VTI Simulation Workshop Suspensions Part 2 and other Modeling Challenges

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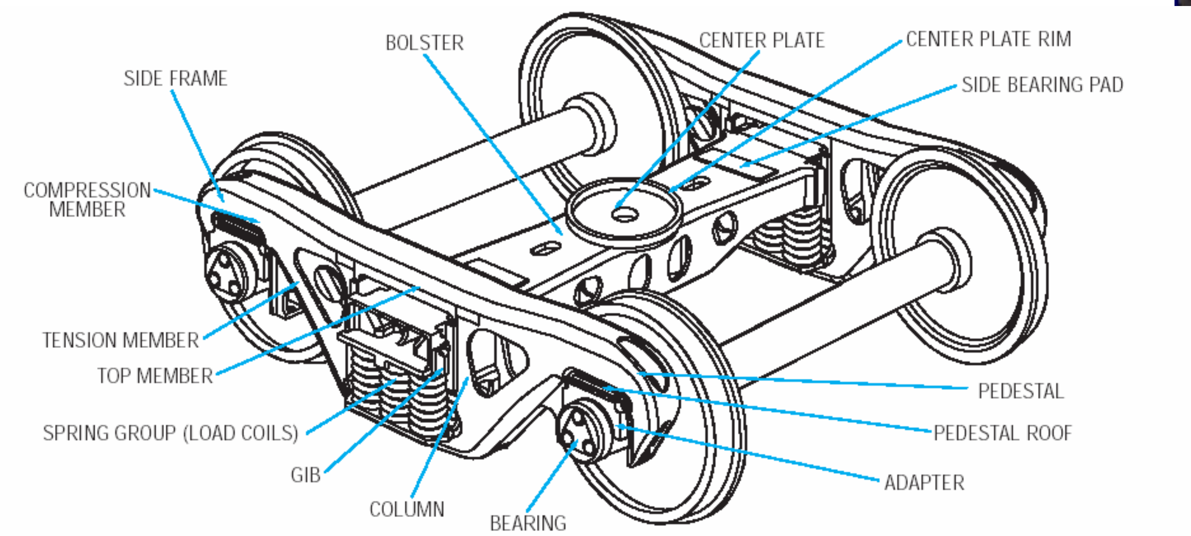
Presentation Overview

- **Suspension components**
  - Coil springs (PEK)
  - Further improvements for friction wedges (PEK)
  - Air suspensions (PEK)
  - Center plates
  - Couplers and Draft gears
  - Polymer Springs
  - Falling and variable friction for friction elements
- **Other simulation challenges**
  - Variation of rail profile along the track
  - 3-D WR contact
  - Special Track Work and Track Structure modeling
  - Parametric variations and stochastic modeling
  - On-line interaction w/FEA
  - Integration methods

