 | 28 | 22 | 969 | 126 | 1000 | 374 | 369 | 3.1 |
| **2013 - Site 1** | 4755 | 461 | 273 | 176 | 115 | 72 | 51 | 45 | 36 | 25 | 687 | 102 | 336 | 321 | 304 | 5.0 |
| **2013 - Site 1** | 4805 | 444 | 265 | 165 | 100 | 67 | 49 | 42 | 31 | 20 | 630 | 115 | 541 | 197 | 384 | 4.9 |
| **2013 - Site 1** | 4805 | 465 | 283 | 178 | 106 | 75 | 57 | 49 | 38 | 30 | 665 | 83 | 1000 | 306 | 271 | 2.6 |
| **2013 - Site 1** | 4855 | 267 | 166 | 105 | 71 | 52 | 41 | 36 | 30 | 26 | 1143 | 209 | 513 | 1000 | 318 | 2.9 |
| **2013 - Site 1** | 4855 | 483 | 280 | 174 | 103 | 76 | 60 | 51 | 39 | 32 | 569 | 94 | 1000 | 298 | 258 | 2.7 |
| **2013 - Site 1** | 4955 | 325 | 164 | 104 | 59 | 39 | 28 | 21 | 14 | 10 | 643 | 348 | 328 | 342 | 779 | 2.6 |
| **2013 - Site 1** | 4955 | 513 | 302 | 197 | 108 | 70 | 48 | 33 | 18 | 16 | 533 | 190 | 108 | 299 | 485 | 4.3 |
| **2013 - Site 1** | 5005 | 597 | 373 | 230 | 136 | 92 | 67 | 54 | 39 | 28 | 488 | 84 | 266 | 176 | 278 | 3.9 |
| **2013 - Site 1** | 5005 | 640 | 405 | 267 | 159 | 108 | 81 | 67 | 49 | 36 | 536 | 53 | 890 | 141 | 224 | 2.8 |
| **2013 - Site 1** | 5005 | 527 | 343 | 229 | 140 | 95 | 71 | 59 | 43 | 31 | 697 | 64 | 989 | 144 | 264 | 3.0 |
| **2013 - Site 1** | 5005 | 606 | 391 | 248 | 159 | 114 | 86 | 70 | 50 | 37 | 513 | 100 | 207 | 148 | 214 | 3.7 |

| Layer | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Material | GR | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 100 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | | Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | E6 | (%) |
| **2013 - Site 2** | 4905 | 413 | 216 | 123 | 60 | 37 | 27 | 23 | 18 | 13 | 528 | 143 | 310 | 579 | 579 | 605 | 4.9 |
| **2013 - Site 2** | 4905 | 355 | 166 | 92 | 55 | 39 | 29 | 22 | 16 | 13 | 521 | 340 | 308 | 460 | 556 | 634 | 3.5 |
| **2013 - Site 2** | 4955 | 513 | 302 | 197 | 108 | 70 | 48 | 33 | 18 | 16 | 539 | 193 | 69 | 183 | 344 | 501 | 4.4 |
| **2013 - Site 2** | 4955 | 325 | 164 | 104 | 59 | 39 | 28 | 21 | 14 | 10 | 666 | 294 | 583 | 245 | 522 | 766 | 2.7 |

| Layer | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Material | GR | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 140 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | | Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | E6 | (%) |
| 2013 - Site 3 | 1655 | 393 | 246 | 145 | 85 | 59 | 45 | 38 | 28 | 20 | 641 | 175 | 232 | 420 | 321 | 392 | 5.6 |
| 2013 - Site 3 | 1655 | 468 | 268 | 153 | 87 | 61 | 46 | 40 | 33 | 26 | 537 | 129 | 168 | 997 | 599 | 301 | 3.9 |
| 2013 - Site 3 | 1855 | 436 | 258 | 146 | 66 | 35 | 25 | 24 | 21 | 13 | 509 | 111 | 222 | 991 | 712 | 583 | 10.2 |
| 2013 - Site 3 | 1855 | 318 | 176 | 91 | 43 | 25 | 17 | 15 | 12 | 7 | 668 | 175 | 414 | 975 | 745 | 1000 | 9.6 |
| 2013 - Site 3 | 1904 | 373 | 207 | 117 | 58 | 38 | 28 | 22 | 14 | 10 | 606 | 166 | 443 | 393 | 453 | 746 | 5.2 |
| 2013 - Site 3 | 1905 | 352 | 171 | 92 | 44 | 27 | 18 | 13 | 9 | 9 | 572 | 253 | 180 | 939 | 1000 | 1000 | 5.3 |
| 2013 - Site 3 | 1955 | 440 | 279 | 165 | 95 | 67 | 49 | 38 | 25 | 19 | 597 | 145 | 291 | 221 | 295 | 412 | 5.1 |
| 2013 - Site 3 | 1955 | 335 | 177 | 104 | 61 | 42 | 31 | 25 | 19 | 15 | 680 | 252 | 237 | 677 | 542 | 542 | 2.7 |
