# OVERVIEW OF DIRECT FIXATION FASTENERS in MAJOR U.S. TRANSIT SYSTEMS


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L.B. FOSTER COMPANY



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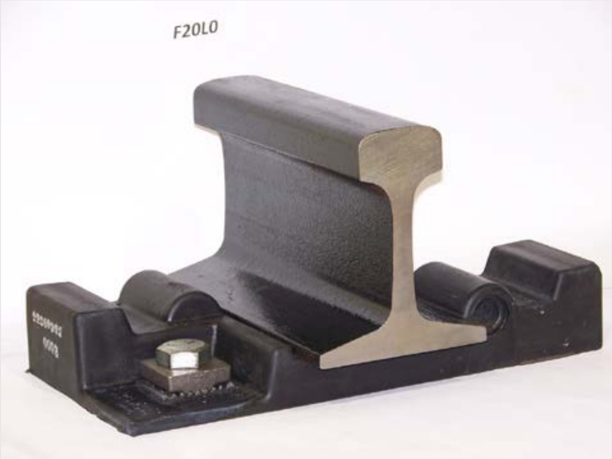
# Introduction & Overview

- Direct fixation track is also known as ballastless track
  - Non-embedded
  - Embedded
- Original use of direct fixation fasteners (DFF) date back 1920s in NYC
- Increased use of slab track design in urban areas in the second half of 20th century (e.g. MARTA, BART, WMATA)
- New fastening systems were needed to accommodated slab track design and construction
- Numerous designs were created over the years in the US and globally, all aiming to:
  - Maintain track integrity under operational loads
  - Offer noise and vibration mitigation
  - Insulate rails electrically





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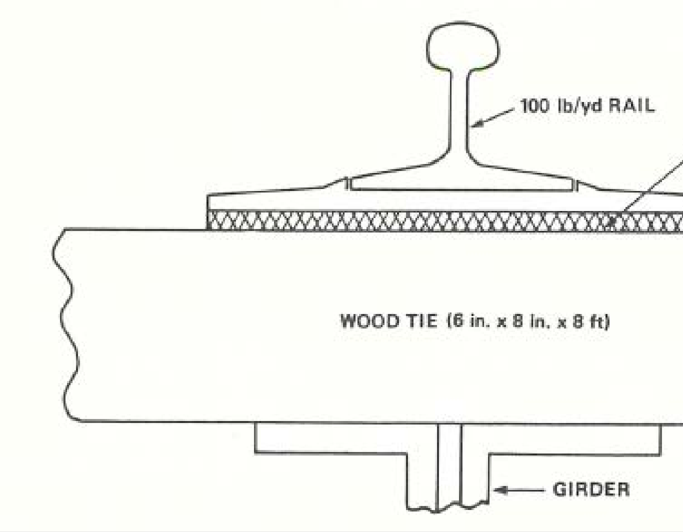
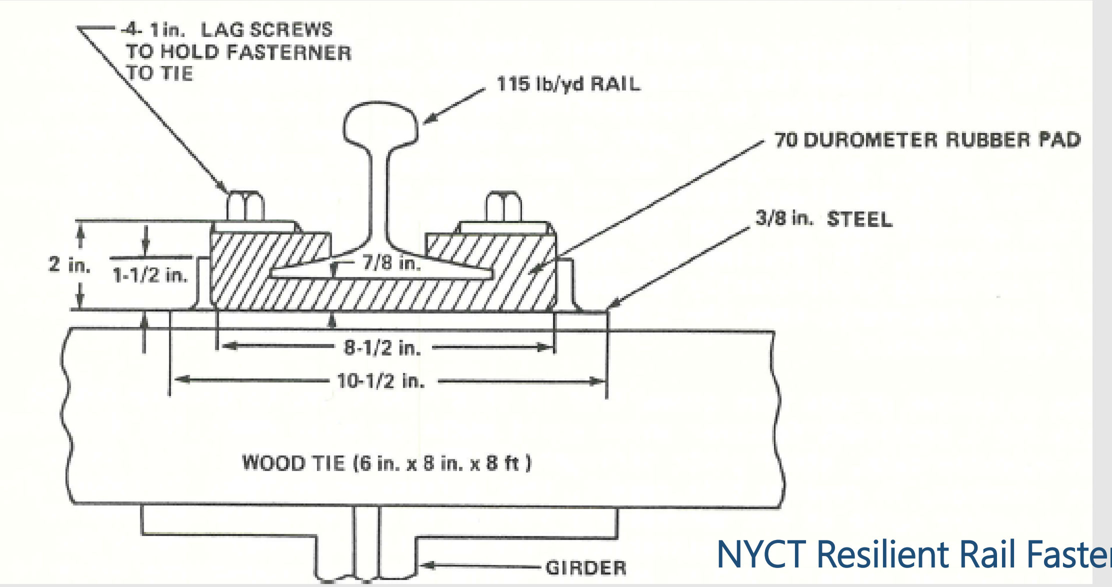
# Pre 1970's Direct Fixation Designs

