Rail Vehicle Suspensions and Components

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National Research Council Canada

June 7, 2023

Overview

- **Rail Car Types.**
- **Rail Car Suspensions: Why are suspensions important; reasons for suspension design choices; freight vs. passenger designs.**
- **Rail Car Truck (Bogie) and Suspension Components.**

Freight Car Types

- **Industry started simple: only a few car types carried everything.**

- **As builders and railroads looked for efficiencies, new car types were developed.**

Freight Car Types

https://www.trinityrail.com/productdetails.aspx?id=121&catid=24

https://www.trinityrail.com/productdetails.aspx?ID=55&catid=31

https://www.trinityrail.com/productdetails.aspx?id=13&catid=29

https://www.trinityrail.com/productdetails.aspx?id=39&catid=30

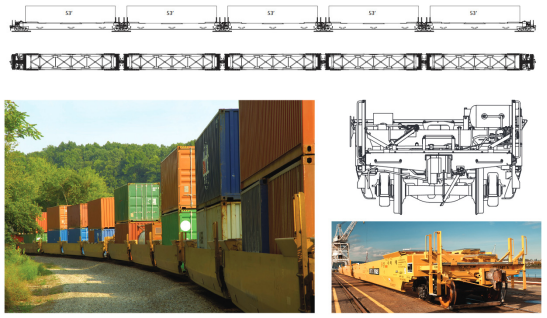
Different commodities have had specialized cars developed for them to:

- **reduce damage to goods,**
- **speed up loading/unloading,**
- **lower overall costs!**

Freight Car Types

https://www.steelcar.com/products/25500g-tank-car

https://www.steelcar.com/products/centerbeam



https://www.gbrx.com/media/2352/gbx-tech-sheet-stack-5-unit-maxi-stack-v.pdf

https://www.gbrx.com/media/1447/flat89.pdf

What is common between all these different cars:

- **They operate empty and loaded.**
- **The car bodies all sit on top of freight trucks.**

Passenger Car

Possibly even greater variety!

- **Often custom or “one-off” designs, unique to a city or a route within a city.**
- **Urban and intercity; streetcars to complete trainsets.**
- **Light to heavy; low speed to very fast.**

Car Types

- **Light weight (LW): weight of the empty car.**
  - **~40,000 pounds to over 100,000 pounds (autorack).**

- **Load Limit (LD LMT): what the commodity weighs.**

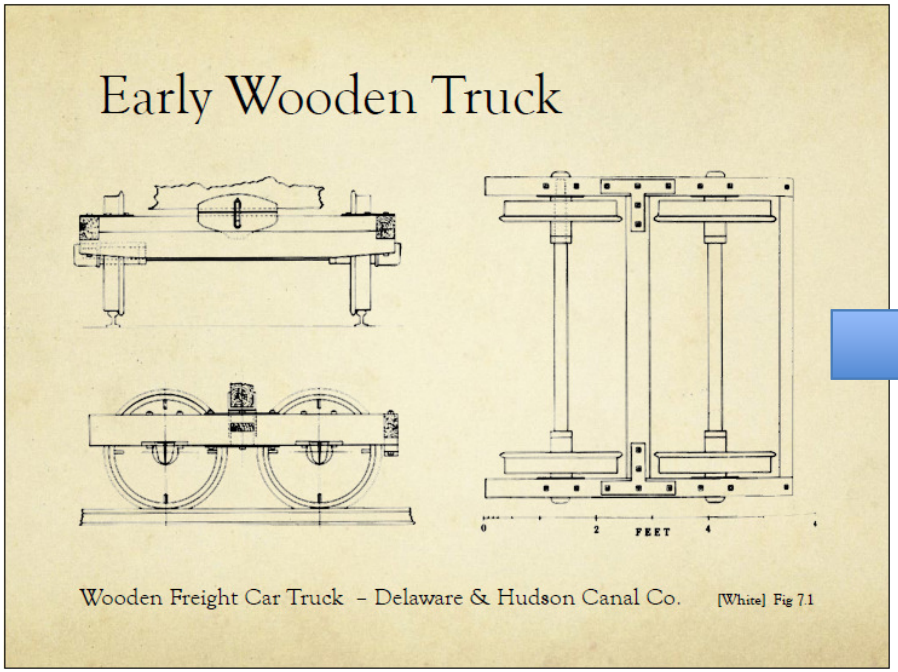
- **Gross Rail Load (GRL): maximum loaded weight.**
  - **263,000 to 286,000 pounds…**
  - **or lower! Depends on commodity (density): eg. autorack GRL of ~ 200,000 pounds.**

