WMATA’S DIRECT FIXATION TRACK FASTENING SYSTEM

INTERNATIONAL CROSSTIE AND FASTENING SYSTEM SYMPOSIUM

BY: RAVI AMIN, PE, WMATA
OVERVIEW OF WMATA’S RAIL SYSTEM

- 238 MAINLINE TRACK MILES, 6 ROUTE SYSTEM, ~40 MGT ON HEAVIEST LINE,
- 600K PASSENGERS ON AVERAGE DAY
- 136 MILES OF DIRECT FIXATED TRACK
- APPROXIMATELY 15 MILES OF FLOATING SLAB
PHOTOS OF TRACK FASTENERS

STANDARD DESIGN

RESILIENT DESIGN
PHOTOS OF TRACK FASTENERS

LEGACY DESIGNS: HIXSON, LORD, LANDIS MODELS
OVERVIEW OF TYPICAL FASTENER AND ANCHORAGE
CROSS SECTION OF A TYPICAL FASTENER
PERFORMANCE SPECIFICATIONS FOR DF TRACK

- **ELECTRICAL ISOLATION:** $10^{11}$ OHM-CM UNDER A WET CONDITION
- **ELASTOMERIC STIFFNESS:** 45-55 DUROMETER
- **SPRING RATE**
  - STANDARD: 94K – 120K PSI
  - RESILIENT: 50K -75K PSI

  LATERAL AND VERTICAL LOAD CAP. IS BASED ON ALLOWED DEFLECTION VS. LOAD

- **RESILIENT FASTENERS:** 8 TO 12 DB OF VIBRATION
- **FLOATING SLAB:** 14 TO 18 DB OF VIBRATION
BENEFITS OF DF TRACK

• BALLASTED DESIGN PROVIDES LESS WEIGHT ON BRIDGE STRUCTURES, REDUCED CAPITOL COST

• TIGHTER CONTROL OF DYNAMIC ENVELOPE. REDUCED COST ON TUNNEL DESIGN AND CONSTRUCTION
DF SPECIAL TRACKWORK
FLOATING SLAB TRACK

- Applied in sensitive locations to mitigate noise and vibrations at or near the ground level.
- Resilient fasteners have been used as an alternative.
PROBLEMS WITH DF TRACK

• LOOSENING OF NUTS DUE TO VIBRATIONS AND DYNAMIC TRACK LOADING
  • VERTICAL AND HORIZONTAL MOVEMENT OF THE PLATE
    • BROKEN STUDS
    • WORN WASHER SERRATIONS AND LOSS OF GAUGE RESTRAINT
    • BROKEN RAIL CLIPS
    • INCREASED RAIL FATIGUE

• IMPROPER SUPPORT OF THE FASTENER
  • ALL THE ABOVE ISSUES
  • IMPROPER CURING AND FINISHING OF MASONRY
  • BATTERED JOINTS
  • DERAILMENT DAMAGE
  • CORROSION (STRAY CURRENT)
PHOTOS OF DEFECTS
PHOTOS OF DEFECTS
FUTURE OF DF TRACK

- WMATA CONTINUES TO BUILD AND MAINTAIN DF TRACK
- MORE ATTENTION TO MATERIAL CONTROL AND FINISHING NEEDED
- SWITCHING TO FLAT GROUT PAD AND CANTED FASTENERS
- UIUC STUDY TO GUIDE UNDERSTANDING OF INTEGRITY OF CURRENT DESIGN
- PERSONALLY WOULD LIKE TO SEE REINFORCED PLINTHS ON FUTURE TRACK (LIKE DULLES EXTENSION) MORE DURABLE AND PERMANENT SUPPORT DESIGN
Field Investigation of the Performance of Direct Fixation Fastening Systems on Heavy Rail Transit Infrastructure

Luis W. Chavez Quiroz, Yu Qian, J. Riley Edwards, and Marcus S. Dersch

International Crosstie and Fastening System Symposium
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Outline

► Objectives & Approach
► Field Experimentation
  • Sites
  • Results
► Finite Element (FE) Model
  • Fastener Failures
  • Stress Concentrations
  • Recommendations
► Results
► Conclusions
Research Motivation

Mission:
Perform a comprehensive study of WMATA’s (Washington Metropolitan Area Transit Authority) track fastening systems to quantify typical load environment and response of the existing fastening system design, then develop analytical models to investigate their performance and recommend alternative designs.

Key Objectives:
► Compare WMATA’s direct fixation track system to industry best practices
► Quantify field performance of fastening systems
► Use finite element (FE) modeling to perform parametric study on fastening system behavior
► Provide recommendations for improved fastening system design and maintenance
Project Approach

Literature Review

Field Testing

Finite Element Modeling

Linked together - field results inform and assist in calibrating finite element model
Field Experimentation

Objectives:

► Quantify fastening system behavior when subjected to revenue service load environment
  • Loading magnitude on rail
  • Displacement levels of rail
► Compare these conditions to the failure modes that have been seen in the field
► Understand variability in loading and displacement associated with rolling stock operation
► Generate data set for model calibration and validation

Approach:

1. Instrument three locations on WMATA infrastructure
2. Monitor typical peak service loads and displacements
Locations of WMATA Field Sites