- Non-Bonded Elastomer Designs
  - Steel Plate
  - "TIE SAVER" Pad
  - Spiked Rail




NYCTA Typical Elevated

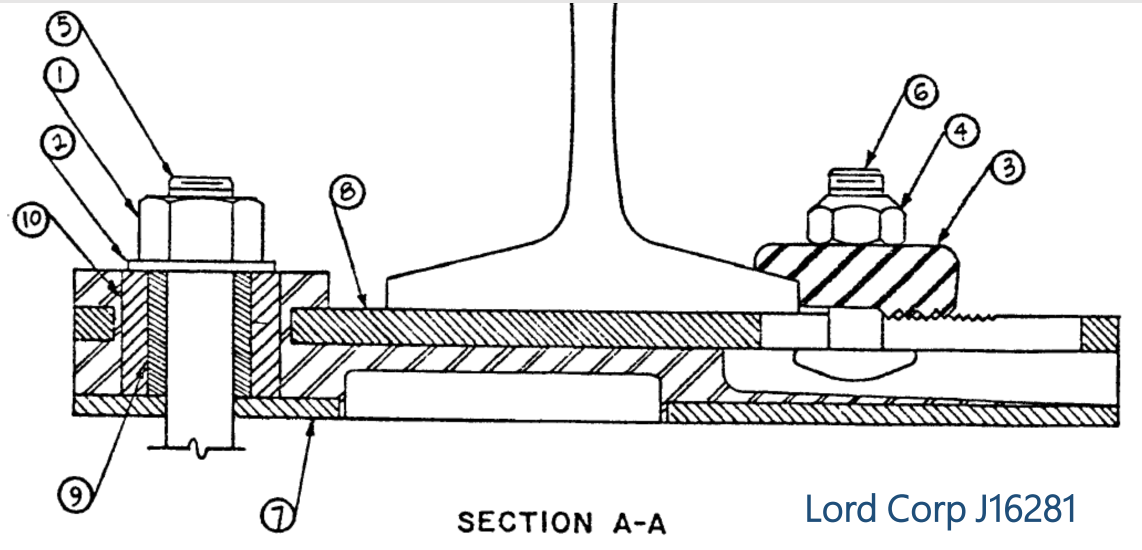
  - Preformed Elastomer encased rail
  - Steel Frame container
  - Bolted rail Clamping




NYCT Resilient Rail Fastener

# 1970's through 1980's Direct Fixation Designs

- **Predominantly Bonded Elastomer**
  - Steel Plate fixed through fastener body anchorage points
  - Vulcanize Bonded Elastomer to form a "one piece" fastener body
  - Various bolted rail clip and spring clip designs
  - Rail Adjustment along top surface of steel plate

