APPLICATION OF AN EXPERIMENTAL ULTRA THIN CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (UTCRCP)

at

THE TRUCK CRAWLER LANE ON NATIONAL ROUTE 1 SECTION 1 between the Huguenot Plaza (km 56.10) and Huguenot Tunnel West Portal (km 61.50)

and

OR TAMBO INTERNATIONAL AIRPORT

10 October 2019
CONTENTS

ULTRA THIN CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (UTCRCP)

1. Objective of this presentation
2. N1-010 - History and Background
3. Finite Element Model analysis
4. UTCRCP Reconstruction – Project Objective
5. Investigation and Failure analysis
6. UTCRCP Pavement design
ULTRA THIN CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (UTCRCP)

7. Detailing the pavement structure
8. Performance
9. Characterization of UTCRCP concrete
10. UTCRCP overlay of Jointed Concrete Pavements
11. Conclusions
1. OBJECTIVE OF THIS PRESENTATION

1. Report on the experimental UTCRCP construction that have been conducted on the N1 crawler lane south of the Huguenot tunnel

2. Discuss the lessons learned over time based on the following
   a) Finite Element Analyses
   b) Material characterization
   c) Performance feedback based on visual observations

3. Report on experimental work where UTCRCP was used as overlay on Jointed Concrete Pavements
2. N1-010 – HISTORY AND BACKGROUND

1. 1\textsuperscript{ST} Construction of experimental section: August 2009 – March 2010

2. Pavement structure

3. UTCRCP design
   - 50mm Thick
   - 5,6mm @ 50mm c/c
   - UCS - 90 MPa
   - Tens strength - 12 MPa
   - Energy absorption with circular panel test > 700 Joule
2. N1-010 – HISTORY AND BACKGROUND

Concrete mix design parameters

- Unconfined compressive strength
- Flexural tensile strength
- Circular panel energy absorption

<table>
<thead>
<tr>
<th>Material</th>
<th>(kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>480</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>87</td>
</tr>
<tr>
<td>Condensed Silica Fume</td>
<td>72</td>
</tr>
<tr>
<td>Stone (6.7mm)</td>
<td>972</td>
</tr>
<tr>
<td>Water</td>
<td>175</td>
</tr>
<tr>
<td>Sand</td>
<td>684</td>
</tr>
<tr>
<td>Chryso Premia 100* (litre)</td>
<td>4 /</td>
</tr>
<tr>
<td>Chryso Optima 100* (litre)</td>
<td>2.4 /</td>
</tr>
<tr>
<td>Polypropylene Fibre</td>
<td>2</td>
</tr>
<tr>
<td>Steel Fibre</td>
<td>100</td>
</tr>
</tbody>
</table>
December 2010 - first signs of failure in the form of buckling and bulging
3. FINITE ELEMENT MODEL ANALYSES

Reasons for failure based on FE analysis
3. FINITE ELEMENT MODEL ANALYSES

For 50mm slab and based on a surface temperature of 65°C and 10°C temperature gradient

1. A slab without imperfections should be able to resist buckling, provided full bond is achieved with supporting layer

2. Honeycombing is the single most important contributing factor for failure, doubling the risk of buckling

3. Lessor factors each adding 10% to the risk are:
   a) 10% reduction in thickness
   b) If steel mesh is in the upper half of the slab

4. For slabs fully restrained/anchored, the longitudinal profile is not expected to impact on the risk of buckling.
3. FINITE ELEMENT MODEL ANALYSES

Other findings included the following recommendations to limit the risk of buckling

1. Reduce the risk of honeycombing by:
   a) Increasing the steel spacing
   b) Improve the workability of the concrete mix

2. Increase the slab thickness (mainly to improve workability)

3. Add edge beams to the slab (if risk of honeycombing cannot be eliminated)
3. FINITE ELEMENT MODEL ANALYSES

Considering different slab thicknesses - a follow-up FE analysis found the following
3. FINITE ELEMENT MODEL ANALYSES

A follow-up FE analysis also found the following

1. It has been confirmed that observed failures cannot be attributed to stresses only in the 50mm UFCRCP.

2. Besides construction imperfections, failure is also caused by total loss of bond

3. Curling of the slab is also an important contributing factor to buckling for the following reasons:
   - Voids are created below the construction joints
   - Voids develop below the slab edge
   - Loss of bond also result in possible downhill sliding
   - Voids can become saturated with water to increase the risk of further debonding
3. FINITE ELEMENT MODEL ANALYSES