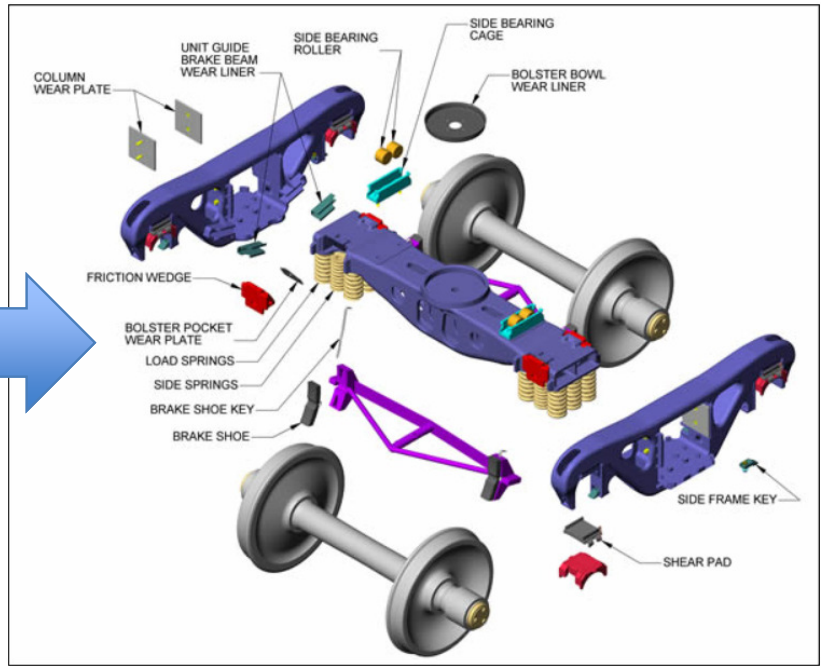
Car Types

- GRL to LW ratio
  - Passenger: ~1.5 to 2
  - Autorack: ~ 1.8 to 2
  - 5-pack container: ~4
  - Ore car: ~5.5 to 6
- Car, pickup truck: ~ 1.2 to 1.4
- Cat 797 mining truck: ~2.5

- How do rail cars handle this difference between empty and loaded weights?

Freight Car Trucks





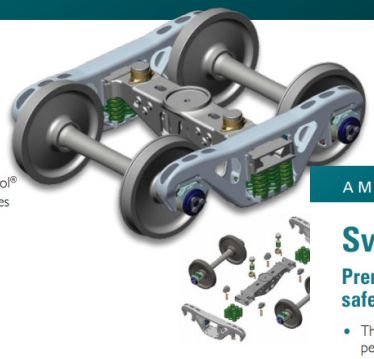
Freight Car Trucks

AMSTED RAIL – BOGIES

Ride Control®

Standard bogie for various applications

- Constant damped bogie
- Predecessor to Super Service Ride Control®
- Smaller wide-winged friction shoe provides good stability
- Widely accepted end truck for articulated intermodal equipment
- Up to 286,000 pound Gross Rail Load/ 32.5 tonne Axle Load

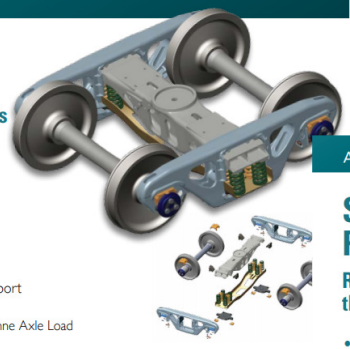


AMSTED RAIL – BOGIES

Swing Motion®

Premier suspension design for safety and stability at high speeds

- The ultimate in freight rail bogie performance for lading protection
- Proprietary Swing Motion stabilization system unsurpassed in high-speed stability
- Superior ride quality
  - Improved lading protection
  - Reduced wheel and component wear
  - Lower maintenance and lifecycle costs
- Ideal for automobile and finished goods transport
  - Reduced damage claims
- Up to 286,000 pound Gross Rail Load/32.5 tonne Axle Load