| 2013 - Site 3 | 4155 | 475 | 318 | 203 | 128 | 89 | 67 | 56 | 41 | 29 | 657 | 122 | 266 | 227 | 191 | 277 | 4.5 |
| 2013 - Site 3 | 4155 | 366 | 236 | 154 | 95 | 64 | 46 | 36 | 25 | 17 | 791 | 216 | 190 | 226 | 331 | 440 | 4.2 |
| 2013 - Site 3 | 4205 | 598 | 410 | 271 | 178 | 125 | 92 | 76 | 57 | 45 | 612 | 114 | 59 | 438 | 223 | 176 | 3.1 |
| 2013 - Site 3 | 4205 | 480 | 303 | 207 | 137 | 104 | 82 | 69 | 52 | 40 | 619 | 198 | 99 | 1000 | 129 | 217 | 2.4 |
| 2013 - Site 3 | 4255 | 424 | 283 | 174 | 105 | 75 | 58 | 51 | 40 | 32 | 711 | 147 | 118 | 800 | 480 | 245 | 4.8 |
| 2013 - Site 3 | 4255 | 408 | 247 | 159 | 107 | 87 | 72 | 62 | 47 | 37 | 655 | 156 | 2000 | 403 | 196 | 227 | 3.3 |
| 2013 - Site 3 | 4305 | 502 | 345 | 222 | 143 | 98 | 71 | 59 | 43 | 30 | 632 | 138 | 115 | 250 | 178 | 265 | 4.7 |
| 2013 - Site 3 | 4305 | 393 | 263 | 173 | 108 | 75 | 56 | 47 | 34 | 25 | 799 | 181 | 156 | 299 | 273 | 319 | 4.2 |
| 2013 - Site 3 | 4355 | 438 | 264 | 164 | 100 | 79 | 63 | 50 | 36 | 34 | 602 | 151 | 750 | 148 | 956 | 248 | 5.3 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 - Site 3** | 4355 | 362 | 228 | 150 | 99 | 79 | 65 | 54 | 41 | 34 | 781 | 257 | 159 | 1000 | 250 | 245 | 3.5 |
| **2013 - Site 3** | 4404 | 436 | 262 | 159 | 94 | 63 | 47 | 42 | 35 | 30 | 611 | 151 | 118 | 944 | 990 | 268 | 3.3 |
| **2013 - Site 3** | 4405 | 419 | 257 | 148 | 81 | 56 | 42 | 34 | 26 | 23 | 592 | 199 | 96 | 1000 | 995 | 349 | 5.2 |
| **2013 - Site 3** | 4605 | 431 | 271 | 171 | 96 | 67 | 51 | 42 | 31 | 24 | 665 | 144 | 144 | 515 | 338 | 334 | 4.5 |
| **2013 - Site 3** | 4605 | 457 | 279 | 174 | 111 | 81 | 62 | 51 | 38 | 30 | 615 | 171 | 126 | 652 | 255 | 268 | 3.3 |
| **2013 - Site 3** | 4655 | 361 | 222 | 151 | 97 | 75 | 58 | 44 | 29 | 24 | 798 | 290 | 217 | 232 | 275 | 341 | 3.5 |
| **2013 - Site 3** | 4655 | 412 | 250 | 175 | 118 | 84 | 65 | 56 | 42 | 28 | 658 | 234 | 192 | 355 | 168 | 287 | 3.8 |

| Layer | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Material | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | Error (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | |
| 2017 - Site 1 | 1055 | 583 | 394 | 277 | 171 | 110 | 78 | 59 | 39 | 29 | 717 | 69 | 163 | 156 | 263 | 2.3 |
| 2017 - Site 1 | 1055 | 579 | 372 | 255 | 159 | 108 | 76 | 58 | 39 | 29 | 612 | 108 | 129 | 165 | 266 | 1.9 |
| 2017 - Site 1 | 1105 | 503 | 308 | 203 | 120 | 76 | 52 | 41 | 24 | 17 | 596 | 144 | 162 | 173 | 442 | 3.5 |
| 2017 - Site 1 | 1155 | 603 | 371 | 254 | 169 | 118 | 91 | 75 | 50 | 41 | 518 | 131 | 148 | 163 | 199 | 2.4 |
| 2017 - Site 1 | 1155 | 582 | 388 | 270 | 177 | 129 | 96 | 76 | 52 | 38 | 613 | 131 | 132 | 133 | 203 | 2.7 |
| 2017 - Site 1 | 1155 | 575 | 387 | 272 | 179 | 122 | 91 | 72 | 56 | 42 | 735 | 71 | 190 | 203 | 184 | 2.4 |
| 2017 - Site 1 | 1205 | 645 | 453 | 321 | 214 | 146 | 110 | 87 | 61 | 50 | 706 | 63 | 145 | 157 | 161 | 2.0 |
| 2017 - Site 1 | 1205 | 600 | 395 | 285 | 178 | 119 | 88 | 71 | 52 | 42 | 723 | 51 | 361 | 200 | 191 | 1.3 |
| 2017 - Site 1 | 1255 | 568 | 394 | 278 | 184 | 129 | 96 | 76 | 53 | 40 | 755 | 86 | 156 | 143 | 196 | 2.3 |
| 2017 - Site 1 | 1255 | 484 | 322 | 237 | 157 | 109 | 82 | 66 | 47 | 39 | 915 | 86 | 226 | 211 | 208 | 0.8 |
