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# National Route 2 Section 1: East of Baden Powell Interchange at Km 29.0 to East of the Broadway Boulevard Interchange at Km 40.202

## Using Bitumen Rubber Asphalt to Rehabilitate an Alkali-Silica Affected Jointed Concrete Pavement

## Reflection Cracking & Structural Performance


**Authors**

(1) Strauss PJ, Specialist Consulting Engineer, Pretoria South Africa
(2) van Heerden JL, Royal HaskoningDHV, Western Cape, South Africa



**Thirty-Sixth Road Pavements Forum**
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## Using Bitumen Rubber Asphalt to Rehabilitate an Alkali-Silica Affected Jointed Concrete Pavement:

### Reflection Cracking and Structural Performance:

### Contents





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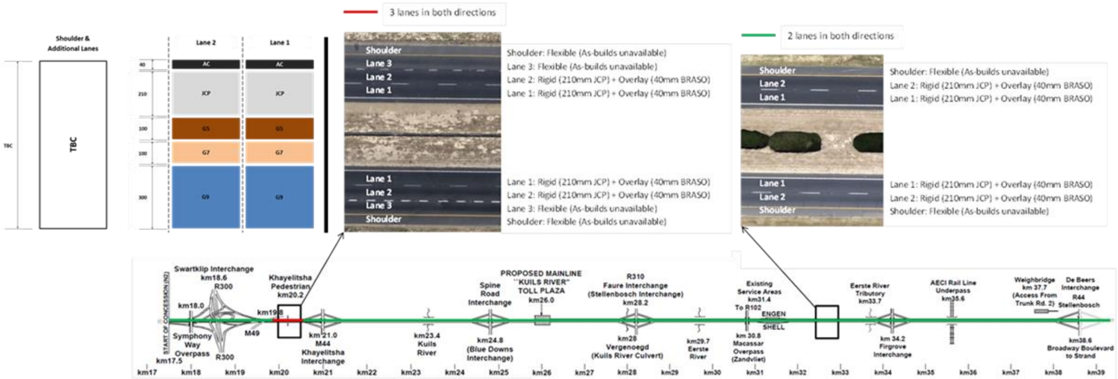
# 1. Project Background

- Once a Concrete Pavement (CP) has reached the end of its structural life;
- Various Remedial Options;
- Road authorities in South Africa were confronted in the 1980’s with such a problem;
- 22 kilometre Structurally Failing Jointed Concrete (JC) Section;

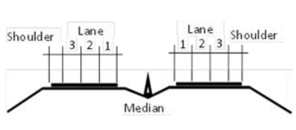
# 2. Original Pavement History

## Initial Construction

- The National Route 2 Section 1 Comprising of:
  - Jointed Unreinforced (Plain) Concrete Pavement (JCP); and
  - Flexible Pavement Structures;



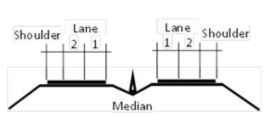

**Cross Section**




**Existing Pavement Structure**

| Shoulder | Lane 3 | Lane 2 | Lane 1 |
|---|---|---|---|
| Unknown (1990) | Unknown (1986) | 40 AC (1986) | 40 AC (1986) |
| Unknown (1990) | Unknown (1971) | 210 JCP (1971) | 210 JCP (1971) |
| Unknown (1990) | Unknown (1971) | 100 G5 (1971) | 100 G5 (1971) |
| Unknown (1990) | Unknown (1971) | 100 G7 (1971) | 100 G7 (1971) |
| Unknown (1990) | Unknown (1971) | 300 G9 (1971) | 300 G9 (1971) |

**Cross Section**




**Existing Pavement Structure**

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| Unknown (1971) | 100 G7 (1971) | 100 G7 (1971) |
| Unknown (1971) | 300 G9 (1971) | 300 G9 (1971) |

- Originally Constructed between 1971 and 1972;