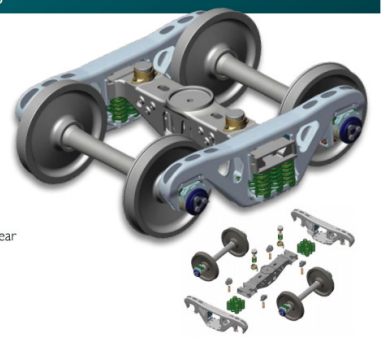


AMSTED RAIL – BOGIES

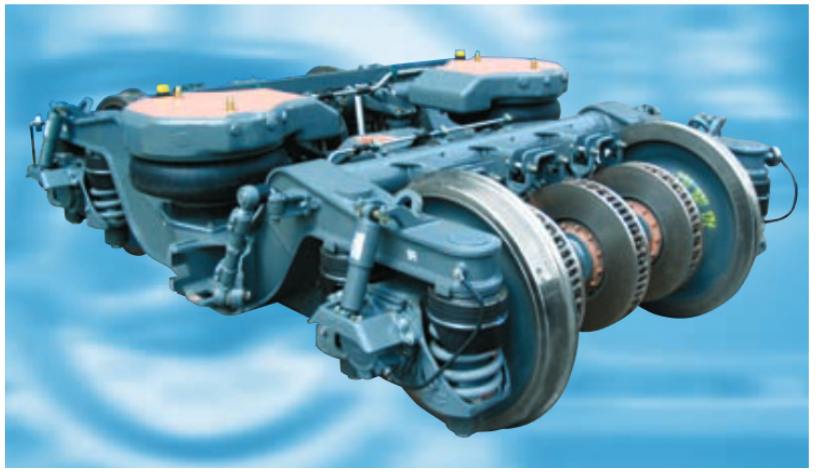
Super Service Ride Control®

Reduces wear and keeps the bogie square

- Constant damped bogie
- Wide-winged friction wedge
  - Provides good stability
  - Keeps bogie square as components wear
- Up to 286,000 pound Gross Rail Load/ 32.5 tonne Axle Load



Passenger Car Truck



https://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/rail-solutions/components-and-systems/bogies-catalog-en.pdf

Rail Car Suspensions

Why is there a suspension?

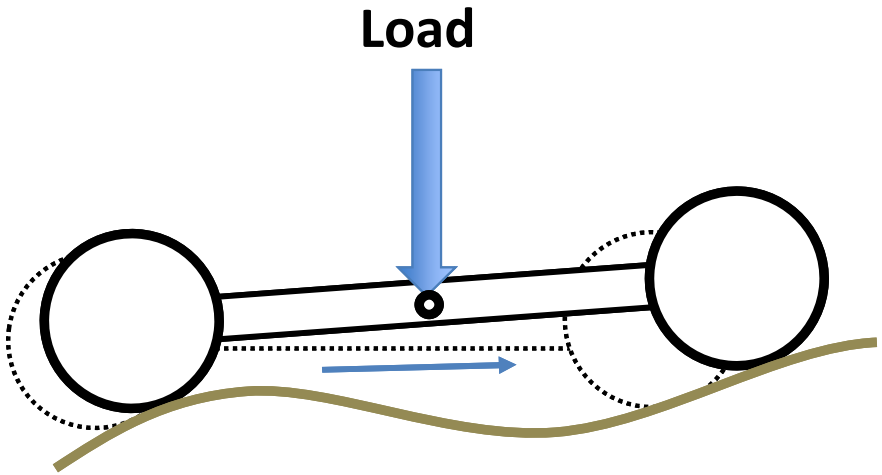
1. Load equalization: transfer the car load evenly to the rails.
2. Vibration Isolation: Passenger comfort, prevent damage to goods and to the car itself.
3. Control vehicle motion: Traction, braking, lateral curving forces, dynamic stability.

Load Equalization

1. Transfer the car load evenly to the rails.
2. A car with no suspension would lift wheels on even slightly uneven track, such as when entering curves.
3. Rail and subgrade designs place a limit on the maximum wheel load on the rail.

Load Equalization

- The truck balances the load between the front and rear wheels by pivoting at the bolster.
- The wheel load is always equally split!
- Not as effective at higher speeds…