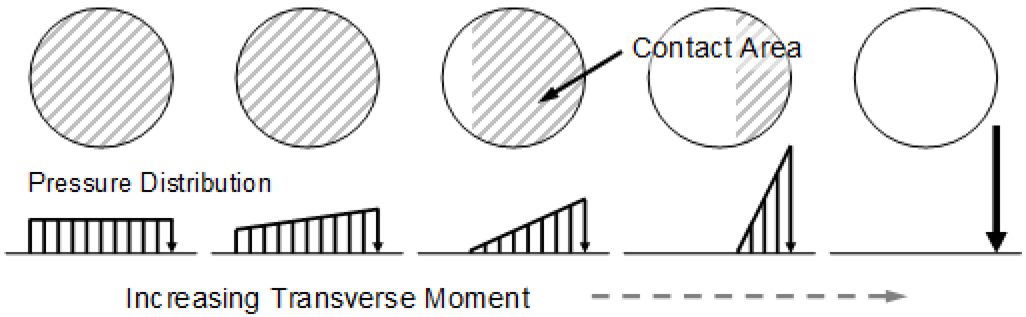
Centerplates & Centerbearings

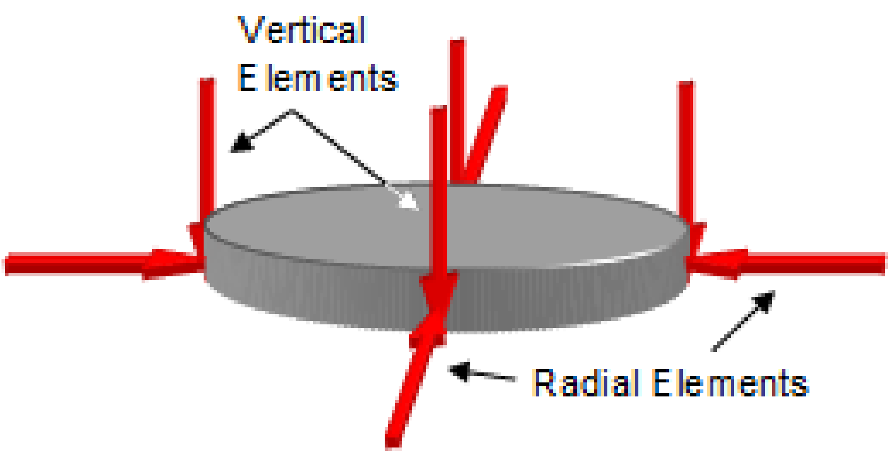
- Center plates and bowls with inner or outer rim contact
- Hemispherical bowls
- Friction surfaces with varying load distribution



Centerplates & Centerbearings
Simulation Challenges

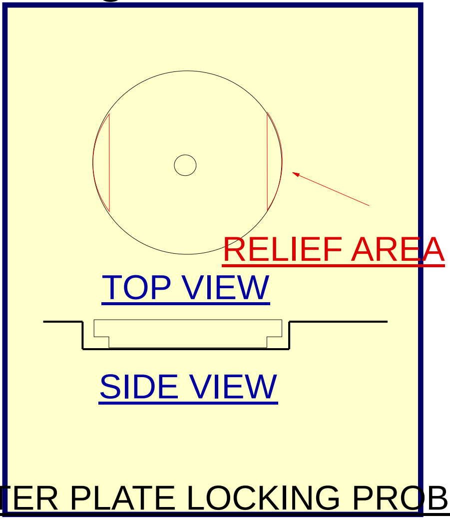
- **Representation of load distribution across surface under influence of pitching and rocking motions**
  - Often simulated by multiple point load line or surface friction elements
- **Load dependent stick slip friction**
  - What mu?
  - Effects of lubrication and polymer liners





Centerplates & Centerbearings More
More Simulation Challenges

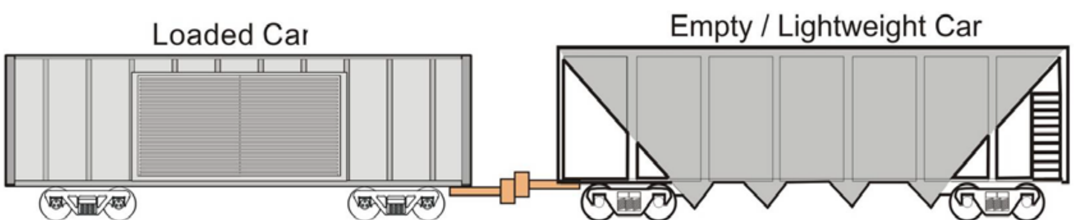
- **Effect of chamfers on centerplate**
  - Chamfers can complicate analysis
  - Corners can dig in, act as center of rotation
- **Effects of wear and galling on surfaces:** What mu? Falling friction?
- **Centerbowl rim contact friction – effect of radial gap and moving points of contact around the circumference of rim**
  - Can significantly increase effective turning resistance
  - Need numerous point load elements to capture the effects
- **MAY NEED TO DEVELOP A VERY DETAILED SPECIFIC MODEL!**