| 2017 - Site 1 | 1305 | 574 | 375 | 272 | 182 | 124 | 89 | 70 | 48 | 39 | 749 | 88 | 129 | 188 | 203 | 0.8 |
| 2017 - Site 1 | 1305 | 488 | 319 | 230 | 145 | 98 | 76 | 60 | 43 | 34 | 817 | 92 | 223 | 216 | 234 | 1.7 |
| 2017 - Site 1 | 1355 | 435 | 302 | 222 | 155 | 118 | 94 | 75 | 56 | 44 | 1028 | 101 | 516 | 128 | 191 | 1.6 |
| 2017 - Site 1 | 1355 | 529 | 357 | 268 | 189 | 135 | 105 | 85 | 63 | 50 | 838 | 115 | 142 | 187 | 157 | 0.8 |
| 2017 - Site 1 | 1405 | 567 | 394 | 285 | 197 | 147 | 119 | 97 | 72 | 53 | 780 | 64 | 968 | 76 | 164 | 1.8 |
| 2017 - Site 1 | 1405 | 551 | 355 | 264 | 182 | 137 | 111 | 95 | 68 | 49 | 722 | 83 | 904 | 71 | 182 | 1.6 |
| 2017 - Site 1 | 1455 | 558 | 367 | 250 | 152 | 91 | 58 | 39 | 22 | 17 | 702 | 102 | 86 | 241 | 416 | 1.9 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 1** | 1455 | 528 | 330 | 240 | 157 | 110 | 82 | 61 | 41 | 25 | 631 | 240 | 126 | 107 | 301 | 4.3 |
| **2017 - Site 1** | 1505 | 573 | 361 | 238 | 138 | 76 | 44 | 28 | 15 | 4 | 511 | 416 | 43 | 484 | 1000 | 19.4 |
| **2017 - Site 1** | 1505 | 479 | 278 | 180 | 100 | 61 | 41 | 32 | 20 | 15 | 586 | 118 | 241 | 227 | 521 | 2.7 |
| **2017 - Site 1** | 1555 | 413 | 237 | 144 | 76 | 38 | 24 | 19 | 12 | 11 | 735 | 84 | 452 | 581 | 740 | 3.3 |
| **2017 - Site 1** | 1555 | 490 | 303 | 200 | 123 | 77 | 52 | 36 | 25 | 19 | 690 | 123 | 140 | 253 | 406 | 2.0 |
| **2017 - Site 1** | 1605 | 446 | 287 | 182 | 108 | 67 | 43 | 33 | 20 | 18 | 783 | 109 | 163 | 360 | 444 | 3.7 |
| **2017 - Site 1** | 1605 | 423 | 257 | 166 | 100 | 59 | 46 | 37 | 27 | 18 | 749 | 89 | 868 | 224 | 426 | 4.0 |
| **2017 - Site 1** | 1705 | 375 | 211 | 129 | 69 | 39 | 26 | 19 | 13 | 11 | 732 | 144 | 268 | 518 | 733 | 2.7 |
| **2017 - Site 1** | 1705 | 350 | 213 | 140 | 83 | 47 | 34 | 21 | 16 | 5 | 753 | 384 | 148 | 234 | 1000 | 16.2 |
| **2017 - Site 1** | 1755 | 383 | 251 | 173 | 117 | 84 | 63 | 51 | 36 | 27 | 918 | 197 | 219 | 211 | 294 | 2.4 |
| **2017 - Site 1** | 1755 | 475 | 316 | 226 | 153 | 98 | 72 | 56 | 38 | 28 | 873 | 112 | 156 | 186 | 273 | 2.0 |
| **2017 - Site 1** | 1805 | 336 | 186 | 120 | 63 | 37 | 24 | 18 | 12 | 10 | 858 | 144 | 351 | 509 | 799 | 1.5 |
| **2017 - Site 1** | 1805 | 253 | 145 | 80 | 40 | 23 | 16 | 13 | 10 | 7 | 1019 | 165 | 869 | 1000 | 1000 | 8.3 |
| **2017 - Site 1** | 1855 | 381 | 207 | 118 | 61 | 38 | 29 | 22 | 19 | 13 | 639 | 118 | 1000 | 458 | 611 | 5.3 |
| **2017 - Site 1** | 1855 | 315 | 168 | 96 | 45 | 29 | 23 | 19 | 16 | 14 | 702 | 153 | 1000 | 1000 | 637 | 5.8 |
| **2017 - Site 1** | 2005 | 749 | 519 | 382 | 239 | 146 | 92 | 62 | 36 | 26 | 655 | 54 | 64 | 155 | 267 | 2.0 |
| **2017 - Site 1** | 2005 | 349 | 239 | 168 | 108 | 71 | 54 | 38 | 27 | 15 | 1270 | 147 | 307 | 131 | 524 | 5.9 |
| **2017 - Site 1** | 2055 | 653 | 437 | 324 | 206 | 131 | 89 | 65 | 39 | 29 | 681 | 85 | 79 | 143 | 258 | 1.5 |
| **2017 - Site 1** | 2055 | 585 | 389 | 281 | 181 | 111 | 76 | 56 | 35 | 24 | 703 | 99 | 106 | 131 | 311 | 3.2 |
| **2017 - Site 1** | 2105 | 800 | 554 | 399 | 254 | 155 | 101 | 71 | 40 | 30 | 586 | 58 | 61 | 129 | 242 | 2.1 |
| **2017 - Site 1** | 2105 | 623 | 417 | 296 | 186 | 117 | 80 | 60 | 36 | 26 | 623 | 96 | 93 | 145 | 282 | 2.8 |