walking beam suspension

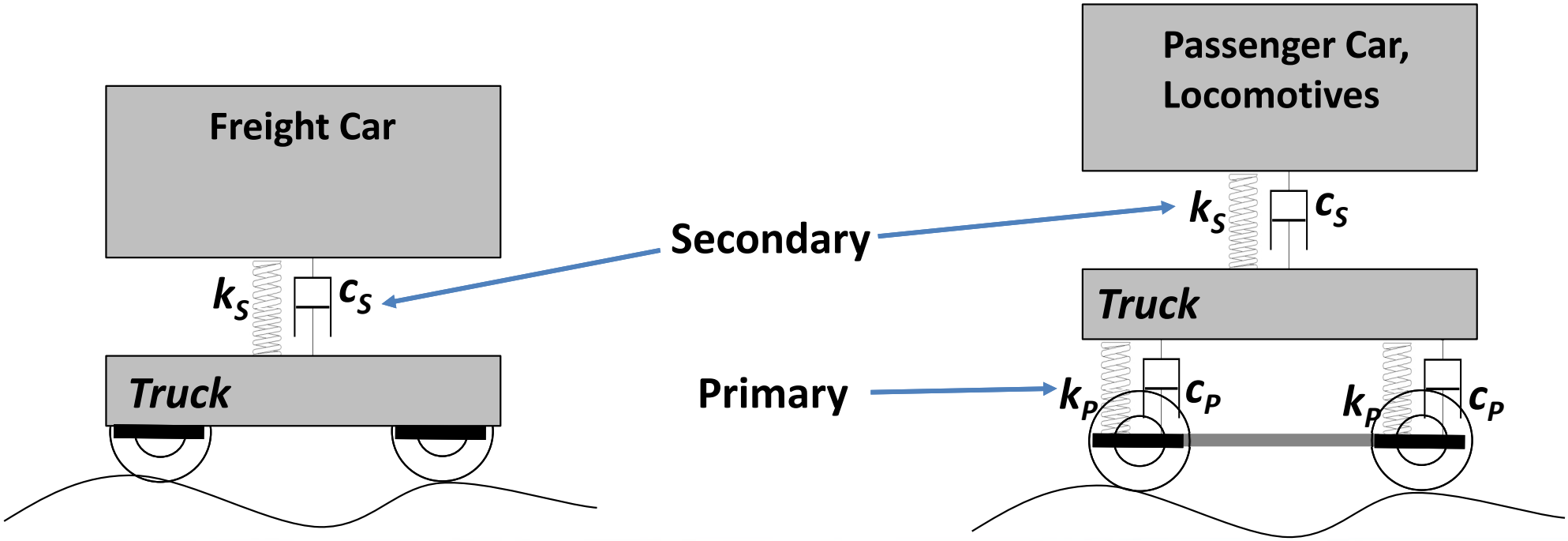
Load Equalization

- **Passenger car truck frames are usually rigid frames. A primary and a secondary suspension aids in balancing the wheel loads.**
- **Locomotive trucks have powered axles. To maximize traction the vertical loads must be balanced, so a primary and a secondary suspension is used on freight locomotive trucks.**

Primary and Secondary Suspension

1. **Primary Suspension: A suspension at a wheel location, between a wheelset and the truck frame.**
2. **Secondary Suspension: A suspension between a car body and a truck frame.**