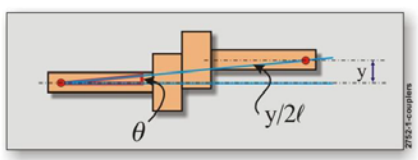


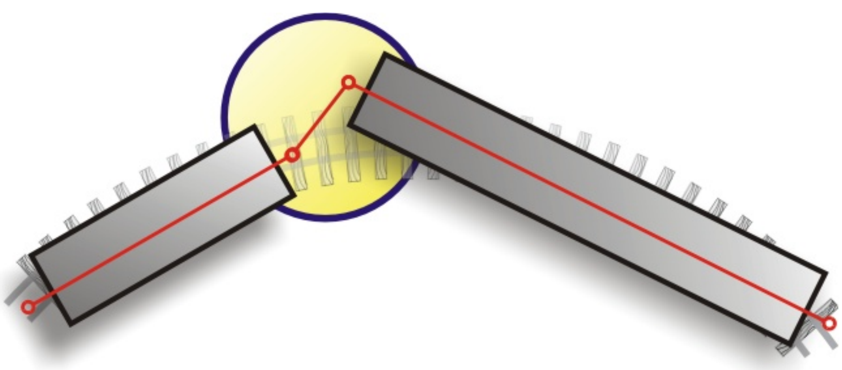
CENTER PLATE LOCKING PROBLEM

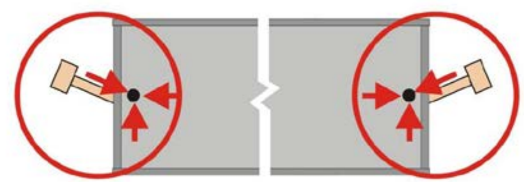
Couplers, Draft Gears & Train Forces

- **Buff-draft forces, coupler offsets & angles an generate significant off-axis forces between cars => derailment**
  - Buff-Draft forces can increase lateral WR forces and L/Vs
  - 250 k-lb buff force can lift a 20,000lb empty carbody car off of its trucks with a coupler misalignment of only 0.4 inch









Couplers & Draft Gears: Challenges

- **Train action models such as TOES™ can provide macroscopic analysis**
- **Detailed MBD models required for accurate analyses**
  - Effect on WR forces and L/V ratios
  - Draft gear action
    - Stiffness and damping, including hysteresis of polymer springs
    - Friction effects
    - Limit stops
    - Rough castings may change line of action
    - Manufacturing tolerances
  - Coupler-Coupler interface
    - Vertical sliding
    - Toggling action can be indeterminate, might pop to left or right => stochastic modeling required?

Polymer Suspension Elements

- **Used in:**
  - Primary suspensions, side bearings, damper bushings, coupler draft gears, centerpins, main secondary suspension element
  - Materials can have very non-linear response
    - Hysteretic damping
    - Velocity dependent damping
    - Stroke dependent damping
    - Material Creep – from age, and also short term settling
      - Can make identification of static load conditions difficult
    - Shaping to generate non-linear characteristics
    - Shear stiffness sometimes dependent on axial loads
      - Can result in unstable conditions with negative effective stiffness
    - Internal damping (energy dissipation) can change the effective stiffness and damping response

Example: Polymer Primary Suspension

- **Lateral flexibility, shape of ears and ridges, and tolerances in pedestal jaws allow small sliding on top surface: surface friction**
- **Material should be designed/tuned for balance of curving and hunting response**
  - Early soft versions allowed hunting under loaded (286k-lb) cars

Wilson, N.G., Wu, H., Tournay, Urban, C.,"*Effects of Wheel/Rail Contact Patterns and Vehicle Parameters on Lateral Stability,*" Supplement to the International Journal of Vehicle Systems Dynamics, Volume 48, pp. 487-504, Taylor Francis, 2010, ISBN 978-0-415-66949-8. Presented at the 21st IAVSD Symposium, Stockholm, Sweden, August 2009

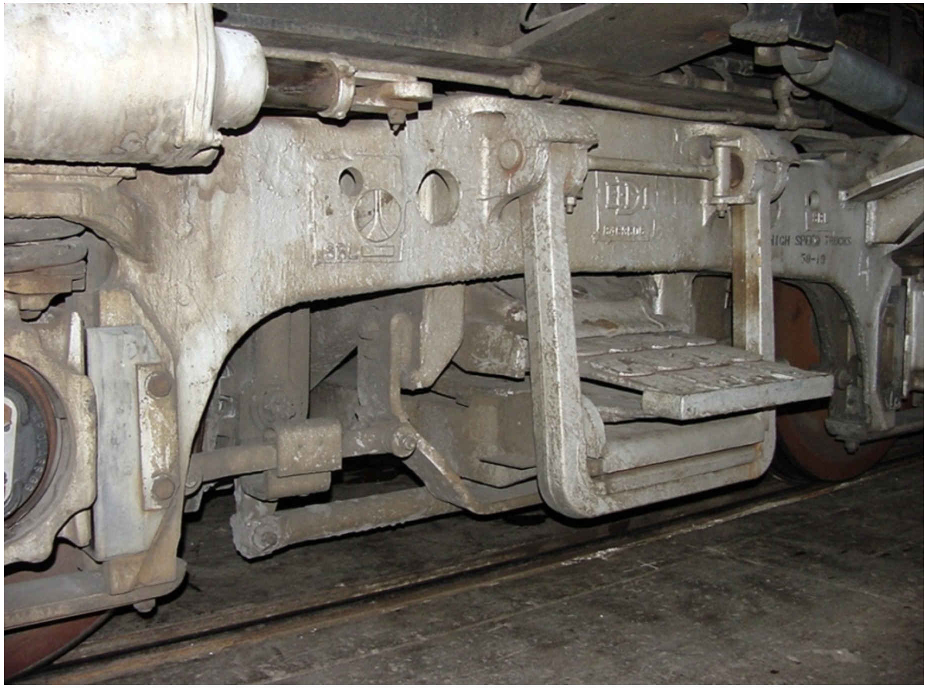
- **Required combination of several types of standard connection to capture the response**