| **2017 - Site 1** | 2155 | 437 | 288 | 197 | 115 | 73 | 53 | 41 | 30 | 20 | 831 | 95 | 271 | 227 | 370 | 4.1 |
| **2017 - Site 1** | 2155 | 481 | 297 | 203 | 128 | 81 | 56 | 45 | 34 | 19 | 720 | 116 | 231 | 150 | 390 | 6.9 |
| **2017 - Site 1** | 2205 | 762 | 533 | 385 | 240 | 155 | 101 | 74 | 47 | 33 | 614 | 55 | 77 | 130 | 218 | 2.5 |
| **2017 - Site 1** | 2205 | 422 | 268 | 191 | 126 | 86 | 64 | 53 | 36 | 28 | 887 | 133 | 229 | 222 | 280 | 1.6 |
| **2017 - Site 1** | 2255 | 691 | 460 | 334 | 217 | 139 | 89 | 57 | 32 | 23 | 670 | 95 | 54 | 170 | 300 | 1.0 |
| **2017 - Site 1** | 2255 | 589 | 410 | 292 | 179 | 107 | 65 | 45 | 25 | 20 | 814 | 60 | 90 | 238 | 366 | 2.2 |
| **2017 - Site 1** | 2305 | 613 | 391 | 265 | 160 | 93 | 54 | 33 | 18 | 13 | 537 | 177 | 49 | 593 | 495 | 3.7 |
| **2017 - Site 1** | 2305 | 576 | 385 | 273 | 163 | 97 | 58 | 39 | 16 | 19 | 849 | 73 | 60 | 882 | 423 | 8.7 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 1** | 2355 | 553 | 348 | 239 | 138 | 83 | 54 | 40 | 25 | 17 | 620 | 87 | 163 | 173 | 426 | 3.3 |
| **2017 - Site 1** | 2355 | 492 | 305 | 204 | 113 | 63 | 38 | 25 | 15 | 11 | 726 | 82 | 182 | 257 | 641 | 2.0 |
| **2017 - Site 1** | 2405 | 429 | 278 | 184 | 106 | 64 | 41 | 31 | 17 | 12 | 712 | 148 | 173 | 195 | 620 | 4.6 |
| **2017 - Site 1** | 2405 | 409 | 227 | 134 | 59 | 26 | 14 | 9 | 5 | 4 | 563 | 119 | 194 | 1000 | 1000 | 42.1 |
| **2017 - Site 1** | 2455 | 416 | 262 | 172 | 96 | 57 | 34 | 24 | 14 | 8 | 952 | 101 | 272 | 184 | 897 | 6.0 |
| **2017 - Site 1** | 2455 | 462 | 276 | 177 | 101 | 61 | 40 | 27 | 16 | 11 | 606 | 175 | 146 | 232 | 646 | 3.7 |
| **2017 - Site 1** | 2505 | 373 | 245 | 161 | 101 | 69 | 50 | 38 | 24 | 17 | 844 | 229 | 192 | 211 | 441 | 3.7 |
| **2017 - Site 1** | 2505 | 643 | 417 | 287 | 174 | 99 | 60 | 39 | 21 | 18 | 616 | 102 | 55 | 514 | 392 | 1.9 |
| **2017 - Site 1** | 2555 | 425 | 257 | 171 | 104 | 67 | 44 | 31 | 18 | 12 | 661 | 247 | 133 | 222 | 589 | 2.3 |
| **2017 - Site 1** | 2555 | 466 | 301 | 203 | 109 | 61 | 38 | 27 | 17 | 12 | 732 | 87 | 196 | 257 | 603 | 4.0 |
| **2017 - Site 1** | 2605 | 438 | 284 | 197 | 128 | 87 | 63 | 48 | 31 | 21 | 729 | 216 | 149 | 167 | 353 | 3.1 |
| **2017 - Site 1** | 2605 | 376 | 237 | 160 | 100 | 67 | 47 | 39 | 27 | 19 | 900 | 152 | 269 | 248 | 397 | 3.1 |
| **2017 - Site 1** | 2655 | 394 | 270 | 189 | 118 | 72 | 47 | 32 | 19 | 13 | 1108 | 130 | 127 | 258 | 532 | 2.1 |
| **2017 - Site 1** | 2655 | 554 | 353 | 255 | 170 | 112 | 76 | 55 | 31 | 20 | 600 | 273 | 69 | 151 | 352 | 2.5 |
| **2017 - Site 1** | 2705 | 662 | 456 | 333 | 219 | 142 | 93 | 66 | 39 | 28 | 732 | 83 | 66 | 147 | 257 | 1.6 |
| **2017 - Site 1** | 2705 | 313 | 206 | 145 | 90 | 64 | 47 | 38 | 25 | 20 | 1146 | 185 | 303 | 272 | 399 | 2.7 |
| **2017 - Site 1** | 2755 | 402 | 242 | 156 | 89 | 55 | 38 | 29 | 20 | 14 | 774 | 116 | 335 | 275 | 538 | 2.4 |
| **2017 - Site 1** | 2755 | 287 | 177 | 113 | 66 | 42 | 29 | 21 | 22 | 8 | 858 | 435 | 253 | 264 | 886 | 16.5 |
| **2017 - Site 1** | 2805 | 633 | 406 | 286 | 168 | 93 | 50 | 30 | 16 | 12 | 591 | 107 | 53 | 498 | 525 | 4.2 |
| **2017 - Site 1** | 2805 | 464 | 298 | 197 | 111 | 62 | 40 | 28 | 19 | 15 | 813 | 64 | 316 | 321 | 521 | 2.1 |