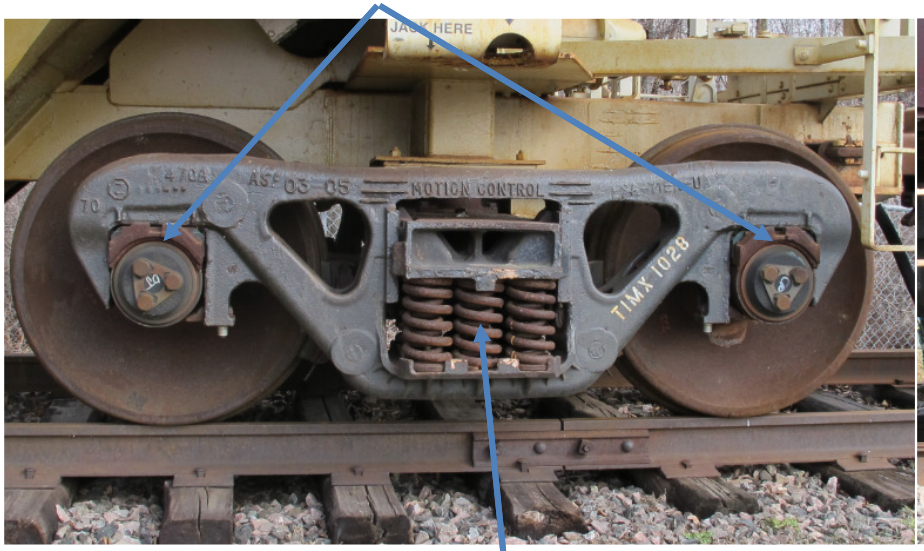
Primary and Secondary Suspension

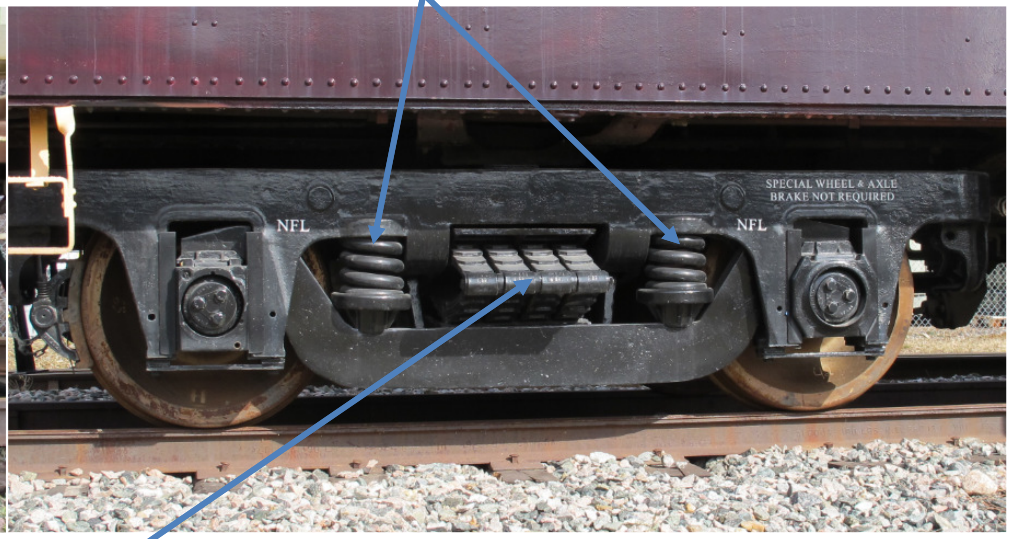


Primary and Secondary Suspension

No Primary Springs: "Hard" Connection

Primary springs





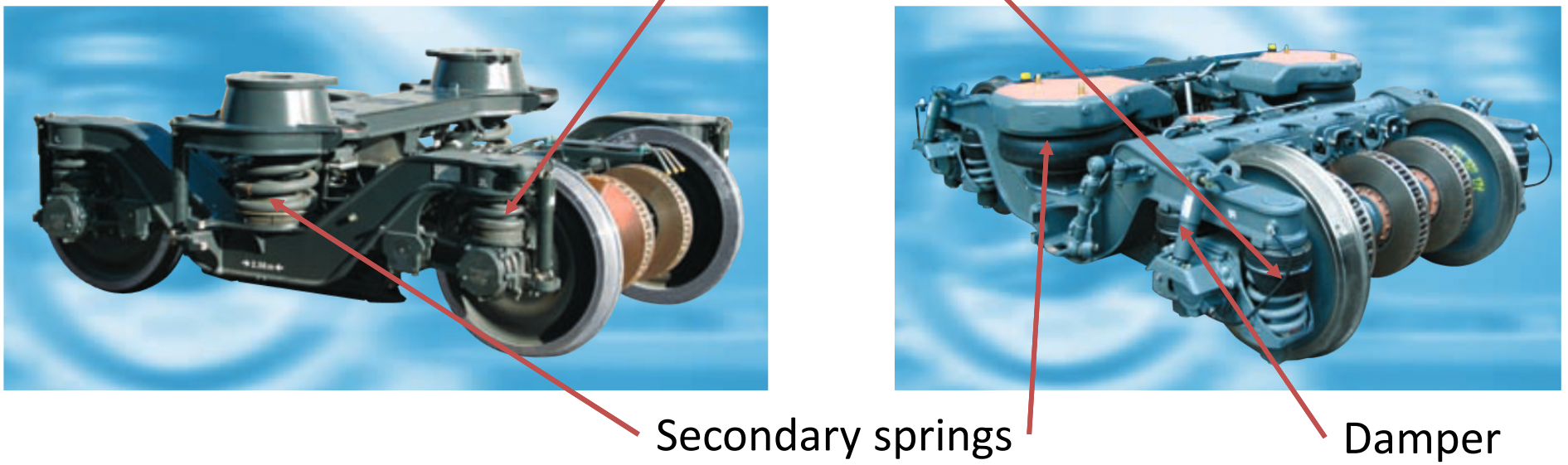
Freight Truck

Secondary springs

Passenger Truck

(really old design…)

Passenger Car Truck

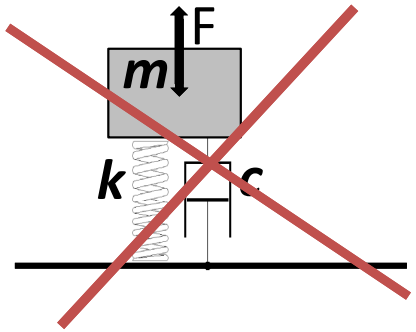


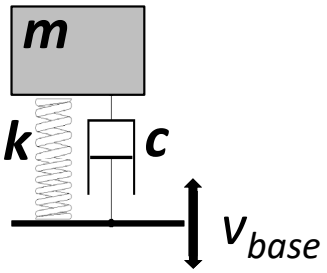
https://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/rail-solutions/components-and-systems/bogies-catalog-en.pdf

Vibration Isolation

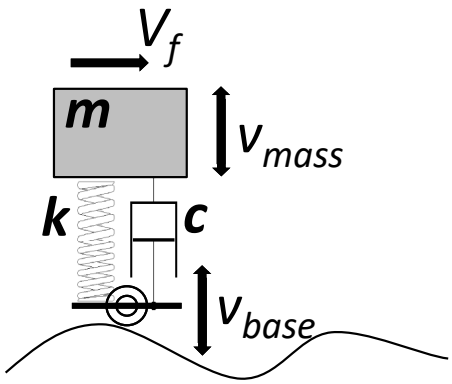
1. As car speeds increase, vibration isolation becomes important – the suspension isolates the car from the changing forces of the wheels on the rails.
2. The car and the suspension form a spring-mass system.
3. A car with no suspension would move up-down with every undulation on the track. A suspension allows the wheels to “follow” the rails, but keeps the body “isolated”.