Additional recommendations based on the FE analysis

1. Prevent curling by introducing edge beams and thickening of construction joints to:
   ▪ Reducing uplift and limiting the development of voids on the edge
   ▪ Reduce joint movement and increase load transfer
   ▪ Limit the ingress of water at the edge
   ▪ Intermediate anchoring of the slab at the joints

2. Consider increasing the slab thickness to:
   ▪ Reduce curling
   ▪ Reduce stress on subbase
   ▪ Reduce risk of pumping and stripping (reason for loss of bond)

3. It was advised to reconstruct the failed crawler lane with
   ▪ 70mm Slab with edge beam and 100mm slab without edge beam
4. UTCRCP RECONSTRUCTION – PROJECT OBJECTIVE

1. The main objective of this project was to
   a) reconstruct the previously constructed UTCRCP for long term structural performance
   b) applying the lessons learned from the previous failure and
   c) implement state of the art material characterization and mechanistic design tools.

2. Review the findings of previous investigations and analyses of the original UTCRCP failure

3. Apply state of the art technology to test and define the engineering properties of the proposed concrete materials and pavement structure

4. Use finite element analysis methods to model the proposed pavement structure and confirm expected performance
5. INVESTIGATION AND FAILURE ANALYSIS

1. Pavement structure (Theoretical)
5. INVESTIGATION AND FAILURE ANALYSIS

Cause and origin of failure

1. Excessive thermal movement and buckling of the UTCRCP slab
2. Day (construction) joint failure due to curling
3. Crocodile cracking and punch-out due to honeycombing below the steel
4. Edge failure also due to voids, loss of support and curling
5. Slab-support failure due to stripping of the asphalt and erosion of the BSM
5. INVESTIGATION AND FAILURE ANALYSIS

1. Slab movement
5. INVESTIGATION AND FAILURE ANALYSIS

2. Concrete failure
5. INVESTIGATION AND FAILURE ANALYSIS

3. Support failure
6. UTCRCP PAVEMENT DESIGN

1. Probabilistic computer added design software package (cncPave)

2. Recommended improvements to UTCRCP slab geometry
   a) Increased thickness to 70 mm with edge beam
   b) 100mm thickness

3. Modeling the pavement structure
   a) Layer thickness and stiffness
   b) Variability

4. cncPave input
   a) Climate
   b) Traffic spectrum and design load
   c) Moisture performance indicators
   d) Concrete material characteristics
6. UTCRCP PAVEMENT DESIGN

5. Design approach
   a) 30 year maintenance free period aiming for 0.5m crack spacing
   b) Failure defined as
      ▪ < 0.8% shattered slab and
      ▪ < 5% pumping
   c) Acceptable performance.

6. Modeling the pavement structure
   a) Layer thickness and stiffness
      ▪ 70 and 100mm slab thickness
      ▪ 30mm AC @ 2000 MPa
      ▪ BSM 110 – 140 mm @ 125 - 1000 MPa
      ▪ C3 335 mm @ 750 - 5000 MPa
      ▪ Subgrade @ 190 MPa
6. UTCRCP PAVEMENT DESIGN

7. cncPave input

e) Concrete material characteristics

- Aggregate size and shape
- Aggregate strength
- Concrete properties such as
  - flexural strength - thick UTCRC allow a lower strength of 7.5 MPa and
  - Youngs Dynamic Modulus in terms of the E/f ratio

- The reinforcing comprised a standard mesh of 5.6mm dia x 67mm c/c although a spacing of 100mm would have been preferred

- The contractor chose to use a mix with 12 MPa flexural strength.

- Youngs Dynamic Modulus of 49 GPa resulting was determined at the University of Stellenbosch resulting in a E/f ratio of 4000.

- cncPave does not consider the concrete strength in terms of the circular panel test results.
7. DETAILING THE PAVEMENT STRUCTURE

1. Edge beams
7. DETAILING THE PAVEMENT STRUCTURE

2. Intermittent anchor beams at day (construction) joints

- Tied key joint for load transfer
3. Anchor blocks

a) 550mm deep and 500mm wide

b) 3 x @ 4m c/c
8. PERFORMANCE

November 2016 – one year after construction – general condition
8. PERFORMANCE

November 2016 – one year after construction

1. 100mm slap buckling/bulging
8. PERFORMANCE

100mm slab repair and joint failure

Jan 2017 – CRCP replacement

Mid 2018 – CRCP/UTCRCP joint
8. PERFORMANCE

100mm slab repair and joint failure
Localized associated closely spaced cracks and open construction joint
8. PERFORMANCE