| **2017 - Site 1** | 2855 | 429 | 267 | 197 | 130 | 91 | 70 | 55 | 40 | 31 | 871 | 145 | 215 | 216 | 258 | 1.0 |
| **2017 - Site 1** | 2855 | 479 | 333 | 231 | 140 | 89 | 63 | 50 | 34 | 26 | 929 | 51 | 1000 | 199 | 304 | 2.7 |
| **2017 - Site 1** | 2905 | 380 | 231 | 153 | 87 | 50 | 33 | 25 | 17 | 14 | 936 | 92 | 363 | 420 | 572 | 1.3 |
| **2017 - Site 1** | 2905 | 497 | 297 | 196 | 105 | 54 | 34 | 25 | 17 | 13 | 640 | 73 | 275 | 320 | 590 | 3.4 |
| **2017 - Site 1** | 2955 | 419 | 253 | 151 | 83 | 53 | 36 | 27 | 18 | 13 | 643 | 132 | 295 | 274 | 586 | 3.7 |
| **2017 - Site 1** | 2955 | 520 | 322 | 202 | 105 | 60 | 37 | 27 | 17 | 13 | 562 | 85 | 219 | 247 | 585 | 3.6 |
| **2017 - Site 1** | 3005 | 370 | 194 | 124 | 71 | 45 | 35 | 28 | 20 | 16 | 694 | 150 | 551 | 380 | 520 | 1.7 |
| **2017 - Site 1** | 3005 | 486 | 291 | 190 | 98 | 65 | 40 | 31 | 31 | 24 | 721 | 54 | 999 | 1000 | 338 | 5.7 |
| **2017 - Site 1** | 3055 | 523 | 375 | 273 | 177 | 115 | 78 | 58 | 36 | 26 | 931 | 91 | 101 | 163 | 288 | 2.6 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 1** | 3055 | 511 | 329 | 236 | 153 | 103 | 75 | 58 | 37 | 26 | 731 | 154 | 122 | 160 | 285 | 2.3 |
| **2017 - Site 1** | 3103 | 230 | 203 | 151 | 99 | 67 | 48 | 38 | 28 | 22 | 2000 | 158 | 267 | 372 | 365 | 6.9 |
| **2017 - Site 1** | 3155 | 613 | 405 | 289 | 174 | 101 | 67 | 49 | 31 | 22 | 663 | 68 | 113 | 190 | 324 | 2.9 |
| **2017 - Site 1** | 3155 | 454 | 298 | 211 | 135 | 88 | 61 | 48 | 30 | 22 | 836 | 146 | 137 | 192 | 345 | 2.4 |
| **2017 - Site 1** | 3205 | 704 | 411 | 282 | 153 | 85 | 46 | 28 | 17 | 13 | 503 | 61 | 102 | 238 | 542 | 2.1 |
| **2017 - Site 1** | 3205 | 609 | 389 | 255 | 141 | 73 | 41 | 28 | 17 | 13 | 596 | 51 | 183 | 262 | 542 | 2.9 |
| **2017 - Site 1** | 3255 | 500 | 339 | 230 | 147 | 100 | 72 | 50 | 34 | 23 | 705 | 177 | 104 | 172 | 322 | 3.9 |
| **2017 - Site 1** | 3255 | 455 | 313 | 224 | 149 | 106 | 79 | 60 | 37 | 27 | 856 | 233 | 105 | 166 | 280 | 2.6 |
| **2017 - Site 1** | 3305 | 604 | 431 | 299 | 191 | 124 | 82 | 58 | 37 | 25 | 739 | 87 | 84 | 151 | 285 | 3.1 |
| **2017 - Site 1** | 3305 | 555 | 393 | 262 | 170 | 113 | 70 | 56 | 39 | 25 | 747 | 80 | 136 | 155 | 291 | 5.6 |
| **2017 - Site 1** | 3355 | 500 | 305 | 206 | 126 | 78 | 51 | 41 | 23 | 34 | 701 | 104 | 133 | 451 | 333 | 12.4 |
| **2017 - Site 1** | 3355 | 466 | 305 | 185 | 96 | 54 | 36 | 29 | 18 | 15 | 661 | 73 | 393 | 325 | 527 | 5.2 |
| **2017 - Site 1** | 3405 | 339 | 195 | 127 | 77 | 51 | 38 | 31 | 22 | 18 | 853 | 172 | 367 | 416 | 452 | 2.0 |
| **2017 - Site 1** | 3405 | 457 | 274 | 186 | 116 | 84 | 63 | 49 | 36 | 28 | 670 | 150 | 223 | 248 | 281 | 2.0 |
| **2017 - Site 1** | 3455 | 558 | 371 | 250 | 136 | 73 | 43 | 31 | 19 | 15 | 665 | 56 | 187 | 265 | 501 | 3.5 |
| **2017 - Site 1** | 3455 | 531 | 339 | 228 | 138 | 84 | 52 | 36 | 21 | 16 | 683 | 113 | 102 | 236 | 452 | 1.8 |
| **2017 - Site 1** | 3505 | 591 | 367 | 237 | 122 | 60 | 34 | 23 | 14 | 11 | 554 | 55 | 220 | 286 | 660 | 3.3 |
| **2017 - Site 1** | 3505 | 543 | 337 | 223 | 121 | 60 | 35 | 23 | 15 | 7 | 573 | 69 | 286 | 157 | 917 | 8.9 |
| **2017 - Site 1** | 3555 | 606 | 397 | 271 | 151 | 92 | 56 | 40 | 22 | 17 | 626 | 70 | 127 | 173 | 435 | 2.9 |