- **Site 1 (D02)**
- **Site 2 (D07)**
- **Site 3 (A02)**
# WMATA Site Summary

<table>
<thead>
<tr>
<th>Descriptor Category</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMATA Site ID</td>
<td>D02</td>
<td>D07</td>
<td>A02</td>
</tr>
<tr>
<td>Service Line(s)</td>
<td>Blue, Orange, Silver</td>
<td>Blue, Orange, Silver</td>
<td>Red</td>
</tr>
<tr>
<td>Curve Radius (ft)</td>
<td>769</td>
<td>755</td>
<td>1,200</td>
</tr>
<tr>
<td>Degree of Curve (°)</td>
<td>7.44°</td>
<td>7.59°</td>
<td>4.77°</td>
</tr>
<tr>
<td>Max Speed (mph)</td>
<td>35</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Balance Speed (mph)</td>
<td>24</td>
<td>27</td>
<td>36</td>
</tr>
<tr>
<td>Actual Superelevation (E_a)</td>
<td>3.00”</td>
<td>4.00”</td>
<td>4.00”</td>
</tr>
<tr>
<td>Unbalanced Super. (E_u)</td>
<td>3.38”</td>
<td>4.50”</td>
<td>4.36”</td>
</tr>
</tbody>
</table>
WMATA Field Instrumentation Map

Deployed at All Three Sites

Metrics to quantify:
- Vertical and lateral loads (wheel-rail interface)
- Rail displacements
Vertical Wheel Loads
Lateral Wheel Loads

- Site 1 (D02) - High Rail
- Site 1 (D02) - Low Rail
- Site 2 (D07) - High Rail
- Site 2 (D07) - Low Rail
- Site 3 (A02) - High Rail
- Site 3 (A02) - Low Rail

Percent Exceeding

Lateral Load (kips)
Rail Head Displacement – Lateral

Displacement (in.)

(+)

High

Low

Displacement (in.)

(+)

High

Low

Displacement (in.)

(+)

High

Low

Displacement (in.)

(+)

High

Low

Displacement (in.)
Rail Base Displacement – Lateral

Displacement (in.)

0.15 0.10 0.05 0.00

(+)

Site 1

High

Low

Displacement (in.)

0.00 0.05 0.10 0.15

Displacement (in.)

0.15 0.10 0.05 0.00

(+)

Site 2

High

Low

Displacement (in.)

0.00 0.05 0.10 0.15

Displacement (in.)

0.15 0.10 0.05 0.00

(+)

Site 3

High

Low

Displacement (in.)

0.00 0.05 0.10 0.15
Conclusions

Field Experimentation

► Field study allowed us to quantify loading environment, 99th percentiles for three sites were as follows:
  • Vertical loads → 12.4 – 15.9 kips
  • Lateral loads → 5.6 – 9.8 kips
► Median lateral rail head displacement → 0.06 – 0.10 in.
► Maximum gauge widening → 0.27 in.
► Site 2 (D07) showed greater displacements and higher loads
► High rail consistently sees greater vertical loads at all speeds
► Site 1 (D02) had maintenance activities performed prior to data collection may have influenced results
Finite Element (FE) Model

Objectives:
► Evaluate the effect of the following on WMATA’s existing fastener
  • Fasteners mounted on uneven surfaces
  • Fasteners mounted on shim(s)
  • Shim material
► Determine if support condition can withstand load environment
  • Stress criteria
  • Displacement criteria
► Provide recommendations on fastener design and maintenance

Approach:
1. Develop half-track model for simulation
2. Address condition changes via project matrix
Direct Fixation System on WMATA

DF System | B

- Studded Rod
- Hex Nut
- Lock Plate
- E-Clip
- Rubber Fill
- Top Plate
- Frame
Model Environment

Full Size, Half-Track Model

17’6” 115RE on 7 x SW-31 Fasteners @ 30”

210” 115RE

Shim x 7

Rod Couple x 7

E-Clip Couple x 7

SW-31 Fastener x 7 @ 30”
17'6" 115RE on 7 x SW-31 Fasteners @ 30"

- 115RE
- E-Clip Toe
- Top Plate
- Rubber Fill
- Frame
- Threaded Rod
- Hex Nut
- Lock Plate
- Shim
Model Environment – Example Scenario

Fastener Support | A

- **A:** Fully Pinned Model Environment
- **B:** Half Pinned (Field Side) Model Environment
- **C:** Half Pinned (Gauge Side) Model Environment

100% Cover

Fully Pinned Lab Environment

50% Cover
Qualitative Model Results

Stress Concentrations | Top Plate
Acknowledgements

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  • Washington Metropolitan Area Transit Authority (WMATA)

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► For assistance with field instrumentation preparation and manufacturing PDMDs
  • UIUC Machine Shop
Path to Completion

Literature Review

Field Testing

Finite Element Modeling

Linked together - field results inform and assist in calibrating finite element model
Thank you for your attention!

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Rail Transportation and Engineering Center (RailTEC)

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Rail Base Displacement – Vertical

Site 1
High
(+)
Displacement (in.)
0.00
0.05
0.10
-0.05
-0.10

Site 2
High
(+)
Displacement (in.)
0.00
0.05
0.10
-0.05
-0.10

Site 3
High
(+)
Displacement (in.)
0.00
0.05
0.10
-0.05
-0.10