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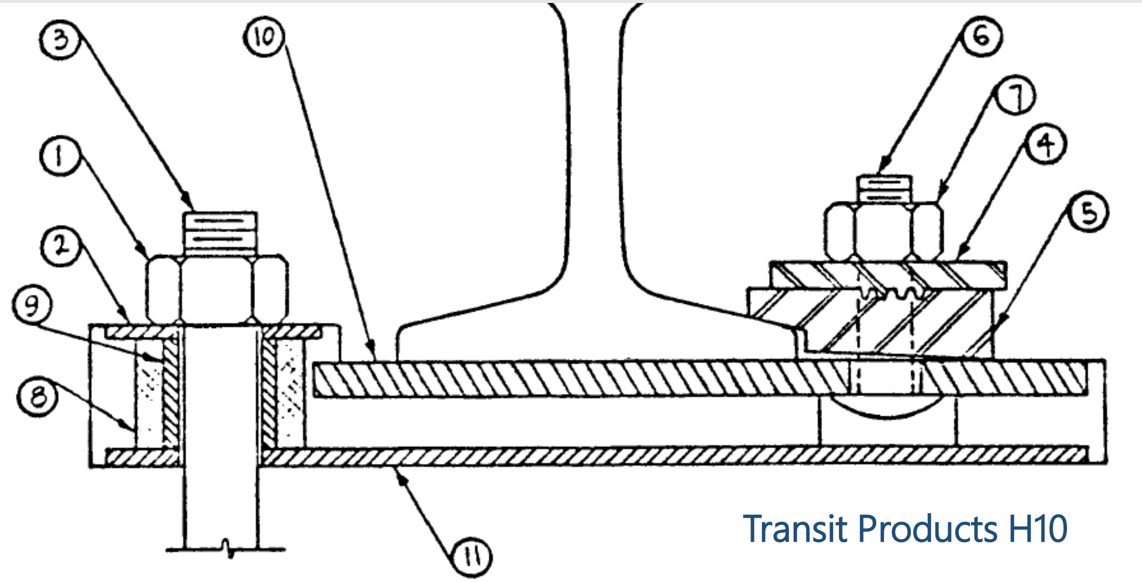

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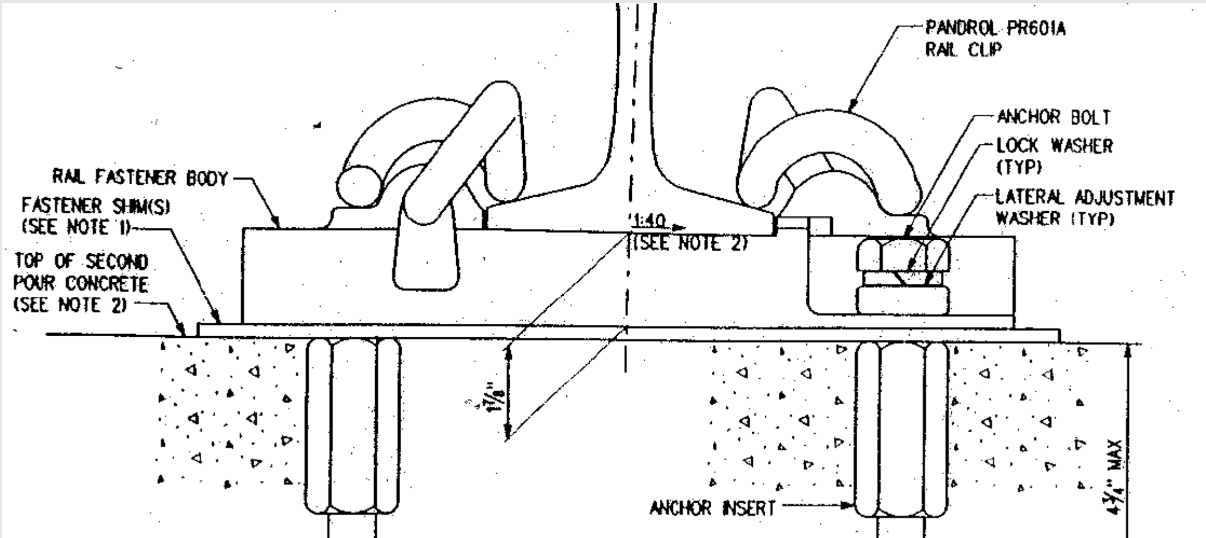
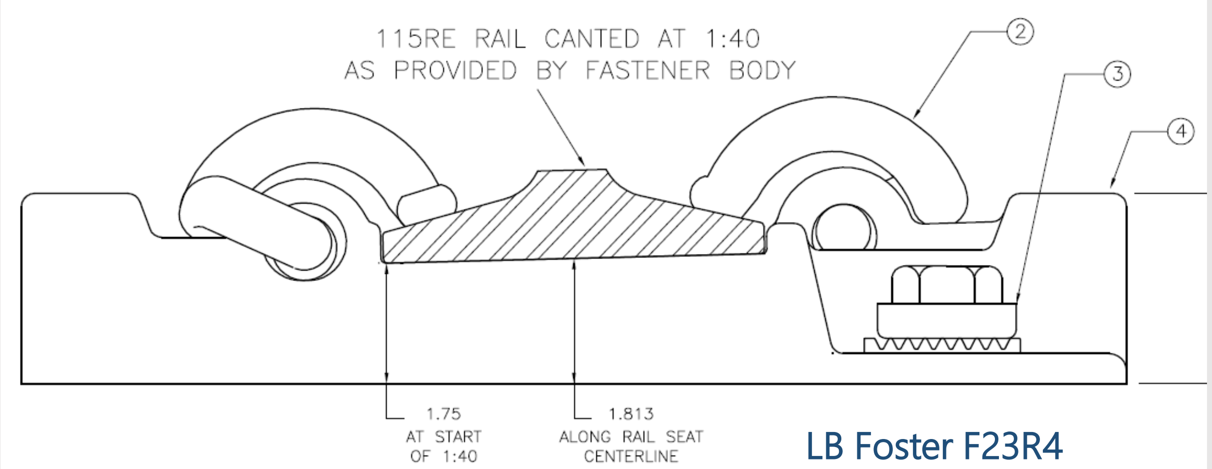
# Mid 1980's to Present Direct Fixation Designs