Polymer Suspension Elements
continued

- **Non-linear response may be difficult to represent using standard connection/suspension elements**
- **Detailed characteristic data often considered proprietary by manufacturers**
- **Extensive laboratory tests of components may be required to measure characteristics for model inputs**
  - Shear under various axial loads
  - Wide range of inputs for loads, frequencies, strokes
  - Some applications such as draft gears and secondary suspension may require very high forces to test correctly
    - Static load + 50% for main spring of 286 klb freight car is 80klb
    - Typical draft gear must withstand 200 – 300 klb buff force

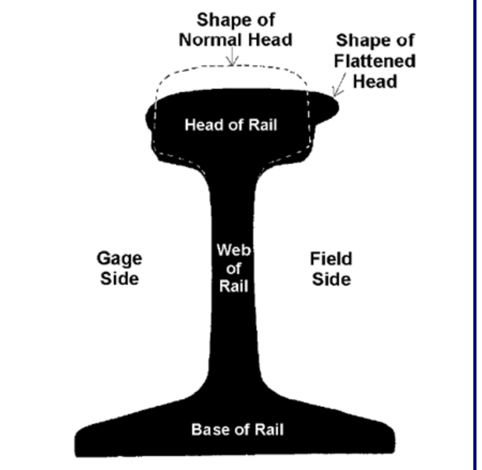
Friction Modeling

- **It is not only in the wheel-rail interface!**
- **Sidebearings, centerplate, friction wedges, pedestal jaws, pin joints, swing hangers, leaf springs**
  - This common locomotive truck has all of them
  - Small variations can have significant effect on results
- **Point load vs distributed load**
- **Surface vs line friction**
- **Stick slip modeling**
- **Falling friction (static vs dynamic)**



3-D W-R Contact

- **Required for:**
  - High AOA (greater than 15 to 20 mrad)
  - Switches and crossings
  - Guard and restraining rails
  - Damaged track such as collapsed railheads
  - Damaged wheels such as broken flanges
  - Switch point guards



Adapted from *Manual of Recommended Practices* by the American Railway Engineers Association

Figure 7 — View of normal and flattened rail heads.

Figure 10 — Flattened rail head at initial POD (looking east).

3 Dimensional W-R Contact
Simulation Challenges

- **Multiple contact points per wheel**
- **Conformal Contact**
- **Variation of rail profile along the track**
- **Likely to require on-line calculation of WR contact, will affect computation speed**
- **Rail contacts may move relative to each other due to flexibility of track structure and components**
- **W-R contact location varies along the track**
  - Not in line with axle centerline – longitudinal offset generates additional moments
  - May also need to keep track of difference in track geometry for each contact point
- **Approximations of 3-d contact have been successful for some applications such as simple guard and restraining rails**
  - Calculate contact angle based on longitudinal offset and AOA