# 2. Original Pavement History

## Structural Failure

- The use of high alkali cement & aggregate high in silica content:
  - in visual cracking by 1975;
  - secondary cracking; and
  - minor structural failures by 1980.
- Alkali Silica Reaction (ASR) - cause - premature failure of the JCP;
- Remedial action - restore & maintain the structural integrity of the concrete pavement;
- Remedial Option Considered - Bitumen Rubber Asphalt (BRA) Overlay;
- Product that was not yet introduced to the local market at the time;

# 2. Original Pavement History

## Design Considerations

- Reflection cracking in an overlay develops above a crack or joint in the layer being overlaid,
- Tension and Shear Stress in the Overlay;
- These stresses can either be caused by:
  - Widening of the contraction joint / crack due to shrinkage of the layer being overlaid i.e. cooling down; or
  - Relative vertical movement due to a rolling wheel that crosses the joint / crack;

# 2. Original Pavement History

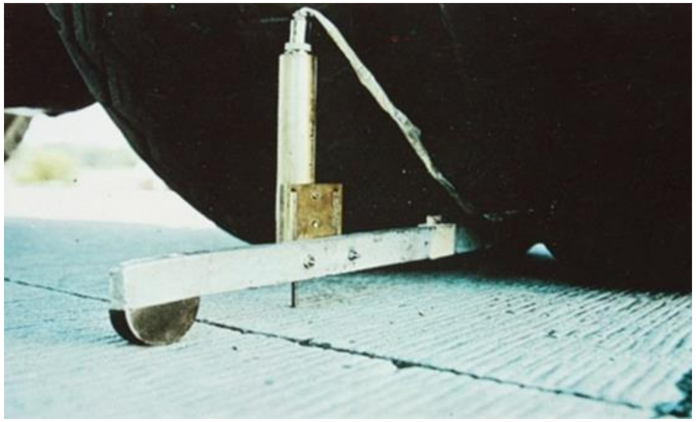
## Design Considerations

- The Alkali-Silica Reaction (ASR) in the Jointed Concrete Pavement (JCP) resulted in the:
  - expansion of the aggregate; and
  - development of micro cracking between the coarser particles;
- The concrete pavement structure as a whole, was under compression;
- The net result was that the transverse contraction joints closed up and were not functional anymore as a result of the expansion effect of the ASR.

# 2. Original Pavement History

## Design Considerations

- In the absence of a Falling Weight Deflectometer (FWD) in the 1980's, a modified Benkelman beam was used to measure deflection and RVM;
- a Geophone attached 150 mm from the end of the beam, was used to measure the RVM as the wheel load passed across the transverse contraction joint;





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# 2. Original Pavement History

## Design Considerations

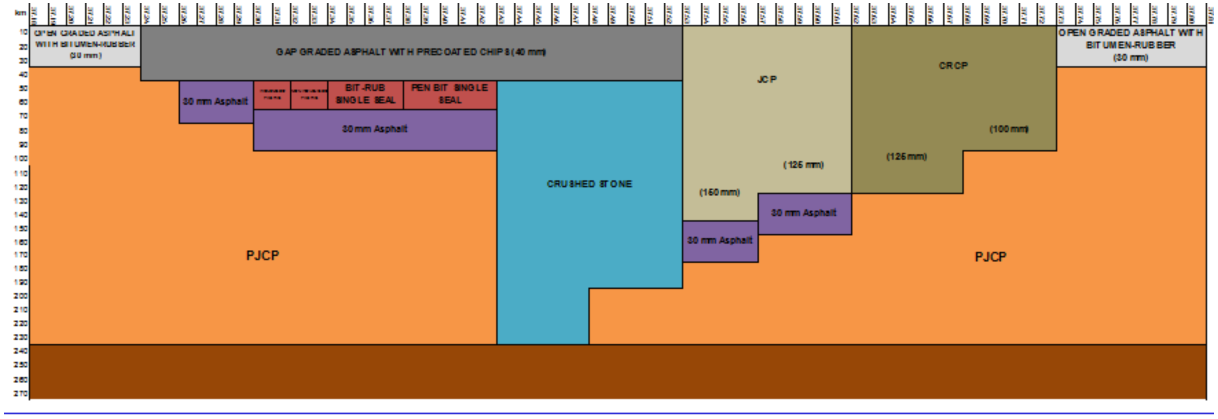
- The range of RVM, measured on twelve experimental sections, before different overlays options were constructed varied:
  - 0.01 mm to 0.45 mm.