- Predominate Bonded Elastomer
  - Ductile Iron Plates fixed through bottom plate anchorage points
  - Vulcanize Bonded Elastomer to form a "one piece" fastener body
  - Predominate fixed spring clip housing
  - Rail Adjustment by moving entire fastener body




Lord Corp LAMTA

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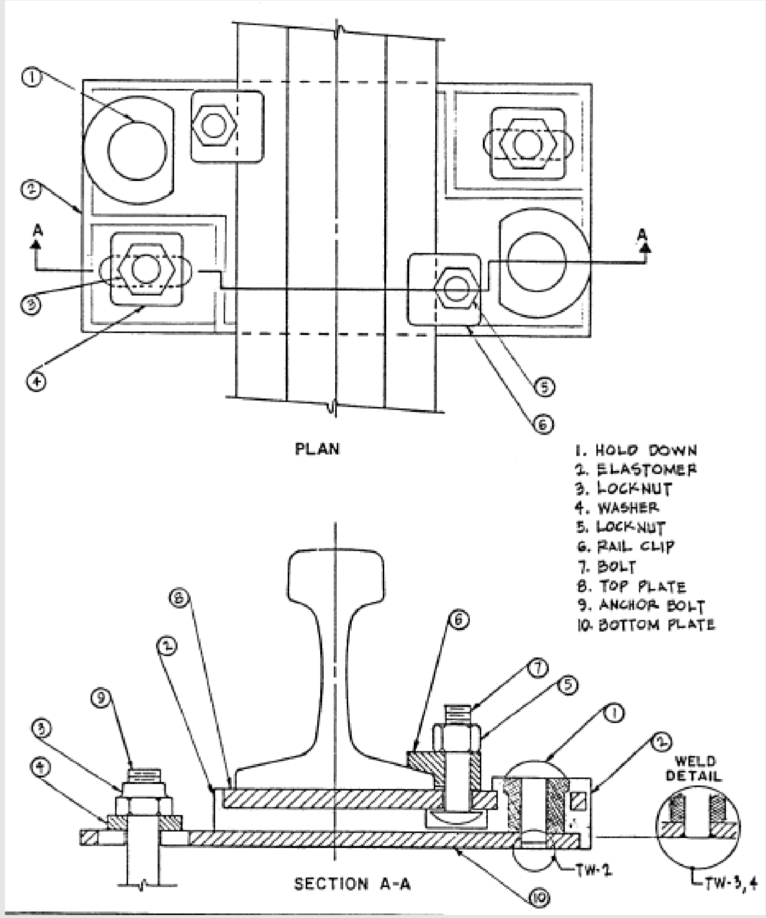
# Design Evolution