Spring-Mass-Damper System





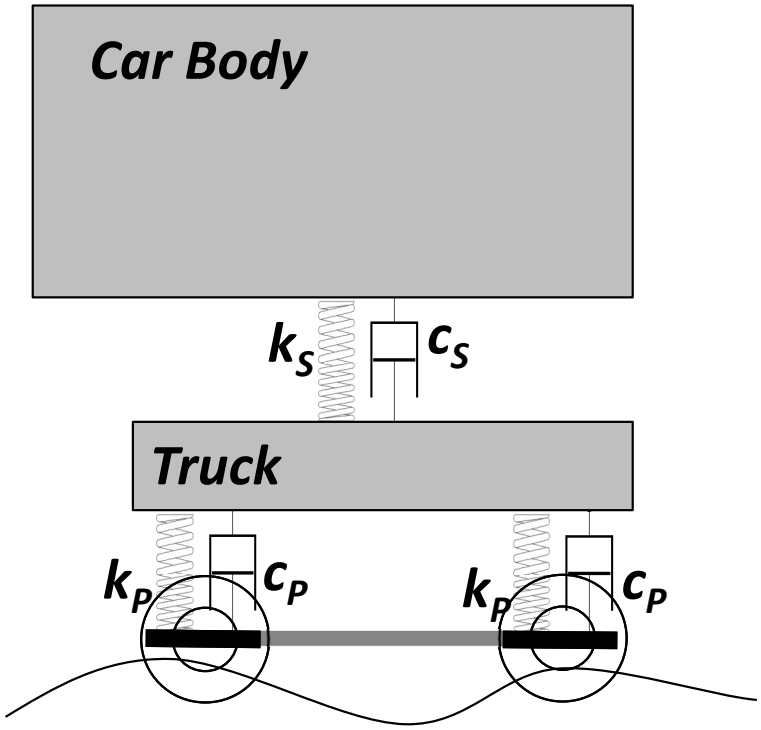
"Quarter Car Model"



Spring-Mass-Damper System

- **For rail cars**
  - **Main mass: car body**
  - **Secondary Suspension: between the car body and the truck**
  - **Primary Suspension: between the wheelset and the truck**

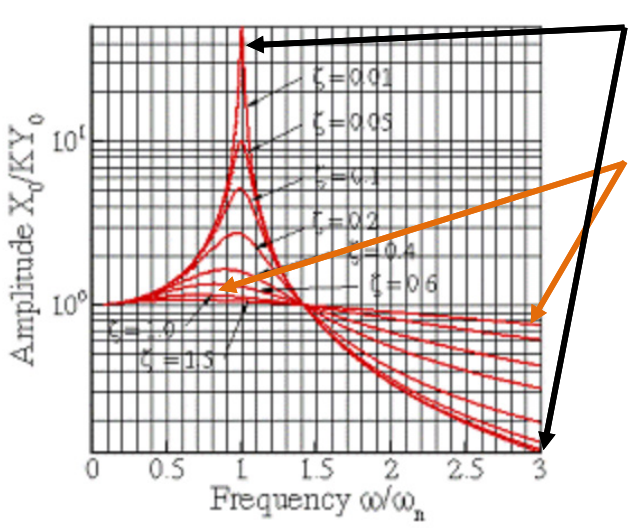
"Quarter Car Model" with Primary and Secondary Suspension



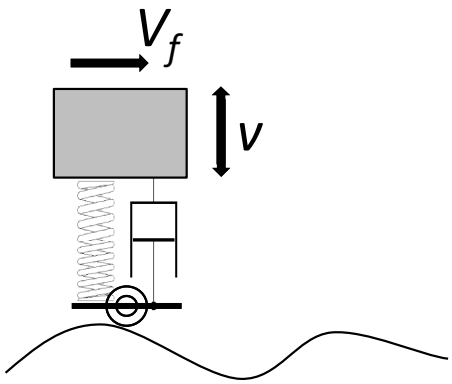
Vibration Isolation

Spring-mass-damper systems have well understood properties:

- **Resonance frequency.**
- **Damping has an effect on the system response.**



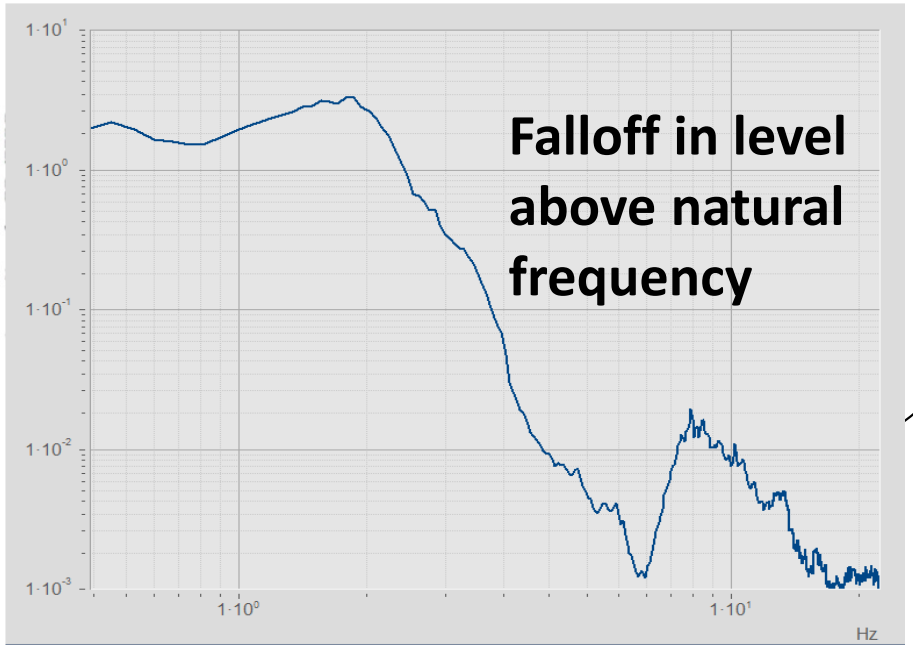
http://www.brown.edu/Departments/Engineering/Courses/En4/Notes/vibrations_forced/vibrations_forced.htm