| Section Number | Average RVM (mm) | Range of RVM (mm) |
|---|---|---|
| 1 | 0.05 | 0.01-0.08 |
| 2 | 0.07 | 0.03-0.15 |
| 3 | 0.06 | 0.03-0.13 |
| 4 | 0.06 | 0.03-0.13 |
| 5 | 0.07 | 0.03-0.16 |
| 6 | 0.07 | 0.02-0.11 |
| 7 | 0.06 | 0.03-0.18 |
| 8 | 0.19 | 0.10-0.25 |
| 9 | 0.35 | 0.22-0.45 |
| 10 | 0.30 | 0.22-0.38 |
| 11 | 0.35 | 0.22-0.45 |
| 12 | 0.15 | 0.08-0.21 |

# 2. Original Pavement History

## Experimental Overlay Options

- Keeping this in mind, several experimental overlay options were considered including:
  - Continuously Reinforced Concrete (CRCP);
  - Crushed Stone Base with an Asphalt Wearing Course;
  - Varying thickness of Asphalt with different types of Interlayers;
  - Chip Seals with Bitumen-Rubber and Pen-Grade Bitumen; and
  - Open-Graded Asphalt with Bitumen-Rubber as Binder.



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# 2. Original Pavement History

## Experimental Overlay Options

- Since overlaying of a JCP with the experimental overlay options, had not yet been attempted at the time in South Africa, it was decided to:
  - First build Different Experimental Sections;
  - Model their Behaviour;
  - Monitor their Performance over a Short Period; and
  - Building the most Cost Effective and Practical Solution



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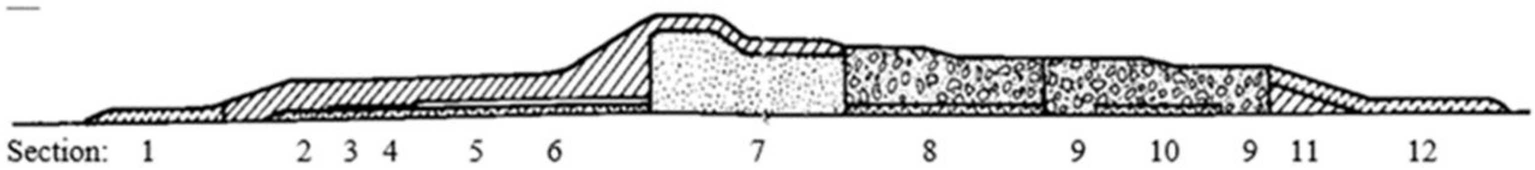
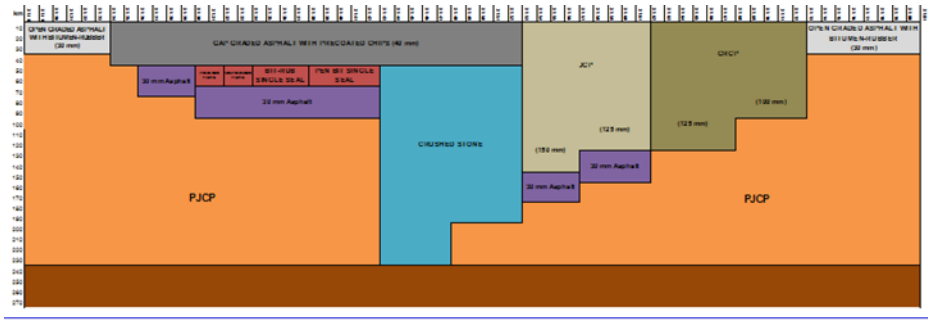
# 2. Original Pavement History

## Experimental Overlay Options

- Subsequently twelve different experimental overlay sections were constructed to determine the most cost effective and practical solution.