Along Track Variation of Rail Profiles

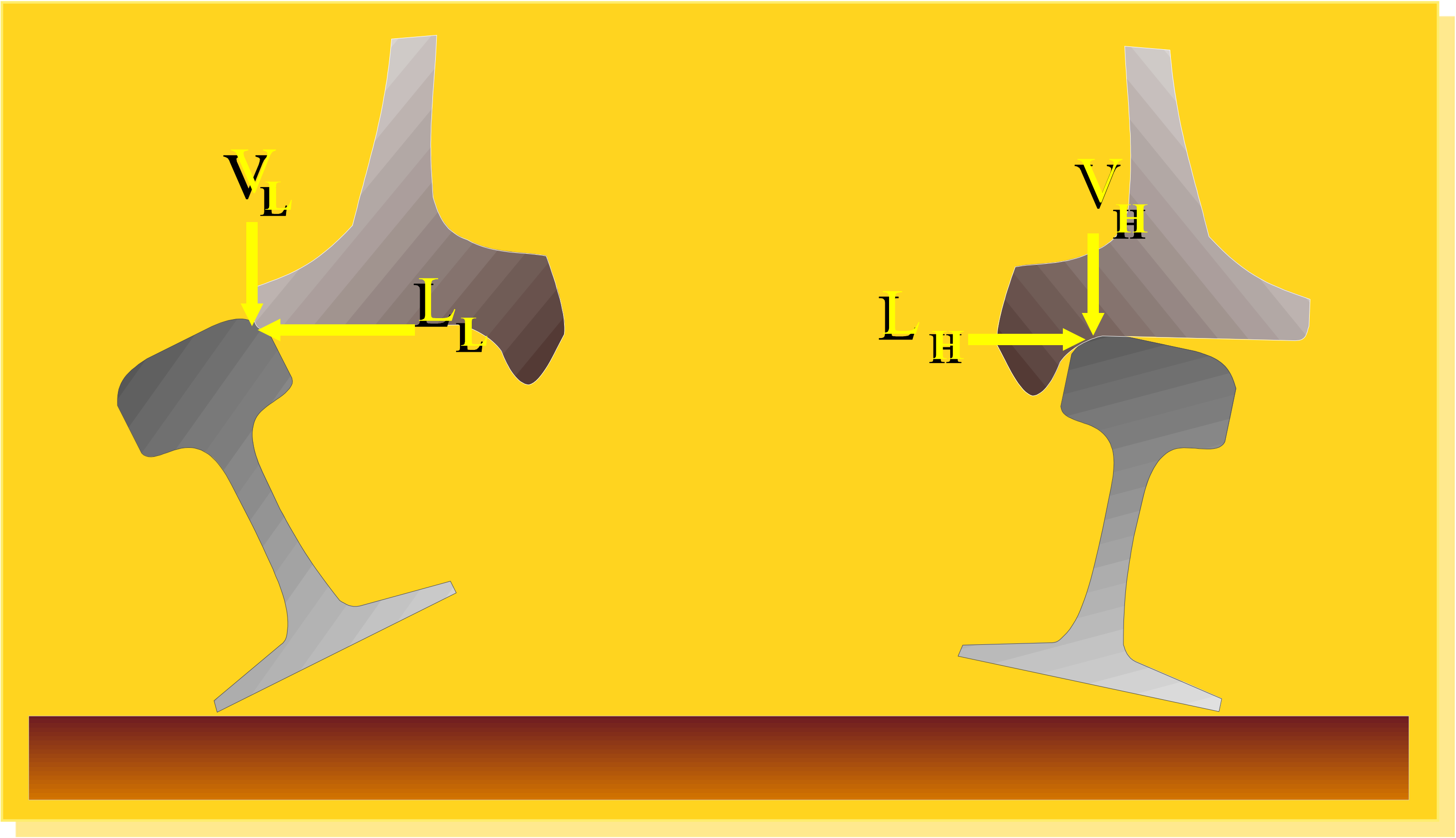
- **Required for:**
  - Accurate simulation of worn rails in tangents, spirals and curves
    - Can have significant effect on axle steering and stability
  - Switches and Crossings
  - Wear and RCF studies
  - Derailment investigation and problem solving
- **Challenges:**
  - Implementation of smooth variations as well as step changes
  - May require on-line calculation of WR contact
    - Likely to affect computation speed
    - Some codes interpolate pre-calculated WR contact tables
  - How many rail profiles are required and how to calculate intermediate shapes?
  - Direct input from track measurement systems
    - How to deal with ”bad” data?
  - How to link to flexible/moving rails?

