Wayside Top of Rail Friction Control:
An embedded track solution in a high density tram network

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Presentation Overview

1. Introduction / Problem background
2. Initial remediation measures
3. Top-of-Rail (TOR) friction modifiers as a solution
   – Preliminary investigation tasks and results
4. Embedded track TOR equipment solution
   – Equipment design
   – Installation details
5. Noise monitoring
   – Data collection methodology
   – Noise reduction results
6. Conclusions / Next steps
Trams in Melbourne

- Yarra Trams (Melbourne, VIC) - World’s largest operational tram network
- Current tram franchise operated and maintained by Keolis Downer
- 75% of tram network shares operating space with other vehicles

- 200 million+ passenger trips per year
- 5,000+ services per day
- 2,000+ employees
- 475+ trams
- 1,750+ tram stops
- 250km of double track
- Nine depots
Trams in Melbourne

• St. Kilda Road - Busiest tram corridor with headways approximately every minute during peak hours
• Mixed tram types operating through eight routes:
  – High floor Comeng fleets (A, B and Z Class trams)
  – Low floor Siemens fleets (D Class trams)
Problem Background

- Emergence of atypical wheel squeal events following St. Kilda Road track realignment accommodating new underground station project
- Predominantly occurring in longer and shallower 80-90m radius curves in both Inbound and Outbound tracks along St. Kilda Road
- Noise events were not linked to a specific tram type or number

*Problem noise locations shown in orange*
Initial Remediation Measures

- Water spray cart to temporarily wet and lubricate the tracks
- Rail grinding restoring the rail head to the target design profile
- Crack sealant application introducing flexibility into the embedded track structure

Lack of success with initial remediation measures lead to investigation of TOR friction modifiers as a possible solution.
TOR Friction Modifiers as a Noise Solution

- Top-of-Rail (TOR) squeal - Use a friction modifier (FM) to:
  - Reduce coefficient of friction (CoF) on the TOR to 0.3 - 0.4
  - Create positive friction conditions to eliminate stick-slip oscillations

- KELTRACK® Trackside Transit (KTT) nominated as the FM for use:
  - Water-based product with proven positive friction characteristics
  - No adverse impacts to vehicle braking or traction
  - Water component rapidly evaporates, leaving a thin dry film on the top of rail surface
  - Environmentally friendly, non-volatile and non-flammable
  - Noise abatement effectiveness range typically 250-300m
Common Causes of Wheel / Rail Noise

1. **Gauge Face (GF) Flanging**
   I. ‘Buzzing’ or ‘hissing’ sound
   II. Broadband high frequency = 5000 – 20,000 Hz
   III. Caused by friction between the wheel flange and rail gauge face

2. **Top-of-Rail (TOR) Squeal**
   I. High pitched, tonal squeal
   II. Predominantly 1000 – 5000 Hz frequency
   III. Caused by stick-slip oscillations due to creep forces and negative friction
“Dry” Wheel / Rail Interface

- Relative wheel/rail motion (creepage) accommodated by:
  1. Rolling
  2. Elasticity
  3. Breaking
  4. Void collapse

Brittle “High Hardness” Wear Particles (Fe₃O₄)
“KELTRACK® treated” Wheel / Rail Interface

- KELTRACK® creates a composite deformation mechanism
- Pliable FM particles provide an elastic shear displacement accommodation mechanism that negates/arrests brittle particle breaking and void collapse
Preliminary Investigation Tasks

Phase 1: FM Impacts to Tram Braking and Traction

- KTT manually applied to top of rail of New Preston Depot Stabling track (tangent segment)
- B and D Class trams tested under the following conditions:
  1. Dry conditions without KTT
  2. Dry conditions with KTT manually applied
  3. Wet conditions - Water sprayed on top of manually applied KTT to mimic heavy rainfall conditions
- Several test runs conducted applying service and emergency braking at different tram speeds
- No adverse impacts to tram stopping distance or tractive effort observed during testing
Preliminary Investigation Tasks

Phase 2: FM Effectiveness on Wheel Squeal Reduction

- One D Class Tram tested on mainline track at St. Kilda Road - Outbound track reverse curve segment used as trial location
- FM manual application method and three test conditions identical to Phase 1 Tram braking and traction investigation
- KTT manually applied in dry conditions demonstrated immediate benefit - No wheel squeal events
- KTT in wet conditions produced similar favourable results – Indicated suitable resiliency under heavy rainfall conditions
- Business case funded for an automated application system
Phase 2 success leads to approval of an embedded track TOR application system as a permanent noise solution for St. Kilda Rd
TOR Equipment Design

• Incorporation of an embedded track TOR application system type-approved as the permanent noise solution
• Includes robust steel enclosures and lids protecting key system components (TOR bars, Tram sensor, etc.) after embedded concrete to surface track structure is restored
• Customized site design accommodated customer-specific operating conditions:
  – Track structure design
  – Vehicle wheel circumference
  – Design and construction standards
  – Road vehicle, Bicycle, Pedestrian Traffic
**TOR Equipment Design**

**LB Foster PROTECTOR® IV (PIV) DC Solar TOR unit selected for use:**

- 95 litres FM product tank capacity
- 4ea. TOR distribution bars mounted on field side
  - 915mm length
  - 2ea. per rail side
- Solar-DC powered (80W solar panel + 12amp VR)
- Field side-mounted Tram sensor – Vibration triggers one FM discharge (X seconds) per Tram
- Remote Performance Monitoring (RPM) hardware for offsite system status health checks
TOR Equipment Installation