## 1977 Design

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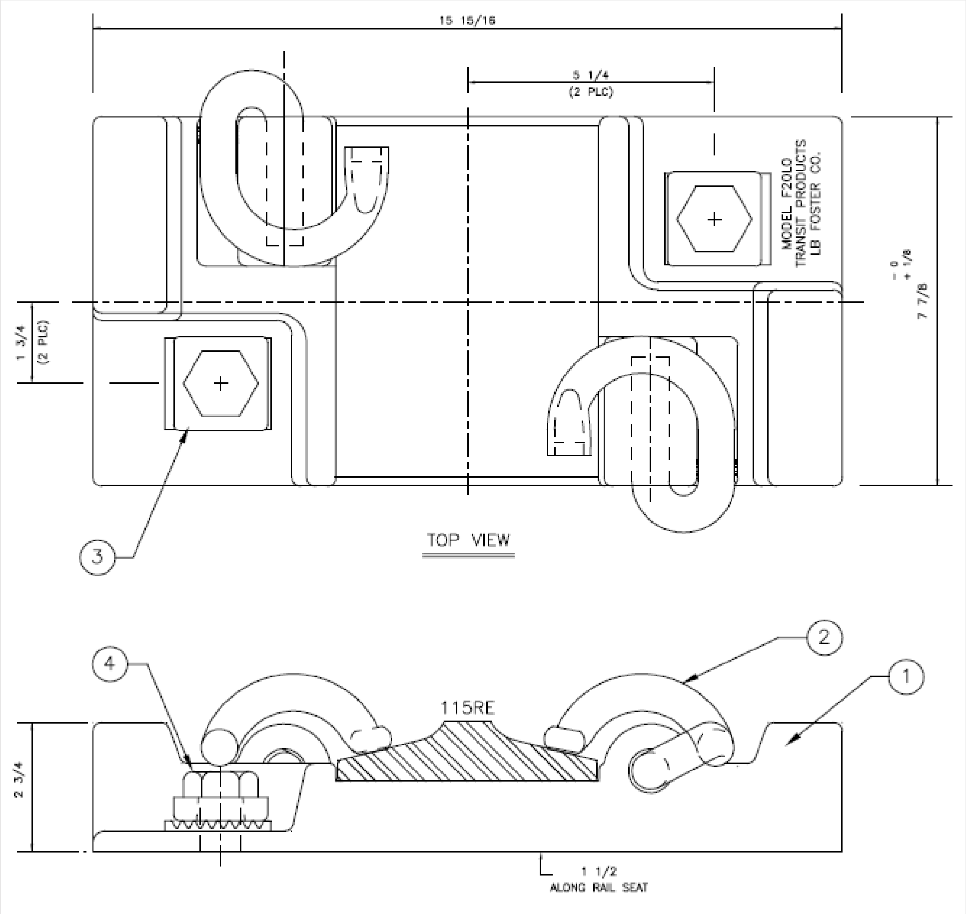
## 1997 Design

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# Key Historical Milestones in the last ~40 Years

- Vulcanize Bonded Elastomer Product to form a "one piece" fastener
  - Simplified installation, improved electrical isolation leakage paths and corrosion protection
- Ductile Iron plate manufacturing provided ability to produce features
  - Bolt the fastener body through the bottom plate
  - Reduction of bolt bending stress and reduced bolt torque loss
  - Eliminate a hard vibration bridge from top plate to the mounting surface
- Introduced improved ability to cant the rail seat allowing flat plinth construction for installed system cant consistency
- Mechanical design features to provide greater lateral resilience

# Typical US Agency DFF Specification Structure

- General
  - Scope, references (ASTM, ASME etc.)
  - Submittal requirements
    - Design
    - Qualification Testing
    - Quality Control Plan
- Products
  - Allowable limits on products and materials
    - Geometry and size of features
    - Limits on fastener components (and subcomponents if applicable)
      - Metal parts, elastomer parts, electrical insulation elements etc.
        - Chemistry, physical, mechanical, electrical and environmental requirements
  - Qualification testing requirements
- Execution
  - Packaging, loading, shipping and handling
  - Production testing