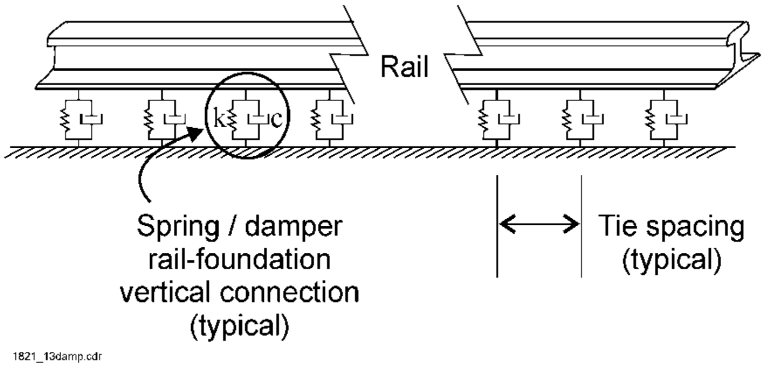
Track Structure Modeling

- **How much detail is required?**
  - Most vehicle simulations use simple representations of stiffness and damping between WR contact point and ground
    - Vertical and lateral motion of rails
  - Reasonable approximation for many vehicle simulations
    - Massless rails with no interconnection to adjacent wheels
- **More detail required for simulations where track dynamic response is important**
  - Rail roll and effects on gage widening and WR contact
  - Corrugations and RCF
  - Analyses of forces in track structure
  - Variations in track structure
    - Missing/weak/broken components,
    - Transitions between track types
  - Switches and crossings
  - Adjacent axle effects on wheel load and rail stress

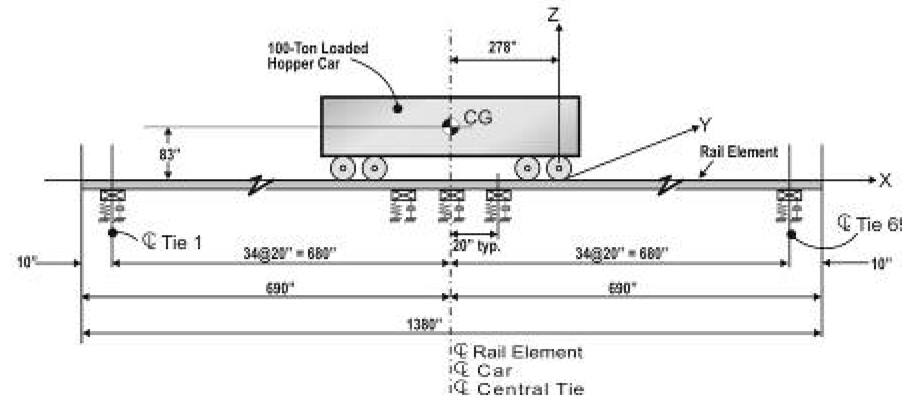
Gauge Spreading & Rail Rollover

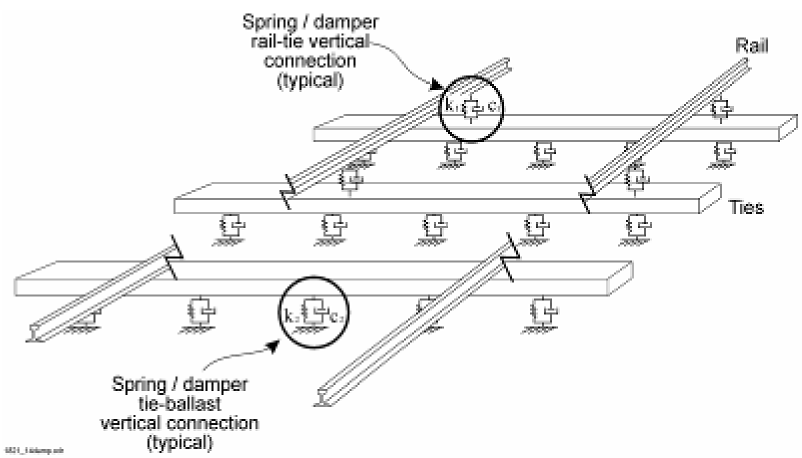
- **Requires: Rail Roll DOF in WR contact calculation, flexible rail model, detailed track fastener model**