| **2017 - Site 1** | 3555 | 491 | 308 | 205 | 124 | 77 | 53 | 40 | 26 | 19 | 677 | 115 | 170 | 206 | 402 | 2.5 |
| **2017 - Site 1** | 3605 | 475 | 296 | 197 | 120 | 74 | 45 | 37 | 22 | 18 | 740 | 112 | 143 | 297 | 429 | 3.4 |
| **2017 - Site 1** | 3605 | 464 | 295 | 197 | 120 | 80 | 54 | 43 | 26 | 18 | 682 | 163 | 153 | 185 | 410 | 3.4 |
| **2017 - Site 1** | 3655 | 440 | 280 | 186 | 115 | 78 | 53 | 40 | 26 | 17 | 729 | 170 | 167 | 182 | 433 | 4.1 |
| **2017 - Site 1** | 3655 | 482 | 318 | 209 | 126 | 76 | 51 | 40 | 24 | 18 | 729 | 103 | 163 | 220 | 415 | 3.5 |
| **2017 - Site 1** | 3705 | 403 | 267 | 189 | 122 | 79 | 56 | 41 | 25 | 17 | 928 | 214 | 125 | 204 | 421 | 2.9 |
| **2017 - Site 1** | 3705 | 502 | 345 | 235 | 143 | 83 | 50 | 34 | 16 | 13 | 884 | 93 | 87 | 277 | 542 | 3.7 |
| **2017 - Site 1** | 3755 | 539 | 355 | 240 | 140 | 84 | 53 | 38 | 23 | 16 | 667 | 92 | 140 | 169 | 461 | 3.6 |
| **2017 - Site 1** | 3755 | 461 | 293 | 205 | 132 | 82 | 55 | 37 | 24 | 15 | 761 | 189 | 104 | 213 | 453 | 3.4 |
| **2017 - Site 1** | 3805 | 404 | 250 | 167 | 101 | 66 | 45 | 33 | 22 | 16 | 793 | 165 | 186 | 248 | 478 | 2.2 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 1** | 3805 | 531 | 346 | 229 | 129 | 73 | 45 | 31 | 16 | 12 | 676 | 89 | 123 | 224 | 576 | 3.7 |
| **2017 - Site 1** | 3855 | 506 | 319 | 211 | 131 | 85 | 61 | 50 | 29 | 27 | 671 | 121 | 143 | 267 | 305 | 5.5 |
| **2017 - Site 1** | 3855 | 477 | 313 | 205 | 125 | 79 | 58 | 46 | 32 | 24 | 751 | 86 | 280 | 221 | 325 | 3.2 |
| **2017 - Site 1** | 3905 | 453 | 298 | 194 | 114 | 75 | 52 | 40 | 26 | 18 | 756 | 115 | 228 | 176 | 429 | 3.9 |
| **2017 - Site 1** | 3905 | 506 | 339 | 219 | 132 | 79 | 52 | 38 | 24 | 15 | 669 | 107 | 158 | 159 | 479 | 4.6 |
| **2017 - Site 1** | 3955 | 511 | 338 | 228 | 142 | 91 | 62 | 44 | 27 | 19 | 704 | 147 | 100 | 202 | 374 | 2.7 |
| **2017 - Site 1** | 3955 | 472 | 317 | 216 | 128 | 83 | 56 | 41 | 24 | 16 | 742 | 141 | 137 | 160 | 455 | 3.5 |
| **2017 - Site 1** | 4005 | 447 | 276 | 166 | 95 | 59 | 39 | 30 | 21 | 23 | 756 | 90 | 204 | 1000 | 396 | 6.0 |
| **2017 - Site 1** | 4005 | 422 | 259 | 167 | 102 | 65 | 47 | 39 | 24 | 18 | 704 | 145 | 264 | 210 | 440 | 3.7 |
| **2017 - Site 1** | 4055 | 423 | 257 | 166 | 101 | 63 | 46 | 36 | 25 | 20 | 760 | 118 | 260 | 312 | 400 | 2.2 |
| **2017 - Site 1** | 4055 | 400 | 243 | 149 | 83 | 54 | 40 | 33 | 23 | 17 | 684 | 122 | 479 | 282 | 466 | 4.0 |
| **2017 - Site 1** | 4105 | 431 | 251 | 157 | 85 | 50 | 34 | 25 | 16 | 11 | 646 | 122 | 284 | 260 | 677 | 3.5 |
| **2017 - Site 1** | 4105 | 545 | 338 | 227 | 131 | 77 | 58 | 41 | 24 | 17 | 581 | 108 | 167 | 157 | 438 | 4.2 |
| **2017 - Site 1** | 4155 | 571 | 381 | 270 | 177 | 112 | 73 | 50 | 29 | 20 | 692 | 153 | 68 | 172 | 355 | 2.1 |
| **2017 - Site 1** | 4155 | 482 | 317 | 225 | 144 | 101 | 75 | 59 | 40 | 29 | 747 | 149 | 161 | 156 | 269 | 2.5 |
| **2017 - Site 1** | 4405 | 789 | 505 | 357 | 227 | 145 | 100 | 73 | 45 | 36 | 472 | 90 | 67 | 144 | 213 | 1.5 |
| **2017 - Site 1** | 4405 | 700 | 429 | 305 | 190 | 121 | 85 | 64 | 42 | 30 | 499 | 93 | 106 | 132 | 250 | 1.7 |
| **2017 - Site 1** | 4455 | 607 | 397 | 277 | 173 | 112 | 77 | 56 | 38 | 27 | 633 | 90 | 115 | 156 | 277 | 2.5 |