Schematic Lay-out of the Experimental Sections Completed in 1983



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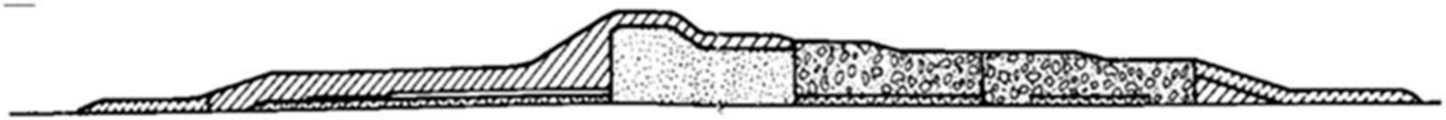
# 2. Original Pavement History

## Experimental Overlay Options




- **01: 30mm Asphalt with Bitumen-Rubber as Binder;**
- 02: 40mm Relatively Stiff HMA with Pen Grade Bitumen;
- 03: 40mm HMA on Woven Geo-Fabric;
- 04: 40mm HMA on Non-Woven Geo-Fabric;
- 05: 40mm HMA on a Bitumen-Rubber Chip Seal;
- 06: Varying Thick HMA on a Bitumen Chip Seal;
- 07: 40mm HMA on 200mm and 150mm thick Crushed Stone Base;
- 08: 150mm and 125mm JCP;
- **09: 150mm bonded Continuously Reinforced Concrete;**
- 10: 125mm and 100mm Continuously Reinforced Concrete;
- 11: 25mm Asphalt with Bitumen-Rubber as Binder on HMA of varying
- thickness.
- 12: 30mm Asphalt with Bitumen-Rubber as Binder (RA);



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# 2. Original Pavement History

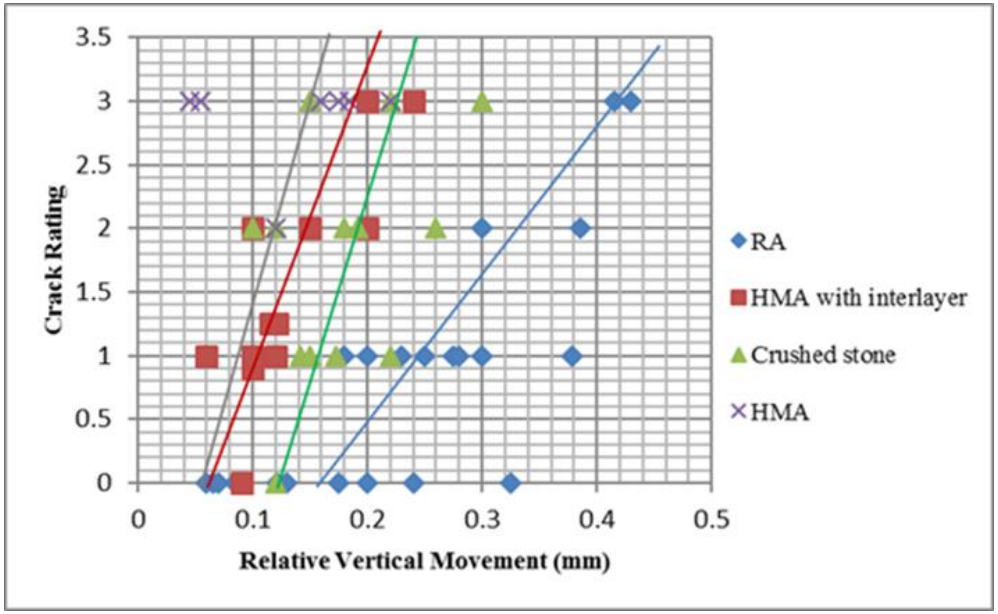
## Performance of Experimental Sections

- The first barely visible reflection cracks appeared 3 years after the experimental overlays were initially constructed ($2x10^6$E80's);
- Extensive cracking was observed after about 6 years ($4x10^6$E80) of service;
- The Bitumen Rubber Asphalt (BRA) and the HMA with interlayer showed superior performance, when compared to the other surface overlay option;
- This already indicated that stress reduction at the contact between the overlay and the JCP was critical;

# 2. Original Pavement History

## Performance of Experimental Sections

- It become clear that relative vertical movement at the transverse contraction joints, had to be taken into consideration, when designing an overlay to reduce the risk of reflection cracking.