• St. Kilda Road wayside TOR equipment installation work was performed in three main phases:
  – **Phase 1**: Pre-installation site mock-up review
  – **Phase 2**: Inbound track installation and commissioning
  – **Phase 3**: Outbound track installation and commissioning

• **Phase 1 work proven to be a critical pre-installation knowledge-sharing exercise amongst project stakeholders:**
  – Confirmed as-designed locations for TOR equipment components were suitable for use
  – Identified minor enclosure design issues requiring correction
  – Improved understanding of responsibilities between work crews
  – Partial assembly of TOR equipment also completed
• Phase 2 (Inbound Track) and Phase 3 (Outbound Track) installation works each completed over a four day period

• Main scope of works:
  – Site excavation
  – TOR equipment fitting
  – Concrete restoration
  – Final commissioning

• Work performed primarily during regularly scheduled non-operating night time hours
TOR Equipment – Completed Installations

**STAGE ONE REALIGNMENT**

**INBOUND TRACK**

**OUTBOUND TRACK**

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Data Collection Methodology

- Information recorded for each data collection cycle:
  - Tram type - A/Z, B or D class
  - Direction of travel: Citybound (Inbound) or Southbound (Outbound)
  - Weather conditions

- Wayside noise measurements recorded in increments of 1 second to capture both Tram approach and pass-by

- The following acoustic parameters were used when analyzing noise data:
  1. $L_{AF_{\text{max}}}$: The maximum A-weighted sound pressure level, measured on “fast” time-weighting
  2. $L_{Z_{\text{eq},1s}}$: The un-weighted equivalent continuous sound pressure level at which the $L_{AF_{\text{max}}}$ occurred

Sound Measurement Locations for Noise Monitoring

Note: Satellite image is outdated and does not reflect the Inbound and Outbound as-built track alignment in place during testing.
Other Noise Data Collection Considerations

- Only tram passes audible over ambient noise sources were used for analysis
- Tram speed not measured
- Concurrent tram pass-bys on both tracks not included in analysis i.e. Unable to assign recorded data to specific tram type
- Precise noise reduction threshold determining measure of success was not assigned within analysis work scope
Noise Reduction Results

Embedded TOR unit significantly reduced noise levels for all tram types in both directions

- Focus on D Class Tram results for symmetry to manual TOR application trial results
- 11-19 dB noise reduction achieved for frequencies previously associated with tram squeals during pre-mitigation noise monitoring for D Class trams (i.e. 3150 Hz and 5000 Hz)
- A drop of 10 dB typically considered to reflect a 50% reduction in subjectively perceived noise loudness (i.e. volume).

<table>
<thead>
<tr>
<th></th>
<th>CITYBOUND</th>
<th>SOUTHBOUND</th>
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<tbody>
<tr>
<td></td>
<td>3150 Hz</td>
<td>3150 Hz</td>
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<tr>
<td>Pre-mitigation</td>
<td>63 dB</td>
<td>62 dB</td>
</tr>
<tr>
<td>(Average L_{eq})</td>
<td>62 dB</td>
<td>63 dB</td>
</tr>
<tr>
<td>Post-FM via TOR unit</td>
<td>51 dB</td>
<td>51 dB</td>
</tr>
<tr>
<td>(Average L_{eq})</td>
<td>46 dB</td>
<td>44 dB</td>
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<tr>
<td>Noise level difference</td>
<td>-12 dB</td>
<td>-16 dB</td>
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<tr>
<td></td>
<td>-11 dB</td>
<td>-19 dB</td>
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L_{eq,1s} of D Class Trams During Pre-mitigation (no TOR) vs Wayside TOR Test Phases
Noise Reduction Results – Preliminary Investigation

Maximum A-weighted Noise Levels for a 1 sec Period
- D Class Test Tram

1/3 Octave Frequency Spectra - D Class Test Tram

Red - Pre-mitigation  Blue - Post-manual KELTRACK® TT application  Yellow - Post-manual KELTRACK® TT application + water
Wayside TOR application eliminated extreme noise events (i.e. those > 65dB) for Citybound and Southbound D Class Trams

1/3 Octave Frequency Spectra for Citybound (Inbound) D Class Trams

1/3 Octave Frequency Spectra for Southbound (Outbound) D Class Trams

Red - Pre-mitigation  Blue - Post-manual KELTRACK® TT application
Results Summary

• A problem wheel squeal issue has been successfully resolved using an embedded track TOR equipment solution dispensing a water-based friction modifier (KELTRACK® Trackside Transit)
  – Initial manual application of KTT demonstrated immediate benefit, with no wheel squeal events recorded
  – TOR equipment solution effectively reduced noise levels for all tram types in both operating directions
  – 11-19 dB noise reduction achieved for D Class trams = ~50% reduction in subjectively perceived noise loudness

• No adverse impacts to Tram braking or traction observed during all project phases

• Prior initial remediation measures failed to achieve similar noise abatement success (i.e. Water spray, Rail grinding, Crack sealant)
Project Update

- St. Kilda Road track alignment recently revised as part of ongoing construction works for underground station
- Inbound TOR site remains the same – Outbound TOR unit has been relocated slightly during construction occupation
Evaluate additional benefits of KELTRACK® TT use:

1. Rolling Contact Fatigue (RCF) / Corrugation Abatement
   - Wheel squeal generation mechanisms similar to those producing RCF and corrugation defects
     - Similar abatement potential and rail grinding efficiencies therefore possible through using TOR friction control

2. Rail Wear Reduction
   - Wear rates accelerate with increased contact pressure, creepage and friction levels
   - TOR friction control reduces curving and flanging forces, thereby decreasing contact pressure at the wheel / rail interface to reduce rail wear
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