| **2017 - Site 1** | 4455 | 587 | 381 | 274 | 186 | 131 | 95 | 71 | 43 | 32 | 569 | 256 | 73 | 146 | 239 | 1.8 |
| **2017 - Site 1** | 4505 | 417 | 244 | 170 | 114 | 81 | 62 | 50 | 35 | 26 | 668 | 265 | 203 | 217 | 303 | 1.7 |
| **2017 - Site 1** | 4505 | 624 | 421 | 309 | 209 | 143 | 100 | 74 | 44 | 33 | 663 | 156 | 67 | 134 | 229 | 1.4 |
| **2017 - Site 1** | 4555 | 588 | 380 | 269 | 179 | 116 | 82 | 58 | 39 | 24 | 572 | 177 | 90 | 126 | 297 | 4.0 |
| **2017 - Site 1** | 4555 | 528 | 362 | 260 | 171 | 114 | 79 | 59 | 38 | 26 | 849 | 114 | 112 | 136 | 289 | 2.7 |
| **2017 - Site 1** | 4705 | 617 | 414 | 296 | 200 | 130 | 89 | 65 | 40 | 28 | 675 | 128 | 75 | 137 | 263 | 2.3 |
| **2017 - Site 1** | 4705 | 594 | 427 | 309 | 200 | 132 | 91 | 68 | 38 | 27 | 821 | 103 | 75 | 130 | 270 | 2.8 |
| **2017 - Site 1** | 4755 | 567 | 370 | 267 | 180 | 123 | 88 | 66 | 42 | 30 | 645 | 187 | 85 | 148 | 250 | 1.8 |
| **2017 - Site 1** | 4755 | 533 | 356 | 256 | 166 | 110 | 79 | 59 | 37 | 26 | 759 | 146 | 99 | 149 | 289 | 2.6 |
| **2017 - Site 1** | 4805 | 666 | 437 | 304 | 190 | 118 | 85 | 62 | 41 | 31 | 574 | 82 | 99 | 159 | 247 | 2.3 |
| **2017 - Site 1** | 4805 | 492 | 299 | 211 | 132 | 89 | 65 | 51 | 35 | 25 | 675 | 135 | 189 | 172 | 310 | 2.3 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 1** | 4855 | 336 | 220 | 160 | 106 | 68 | 51 | 39 | 30 | 23 | 1339 | 105 | 326 | 422 | 332 | 2.2 |
| **2017 - Site 1** | 4855 | 551 | 350 | 247 | 163 | 108 | 77 | 59 | 39 | 29 | 686 | 121 | 123 | 166 | 263 | 1.6 |
| **2017 - Site 1** | 4955 | 602 | 390 | 264 | 162 | 99 | 60 | 46 | 25 | 22 | 672 | 84 | 87 | 268 | 349 | 4.3 |
| **2017 - Site 1** | 4955 | 484 | 291 | 187 | 95 | 47 | 26 | 14 | 7 | 5 | 710 | 117 | 96 | 795 | 1000 | 7.7 |
| **2017 - Site 1** | 5005 | 831 | 547 | 395 | 231 | 139 | 77 | 51 | 32 | 24 | 498 | 50 | 63 | 194 | 293 | 3.3 |
| **2017 - Site 1** | 5005 | 789 | 520 | 369 | 227 | 134 | 85 | 59 | 32 | 23 | 522 | 69 | 65 | 128 | 306 | 2.3 |
| **2017 - Site 1** | 5005 | 696 | 457 | 330 | 208 | 132 | 88 | 64 | 39 | 28 | 606 | 79 | 79 | 138 | 263 | 1.8 |
| **2017 - Site 1** | 5005 | 627 | 435 | 315 | 200 | 128 | 82 | 58 | 34 | 22 | 734 | 90 | 77 | 128 | 316 | 2.9 |

| Layer | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Material | GR | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 100 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | | Error (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | E6 | |
| 2017 - Site 2 | 4905 | 547 | 335 | 218 | 130 | 76 | 49 | 34 | 21 | 14 | 534 | 148 | 103 | 116 | 299 | 506 | 4.5 |
| 2017 - Site 2 | 4905 | 471 | 286 | 200 | 123 | 74 | 49 | 35 | 20 | 14 | 675 | 184 | 118 | 114 | 329 | 510 | 2.1 |
| 2017 - Site 2 | 4955 | 602 | 390 | 264 | 162 | 99 | 60 | 46 | 25 | 22 | 587 | 118 | 50 | 126 | 324 | 359 | 4.4 |
| 2017 - Site 2 | 4955 | 484 | 291 | 187 | 95 | 47 | 26 | 14 | 7 | 5 | 643 | 127 | 70 | 166 | 999 | 1000 | 10.4 |

| Layer | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Material | GR | GR | GR | SG | SG | SG |
| Thickness (mm) | 220 | 150 | 140 | 300 | 500 | 0 |
| Emin (Mpa) | 50 | 50 | 50 | 20 | 20 | 20 |
| Emax (Mpa) | 2000 | 2000 | 2000 | 1000 | 1000 | 1000 |