Degree of Reflection Cracking for some Experimental Sections

# 2. Original Pavement History

## Repair & Rehabilitation Strategy

- Based on data obtained from the experimental sections, the performance of the different overlay options was compared.
- Although the CRC showed the best performance, the most cost effective and practical solution to rehabilitate the failing JCP:
  - Replace only Severely Damaged Transverse Contraction Joints:

The concrete on both sides of the joints were removed to full depth and replaced with new concrete



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# 2. Original Pavement History

## Repair & Rehabilitation Strategy

- Apply a Bitumen Rubber Single Seal;

  sealing the concrete off from the ambient environmental conditions, mainly preventing the exposure to moisture and allow the concrete to dry out.

  also served as a stress absorbing inter layer.

- Construct 40 mm Bitumen Rubber Asphalt Semi Open Graded (BRASO) with a high binder content (8.1%).

# 2. Original Pavement History

## Repair & Rehabilitation Strategy

- Rehabilitation was subsequently completed in 1986;
  - the expected life: 8 years or $6x10^6$ E80's before significant reflection cracking would start occurring.
- Serious maintenance or even rehabilitation was expected after only 12 years of traffic;
- The above measures could be regarded as successful, as since 1986, no major remedial measures had to be performed to improve and/or restore the structural or functional properties of the road;
- The current condition of the road has however now, after 32 years, deteriorated to an extent to warrant maintenance measures.

# 3. Current Pavement Condition

## Terms of Reference

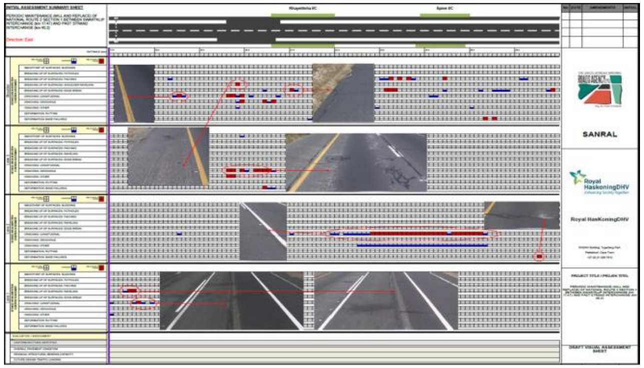
- Royal HaskoningDHV was subsequently appointed by the South African National Roads Agency SOC Ltd (SANRAL) in September 2016:
    - assess the serviceability and structural integrity;
    - investigate and recommend the most appropriate periodic maintenance.

# 3. Current Pavement Condition

## Pavement Condition Assessment

- a Profilometer survey was conducted with a DYNATEST RSP MK3 – ASTM (Class 1) profiler, which produced the following outputs:
  - International Roughness Index (IRI) – [mm/m or m/km];
  - Rutting [mm];
  - Mean Profile Depth (MPD) [mm];
  - Gradient & Cross fall; and
  - JPEG Images at 2 m intervals (down and front images)

- The visual condition was thereafter recorded in detail from the profilometer survey outputs as part of the initial assessment.

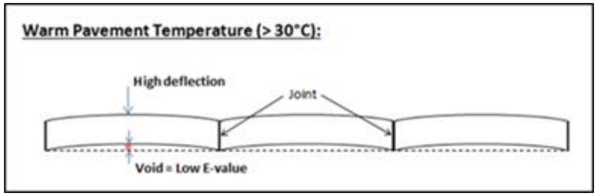


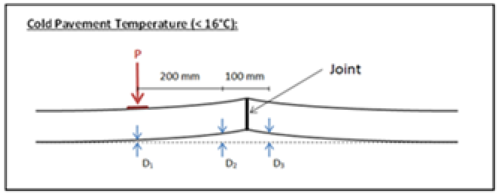
# 3. Current Pavement Condition

## Transverse Reflection Cracks

- Transverse reflection cracks were observed in the Bitumen Rubber Asphalt at a regular four-meter interval, across all four lanes of the dual carriageway;

- Transverse cracks were caused by a combination of:
    - Relative Vertical Movement, due to action of rolling wheels that crosses the transverse contraction joints; coupled
    - Warping and Curling effect of the concrete slabs (still in state of compression) under high and low pavement temperatures; and




    - Loss of bond between the concrete and the bitumen rubber asphalt.