Mid 2018 – 2.5 years after construction

70mm slab construction joint failure
9. CHARACTERISATION OF UTCRCP CONCRETE

Laboratory research conducted by the University of Stellenbosch

1. Standard engineering tests
2. EN notched beam test – fibre reinforced concrete
3. Standard circular disk energy absorption test for reinforced and only fibre reinforced disks
4. Fatigue resistance test – repeated loading of circular disk
### 9. CHARACTERISATION OF UTCRCP CONCRETE

<table>
<thead>
<tr>
<th>Age [days]</th>
<th>Compression</th>
<th>Tensile Splitting</th>
<th>Standard Flexural</th>
<th>Young's Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Average [MPa]</td>
<td>64.7</td>
<td>89.4</td>
<td>8.6</td>
<td>12.0</td>
</tr>
<tr>
<td>COV [%]</td>
<td>1.4</td>
<td>1.1</td>
<td>2.7</td>
<td>12.5</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>2461</td>
<td>2445</td>
<td>2450</td>
<td>2473</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Static Dynamic</td>
</tr>
<tr>
<td></td>
<td>46 320</td>
<td>49 300</td>
<td>3.4</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2425</td>
</tr>
</tbody>
</table>
9. CHARACTERISATION OF UTCRCP CONCRETE

\[ \frac{f_{r1}}{f_L} > 0.4 \text{ (1.13 therefore OK)} \]
\[ \frac{f_{r3}}{f_{r1}} > 0.5 \text{ (0.31 therefore not OK)} \]

- \( f_{r1} \)
- \( f_{r2} \)
- \( f_{r3} \)
- \( f_L \)
- \( f_{r4} \)
9. CHARACTERISATION OF UTCRCP CONCRETE
9. CHARACTERISATION OF UTCRCP CONCRETE

Table 7. Energy absorbed for each of the static round panel tests.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2358</td>
<td>2249</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>2519</td>
<td>2427</td>
<td>2366</td>
</tr>
<tr>
<td>B1</td>
<td>2645</td>
<td>2423</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>427</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>336</td>
<td>320</td>
<td>318</td>
</tr>
<tr>
<td>C2</td>
<td>257</td>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Failure mechanisms of static round panel tests.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Three radial cracks</th>
<th>Failure mechanism</th>
<th>Punching shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (With mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2 (With mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1 (With mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2 (No mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1 (No mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2 (No mesh)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9. CHARACTERISATION OF UTCRCP CONCRETE

Figure 36. Loading-unloading cycles for varying loading with the specimen pre-cracked at onset.
9. CHARACTERISATION OF UTCRCP CONCRETE

Figure 23. The stiffness evolution of the samples that were pre-cracked (PC) at the load levels shown in the legend.
9. CHARACTERISATION OF UTCRCP CONCRETE

Summary of research findings

1. The Modulus of Rupture is not a good indication of the actual tensile capacity of the fibre reinforced concrete - based on post peak behaviour as tested with the EN notch method.

2. Strong deflection softening behaviour has been detected. Different fibres should be considered.

3. The steel fibre show poor bridging capacity for cracks > 1mm.

4. For rigid plastic models the tensile capacity is only 1 MPa after cracking.

5. Steel fibres only contribute 15% of the total energy absorption capacity. Consideration can be given to the combination of steel fibre and reinforcing in the slab and also to the type of steel fibre to be used.

6. The total energy absorption capacity is the same for static and cyclic loading tests.

7. A significant reduction in stiffness was found for cyclic loading on pre-cracked disks.
10. UTCRCP OVERLAY ON JOINTED CONCRETE PAVEMENTS

Experimental pavement at ORTIA

Stand A6 - Failed

Stand A8 - Deteriorated
10. UTCRCP OVERLAY ON JOINTED CONCRETE PAVEMENTS

ORTIA Stand A6 – 2010

38,0m long
24,4m wide

Stand A8 - 2012
10. UTCRCP OVERLAY ON JOINTED CONCRETE PAVEMENTS

ORTIA Stand A6 – 2012
10. UTCRCP OVERLAY ON JOINTED CONCRETE PAVEMENTS

ORTIA Stand A6 – 2017 after 7 years
11. Conclusions

1. Theoretically the (50mm or thicker) UTCRCP should be a suitable pavement structure but specific risks should be eliminated.

2. Risks to be eliminated are
   a) Construction deficiencies (i.e. honeycombs)
   b) Curling (edge restraint and construction joints)
   c) Subsurface water and delamination
   d) Out of sequence construction.

3. A review of design parameters is recommended with regard to i.e.:
   a) Steel fiber content and type
   b) Combination fiber and reinforcing

4. Positive performance of concrete overlay of damaged Jointed Concrete Pavement - further research required.
Thank you for your attention

Questions ?