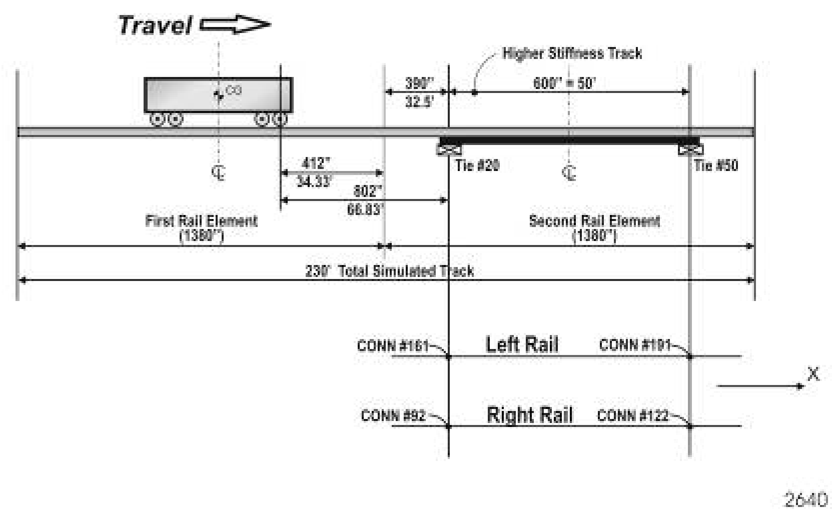


Single layer track model





Two layer track model



Vehicle on infinite track with varying stiffness and damping

Track Structure Modeling Challenges

- **Flexible rails**
  - How to simulate very long track segments?
  - How to simulate varying rail cross sections, joints, gaps and breaks?
  - How to simulate guard/restraining rails, switch points, and movable point frogs that move relative to running rails?
  - What DOFs and how many bending modes?
    - Lateral, Vertical, Roll, Vert/Lat bending and Torsion
    - How to include Longitudinal?
- **Rail fastener modeling**
  - Non–uniform fasteners: Broken, missing, weak, change in fastener type along the track
  - Linear stiffness and damping is not sufficient!
  - Cut spikes may require gaps and a friction model

Track Structure Modeling Challenges
Continued

- **Ties**
  - Flexible ties: What DOFs and how many modes?
  - Special ties: Ladders and dog-bones
  - Uneven tie spacing
  - Ties with principal axis not perpendicular to rail, such as ties in frog area
- **Ballast and subgrade**
  - How to represent distributed support?
    - NUCARS® uses multiple point loads
  - Effects of compaction
  - Variation in stiffness/damping along track
  - Non-uniform spacing

Track Structure Modeling Challenges
Continued

- **Other Track Elements**
  - Bridges
    - Simple spans vs complex structures
  - Bridge abutment effects
  - Slabs, including floating slabs
  - May require FEA mode shape input or in-line link to FEA software
- **Moving Ground Plane**
  - Earthquakes
  - Floating bridges
    - Recent work by TTCI for Sound Transit has demonstrated viable approach for linking Vehicle Dynamics analyses that include track models to FEA models of movable objects such as a floating bridge
    - Ketchum, C., Cooper, T., Foan, A., Joy, R., Sederat, H., Sleavin, J., "Dynamic Simulations in Support of Installation of Light Rail Tracks on the Homer H. Hadley Memorial Floating Bridge," April 2015, The Stephenson Conference Research for Railways, ImechE London

Other Modeling Challenges

- **Prediction of Worn Wheel and Rail Profiles Shapes**
  - Iterative simulations over route with representative selection of curves and tangents
  - Methodology has been demonstrated with some success by Shu and others, needs considerable refinement

    Shu. X., Dembosky, M.A., Urban, C.L., Wilson, N.G., "*RAIL WEAR SIMULATION AND VALIDATION*," Proceedings of 2010 Joint Rail Conference, JRC 2010, Paper JRC2010-36189, Urbana, IL, April 27-29, 2010
  - Apply wear to wheels and rails based on distribution of energy dissipated across the contacting surfaces
    - Simple linear wear index models may not be sufficient
  - Improved calculation of conformal contact, interfacial layers ETC, may be required
  - Dynamic rail motions (such as roll) likely to affect results

Other Modeling Challenges
continued

- **Simulation/calculation methods**
  - Alternative integration methods
    - Need to accommodate sudden step changes in state such as gaps, stick-slip friction, loss of WR contact, impact forces (WR and other)
    - Euler methods have been reliable but may be slow
  - Stochastic modeling, parametric studies using monte-carlo methods
    - Determine vehicle and system performance envelopes based on component design and wear tolerances
    - Will require automated analyses of large data bases of results
  - Direct links for interactive computing with other software such as FEA