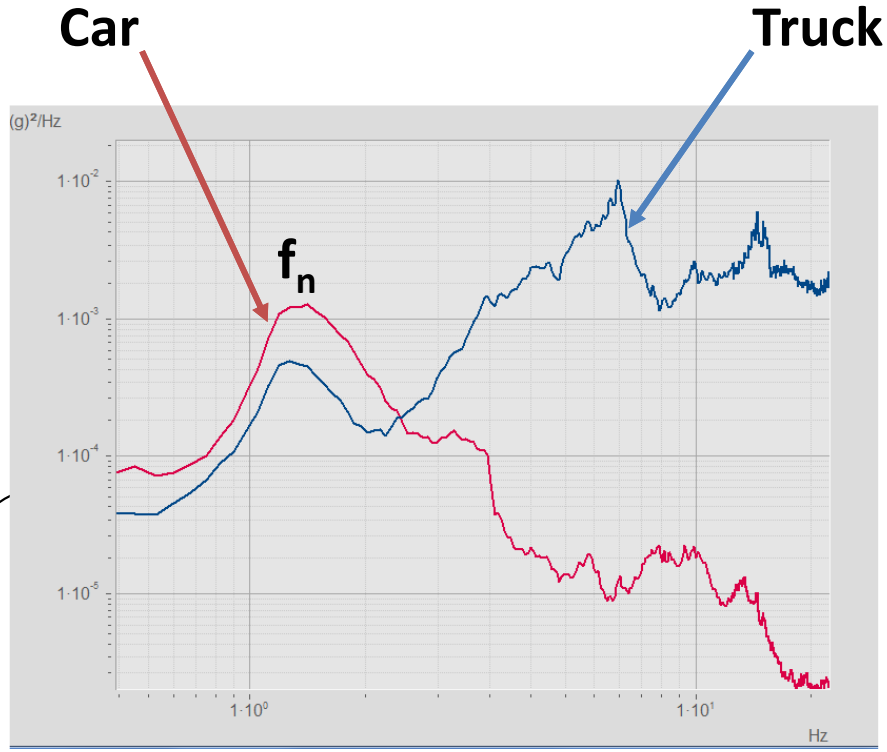


Spring-Mass-Damper System

1. At the resonance frequency, the mass moves at a very high displacement.
   - This can be controlled with damping.
2. Above resonance, the mass is isolated from the vibrations applied to the spring.
3. Less damping = high displacement at resonance.
4. More damping = less isolation!

Vibration Isolation





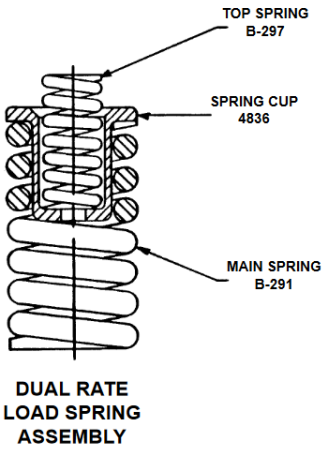
Springs

- Freight typically use coil springs. Passenger; coil or air.
- Freight car “spring groups” are designed to keep the freight car suspension effective when the car is empty and loaded.
  - Concentric springs with different heights.
  - Built up in groups to achieve desired empty and loaded stiffness.
  - Keep empty and loaded resonance low enough.