# Key DFF Design Parameters

- Electrical Insulation
  - Longer leakage path the better, but distance usually constrained due to geometry limitations
  - Typical materials used for electrically insulating the DFF: Vulcanized rubber, polyurethane, nylon etc.
- Lateral stability
  - Anchoring details, number of bolts, location adjustability etc.
- Vertical dynamic stiffness
  - Key parameter for vibration mitigation
  - Different design options to achieve the end goal as specified by the agency
- Durability under environmental and operational conditions
  - Repeated load testing
  - Sustained performance under exposure to various elements (oil, ozone, water, varying temperatures etc.)

# Sampling of Major US Transits - Static Spring Rate Criteria

| Agency | Range of Measure (pounds per fastener body) | Spring Rate Range (pounds / inch deflection) |
|---|---|---|
| Atlanta (MARTA) | 5,000 to 12,000 | 100,000 to 200,000 |
| Denver (RTD) | 4,000 to 12,000 | 91,800 to 124,200 |
| Honolulu (HART) | 4,500 to 12,000 | 94,000 to 200,000 |
| Los Angeles (LAMTA) | 2,000 to 10,000 | 76,000 to 114,000 |
| Miami (MDT) | 4,000 to 12,000<br>4,500 to 12,000 | 80,000 to 120,000<br>94,000 to 200,000 |
| Minnesota | 2,000 to 10,000 | 76,000 to 114,000 |
| New York (NYCT) | 5,000 to 10,000 | 75,000 to 120,000 |
| Phoenix (Valley Metro) | 4,500 to 12,000 | 90,000 to 150,000 |
| Seattle (SST) | 4,500 to 12,000 | 94,000 to 200,000 |
| San Francisco (BART) | 4,000 to 12,000 | 187,000 max |
| Typical High Resilient | 2,000 to 10,000 | 40,800 to 61,200 |

Dynamic Spring Rate ~ 1.5 * Static Spring Rate

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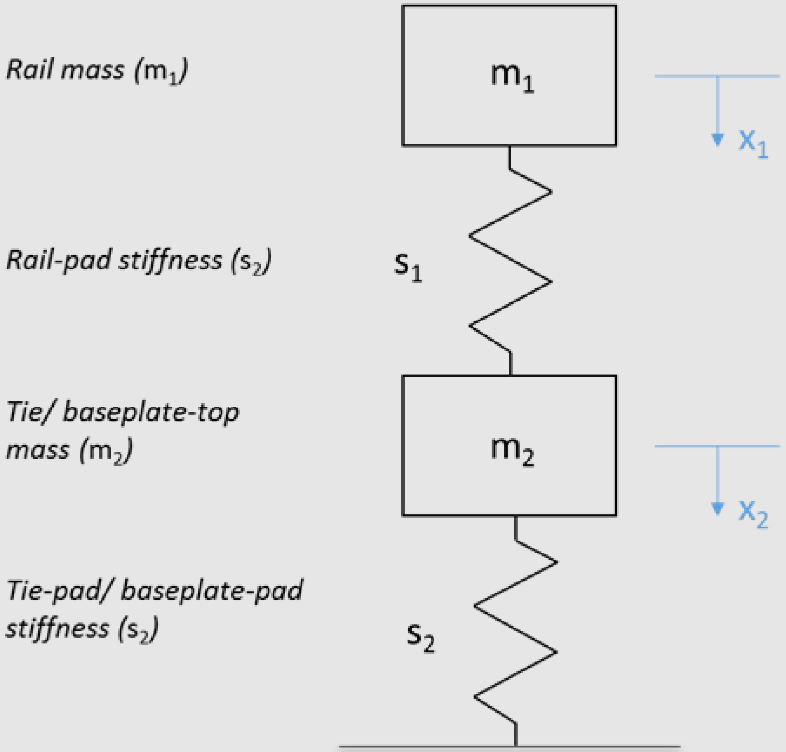
# Vibration Isolation Modeling