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# 3. Current Pavement Condition

## Transverse Reflection Cracks

- Most of the transverse cracks have been sealed but a number of secondary cracks developed mainly in the slow lane, in addition to the transverse cracks.






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# 3. Current Pavement Condition

## Loss of Bond between the Asphalt and Concrete

- Lateral movement of the sealed transverse cracks was also observed;

This indicates a loss of bond between the concrete and the asphalt surface overlay

- Confirmed during the coring and when the asphalt surfacing was removed from the concrete slab at two transverse contraction joints;

Approximately 80 per cent of the 100 mm diameter composite cores displayed delamination of the asphalt surfacing from the concrete



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# 3. Current Pavement Condition

## Loss of Bond between the Asphalt and Concrete

- The loss of bond between the Bitumen Rubber Asphalt overlay and the old Jointed Concrete Pavement, occurred due to the:
  - Migration of moisture up, through the contraction joints (spaced at 4m intervals);
  - Accumulation of moisture at the interface between the concrete and the bitumen rubber single seal (stress absorbing inter layer);
  - Horizontal movement of moisture due to the action of traffic loading (rolling wheels) over time;
  - Warping and Curling effect of the concrete slabs (still in state of compression) under high and low pavement temperatures.



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# 3. Current Pavement Condition

## Condition of the Concrete

- Concrete cores confirmed that the concrete in general, was still in a good structural condition, except at the joints where some of the cores showed longitudinal cracking at various depths below the surface;


- Concrete from patches that were completed in 1986, to repair severely damaged transverse contraction joints, were found to be in a structurally sound condition.




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# 3. Current Pavement Condition

## Rut Depth Measurements

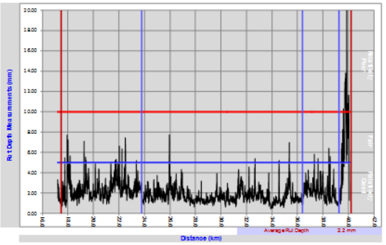
- Rut depth measurements were continuously measured with the DYNATEST RSP MK3 ASTM (Class 1) Profiler in November 2016:
  - Summary Outer Wheel Path Rutting (Eastbound) (2016 Measurements)

| Lane | | Chainage | Average (mm) | P95th (mm) |
|---|---|---|---|---|
| Fast Lane | Jointed Concrete Pavement | 17.8 - 39.4 | 3.8 | 8.4 |
| Slow Lane | Jointed Concrete Pavement | 17.8 - 39.4 | 5.0 | 10.4 |

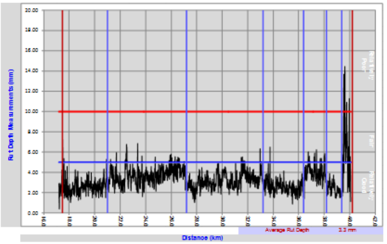
  - Summary Outer Wheel Path Rutting (Westbound) (2016 Measurements)

| Lane | | Chainage | Average (mm) | P95th (mm) |
|---|---|---|---|---|
| Fast Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 3.9 | 9.1 |
| Slow Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 4.6 | 10.3 |

Rutting is only now touching warning levels




Contract NRA.N.002-010-2017-1F : km 17.47 to km 39.531
Average 10 meter Rut Depth
Direction East - Slow Lane - Left Wheel Path - 2016




Contract NRA.N.002-010-2017-1F : km 17.47 to km 39.531
Average 10 meter Rut Depth
Direction East - Slow Lane - Right Wheel Path - 2016