| Ev/Eh | 2 | 2 | 2 | 2 | 2 | 2 |
| Poisson Ratio | 0.35 | 0.35 | 0.35 | 0.45 | 0.45 | 0.45 |

| | Project Chainage (m) | Measured FWD Deflection (micron) | | | | | | | | | Calculated Layer Moduli (MPa) | | | | | | Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D0 | D200 | D300 | D450 | D600 | D750 | D900 | D1200 | D1500 | E1 | E2 | E3 | E4 | E5 | E6 | (%) |
| 2017 - Site 3 | 1655 | 441 | 283 | 199 | 127 | 89 | 66 | 49 | 31 | 23 | 721 | 212 | 153 | 142 | 217 | 345 | 2.4 |
| 2017 - Site 3 | 1655 | 437 | 269 | 185 | 122 | 85 | 64 | 49 | 32 | 22 | 666 | 199 | 314 | 124 | 223 | 355 | 2.2 |
| 2017 - Site 3 | 1855 | 381 | 207 | 118 | 61 | 38 | 29 | 22 | 19 | 13 | 609 | 160 | 228 | 997 | 529 | 608 | 5.8 |
| 2017 - Site 3 | 1855 | 315 | 168 | 96 | 45 | 29 | 23 | 19 | 16 | 14 | 666 | 184 | 495 | 1000 | 1000 | 634 | 6.3 |
| 2017 - Site 3 | 1905 | 412 | 238 | 144 | 79 | 50 | 37 | 29 | 22 | 15 | 625 | 132 | 293 | 472 | 317 | 525 | 4.3 |
| 2017 - Site 3 | 1905 | 377 | 236 | 150 | 88 | 60 | 44 | 34 | 19 | 18 | 753 | 255 | 123 | 257 | 439 | 472 | 6.7 |
| 2017 - Site 3 | 1955 | 533 | 337 | 229 | 149 | 100 | 68 | 50 | 29 | 20 | 587 | 175 | 138 | 91 | 220 | 377 | 2.3 |
| 2017 - Site 3 | 1955 | 269 | 166 | 106 | 65 | 45 | 33 | 27 | 19 | 14 | 1008 | 287 | 311 | 432 | 391 | 581 | 3.9 |
| 2017 - Site 3 | 4155 | 571 | 381 | 270 | 177 | 112 | 73 | 50 | 29 | 20 | 655 | 170 | 52 | 116 | 220 | 372 | 2.0 |
| 2017 - Site 3 | 4155 | 482 | 317 | 225 | 144 | 101 | 75 | 59 | 40 | 29 | 654 | 181 | 151 | 129 | 213 | 271 | 2.9 |
| 2017 - Site 3 | 4205 | 497 | 314 | 227 | 154 | 112 | 80 | 64 | 45 | 36 | 695 | 206 | 85 | 206 | 220 | 225 | 1.4 |
| 2017 - Site 3 | 4205 | 491 | 320 | 222 | 147 | 106 | 80 | 64 | 44 | 33 | 629 | 205 | 119 | 174 | 195 | 238 | 2.5 |
| 2017 - Site 3 | 4255 | 601 | 408 | 298 | 197 | 131 | 92 | 71 | 48 | 38 | 575 | 174 | 50 | 156 | 207 | 212 | 2.5 |
| 2017 - Site 3 | 4255 | 471 | 296 | 211 | 143 | 105 | 79 | 62 | 47 | 34 | 670 | 223 | 116 | 217 | 195 | 232 | 2.1 |
| 2017 - Site 3 | 4305 | 634 | 389 | 278 | 186 | 132 | 91 | 67 | 37 | 31 | 533 | 185 | 79 | 84 | 188 | 265 | 3.4 |
| 2017 - Site 3 | 4305 | 450 | 289 | 202 | 129 | 90 | 66 | 50 | 39 | 23 | 734 | 180 | 183 | 152 | 198 | 324 | 6.1 |
| 2017 - Site 3 | 4355 | 510 | 309 | 207 | 130 | 93 | 65 | 50 | 32 | 25 | 573 | 191 | 116 | 162 | 245 | 317 | 2.4 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2017 - Site 3** | 4355 | 376 | 243 | 172 | 108 | 72 | 55 | 40 | 30 | 22 | 900 | 215 | 116 | 282 | 340 | 349 | 2.8 |
| **2017 - Site 3** | 4405 | 789 | 505 | 357 | 227 | 145 | 100 | 73 | 45 | 36 | 480 | 91 | 53 | 98 | 187 | 217 | 1.6 |
| **2017 - Site 3** | 4405 | 700 | 429 | 305 | 190 | 121 | 85 | 64 | 42 | 30 | 472 | 111 | 78 | 110 | 189 | 252 | 2.1 |
| **2017 - Site 3** | 4605 | 586 | 373 | 266 | 176 | 116 | 83 | 60 | 39 | 25 | 615 | 139 | 116 | 95 | 165 | 297 | 2.7 |
| **2017 - Site 3** | 4605 | 548 | 361 | 251 | 167 | 109 | 76 | 56 | 35 | 24 | 650 | 154 | 94 | 108 | 193 | 314 | 2.3 |
| **2017 - Site 3** | 4655 | 641 | 406 | 305 | 202 | 135 | 92 | 65 | 37 | 28 | 594 | 171 | 50 | 97 | 186 | 276 | 0.6 |
| **2017 - Site 3** | 4655 | 580 | 382 | 267 | 178 | 117 | 80 | 58 | 37 | 26 | 604 | 178 | 54 | 164 | 168 | 297 | 2.2 |