## Equivalent track mass ($m_T$) and track stiffness ($k_T$) calculation

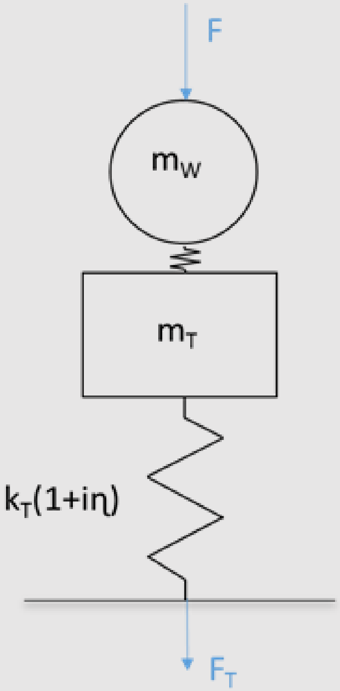



$$k_T = 2\sqrt{2}(EI)^{1/4} s_{eq}^{3/4}$$

$$s_{eq} = m_T w^2$$

$$w = \sqrt{\frac{m_1 s_1 + m_1 s_2 + m_2 s_1 \pm \sqrt{(m_1 s_1 + m_1 s_2 + m_2 s_1)^2 - 4 m_1 m_2 s_1 s_2}}{2 m_1 m_2}}$$

## Vibration isolation model




Natural Frequency

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k_T}{(m_T + m_w)}}$$

Force Transmissibility ($T_f$)

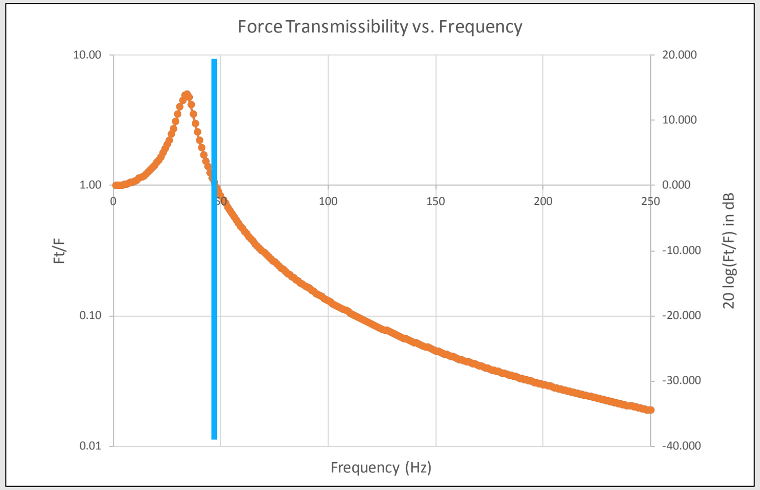
$$\frac{F_T}{F} = \left| \frac{1}{1 - \frac{1}{(1+i\eta)}\left(\frac{n}{f_n}\right)^2} \right|$$