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# 3. Current Pavement Condition

## Riding Quality Measurements

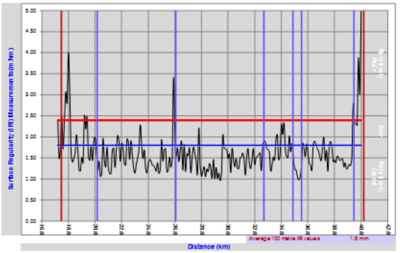
- Riding quality measurements were continuously measured with the DYNATEST RSP MK3 ASTM (Class 1) Profiler in November 2016:

  - Summary 100m IRI Measurements (Eastbound) (2016 Measurements)

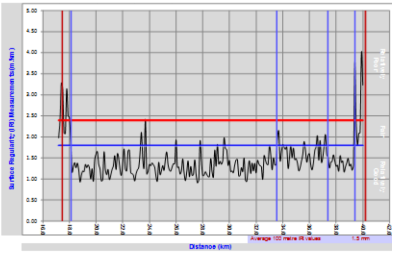
| Lane | | Chainage | Average | P95th |
|---|---|---|---|---|
| Fast Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 1.1 | 1.6 |
| Slow Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 1.5 | 2.0 |

  - Summary 100m IRI Measurements (Eastbound) (2016 Measurements)

| Lane | | Chainage | Average | P95th |
|---|---|---|---|---|
| Fast Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 1.2 | 2.0 |
| Slow Lane | Jointed Concrete Pavement | 39.4 – 17.5 | 1.6 | 2.8 |




Contract NRA.N.002-010-2017-1F: km 17.47 to km 39.531
Average 100 metre IRI values
Direction East - Slow Lane - Left Wheel Path - 2016




Contract NRA.N.002-010-2017-1F: km 17.47 to km 39.531
Average 100 metre IRI values
Direction East - Slow Lane - Right Wheel Path - 2016



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# 3. Current Pavement Condition

## Condition of the Composite Pavement Structure

- The condition of the Jointed Concrete Pavement in general indicated very little signs of structural distress.

- The obvious presence of reflective cracking of the concrete joints in the asphalt surface overlay, had been attended, with crack sealant and the majority of these seals are still functional;

- Remedial measures were therefore mainly required to address:

  - Condition of the Aged; and
  - De-bonded Bitumen Rubber Asphalt Surface Overlay;



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# 4. Remedial Measures Recommended

## Design Philosophy / Strategy

- Remove the deboned Bitumen Rubber Asphalt and 14 mm Stress Absorbing Membrane Interlayer;
- Repair only Severely Damaged Transverse Contraction Joints;
  (Partial depth repairs / joint spall repairs)
- Design and Construct a New Asphalt Surface Overly:
  - with improved binder elasticity and relaxation properties to accommodate;

    warping effect of the concrete under high pavement temperatures;
    curling effect of concrete at low pavement temperatures;
  - that will be resist deformation (rutting) at free-flowing highway speeds;
  - that will be impermeable to the ingress of water;



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# 4. Remedial Measures Recommended

## Design Philosophy / Strategy

- Provide adequate bond strength between the new asphalt surface overly and the old jointed concrete pavement structure;
  - Removing oxidised concrete and texturing the surface to promote bond strength;
  - Applying new generation Rapid Set Tack with Adhesion Promoter;
- Provide superior wet weather skid resistance, spray & noise reduction Surfacing.



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# 4. Remedial Measures Recommended

## Implementation of Recommended Remedial Measures

- 50 mm Bitumen Rubber Asphalt Surface Overlay;
- Ultra-Thin Friction Course;



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# 5. Conclusions

## Summary and Conclusions

- Bitumen rubber asphalt can successfully be used as a surface overlay on top of a distressed jointed concrete pavement;
- It is however important to consider, not only the initial properties of the binder used at the time of construction, but also the change in characteristics over time such as:
  - Adhesion / Bond Strength;
  - Flexibility;
  - Resiliency; and
  - Stiffness

As the Bitumen Rubber Asphalt overlay ages with time.



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