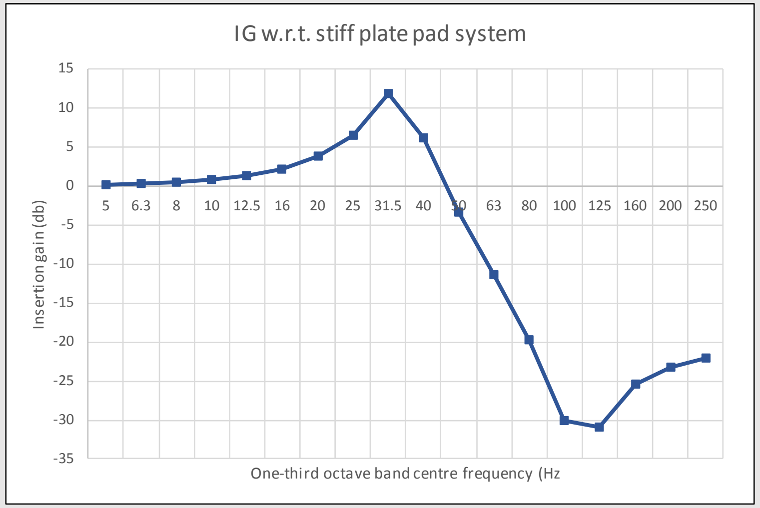
Insertion gain

$$IG = 20 \log_{10}\left(\frac{T_f}{T_f^{reference}}\right)$$

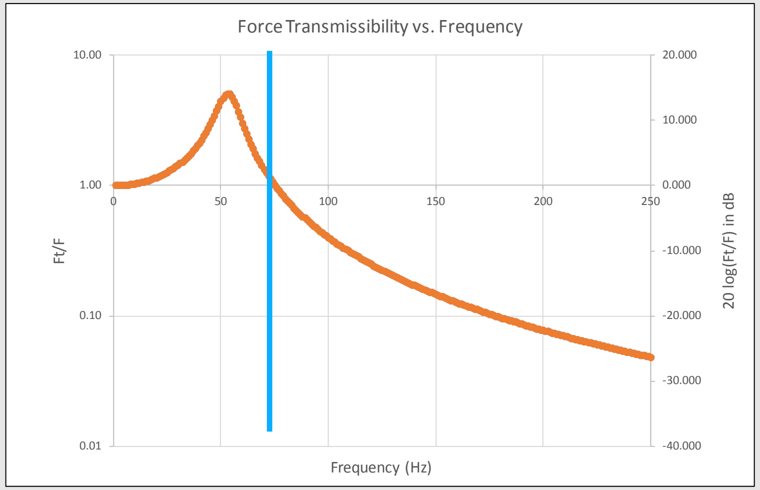
# Typical Vibration Isolation Levels

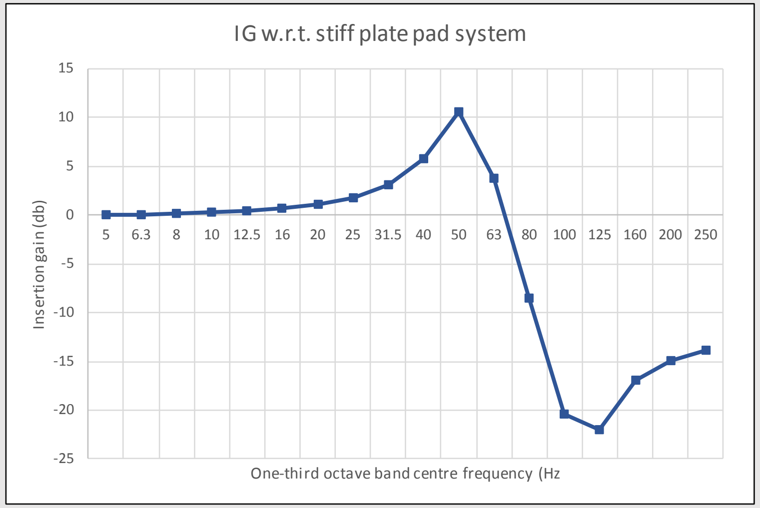
## Hi-Resilient Fastener ~ $K_{dyn}$ = 75 kips/in




## Standard Fastener ~ $K_{dyn}$ = 250 kips/in

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# Summary and Discussion

- Direct fixation fasteners predominantly used in the US were reviewed
- Following challenges remain in direct fixation track design
  - Providing softer designs with minimal allowance of increased height or width perpendicular to track
  - Restrictions of existing plinth support areas
  - Aging plinths leading to uneven support for direct fixation fasteners
  - Added performance desires with demand to match existing footprints
  - No common standards exist in the transit industry for modeling or testing vibration isolation provided by DFF as a result of wheel excitation in the frequency domain

# References


- Proceedings: Direct Fixation Fastener Workshop. Transportation Systems Center, Cambridge MA. UMTA-MA-06-0153-85-3. Final Report, June 1985
- TCRP Project D-7 Task 11, Development of Direct Fixation Fastener Specifications and Related Material, by James M. Tuten III, January 2004
- Thompson, D.J., Railway noise and vibration: mechanisms, modelling and me ans of control. Elsevier, 2009


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# THANK YOU