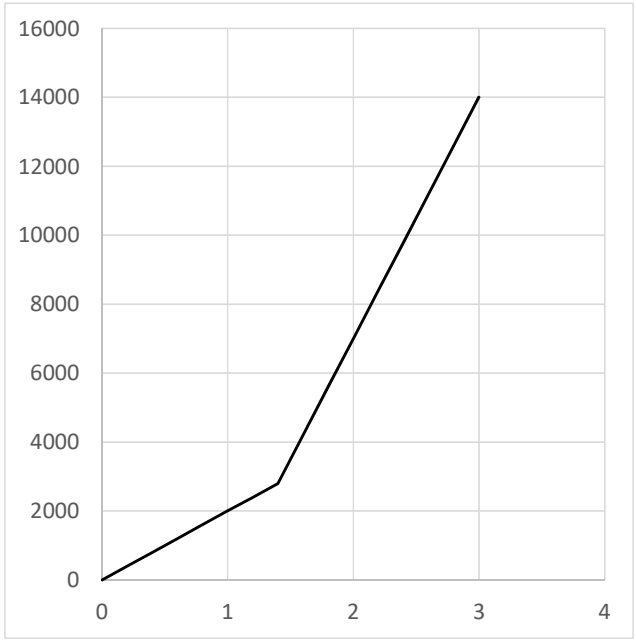
DOUBLE SIDE SPRING DESIGN

	S-2-A	S-2-B	S-2-C
SPRING TRAVEL	2 1/2"	3 1/16"	3 11/16"
FREE HEIGHT (CENTER GROUP)	9 1/16"	9 5/8"	10 1/4" (OUTER COIL)
SOLID HEIGHT	6 9/16"	6 9/16"	6 9/16"
6" X 11" BEARING SIZE 220,000 LBS. MAX RAIL LOAD	 5 OUTERS D-3 4 INNERS D-3 2 OUTER SIDE B-421 2 INNER SIDE B-422	 7 OUTERS D-4 2 INNERS D-4 2 OUTER SIDE B-432 2 INNER SIDE B-433	 7 OUTERS D-5 3 INNERS D-5 2 OUTER SIDE B-432 2 INNER SIDE B-433
*WEIGHT PER CAR SET 4 – GROUP (LBS)	549	622	639
SOLID CAPACITY (LBS)	83,865	84,124	83,836
6 1/2" X 12" BEARING SIZE 263,000 LBS. MAX RAIL LOAD	 7 OUTERS D-3 2 INNERS D-3 2 OUTER SIDE B-421 2 INNER SIDE B-422	 7 OUTERS D-4 6 INNERS D-4 2 OUTER SIDE B-432 2 INNER SIDE B-433	 7 OUTERS D-5 6 INNERS D-5 2 OUTER SIDE B-432 2 INNER SIDE B-433
*WEIGHT PER CAR SET 4 – GROUP (LBS)	657	746	732
SOLID CAPACITY (LBS)	96,709	97,856	96,448
6 1/2" X 12" BEARING SIZE 286,000 LBS. MAX RAIL LOAD			 7 OUTERS D-5 7 INNERS D-6 2 INNER INNER D-6-A 2 SIDE OUTER B-432 2 SIDE INNER B-433
*WEIGHT PER CAR SET 4 – GROUP (LBS)			797
SOLID CAPACITY (LBS)			107,129
7" X 12" BEARING SIZE 315,000 LBS. MAX RAIL LOAD	 8 OUTERS D-3 6 INNERS D-3 2 OUTER SIDE B-421 2 INNER SIDE B-422	 8 OUTERS D-4 8 INNERS D-4 2 OUTER SIDE B-432 2 INNER SIDE B-434	 8 OUTERS D-5 8 INNERS D-6 2 OUTER SIDE B-432 2 INNER SIDE B-434
*WEIGHT PER CAR SET 4 – GROUP (LBS)	866	888-LG	904
SOLID CAPACITY (LBS)	119,000	113,080	116,336

Springs



http://www.sctco.com/pdf/sect_4.pdf



https://www.railway-technology.com/contractors/bogies/amsted-rail/

Piece-wise-linear spring rate: lower spring rate when empty, higher spring rate when loaded.

Air Springs

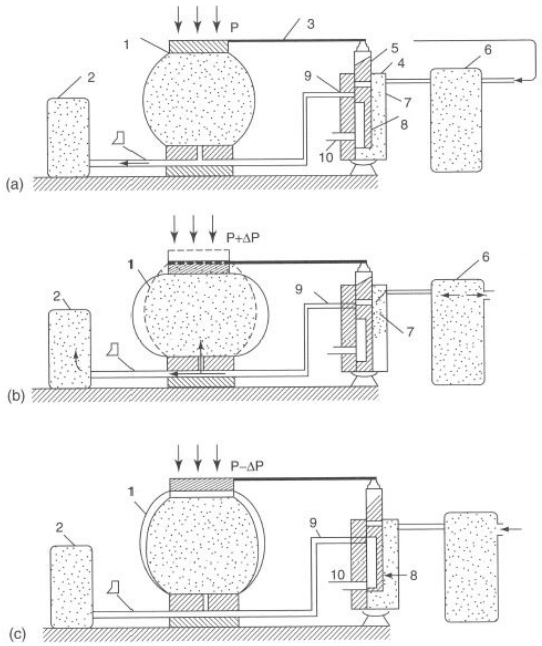
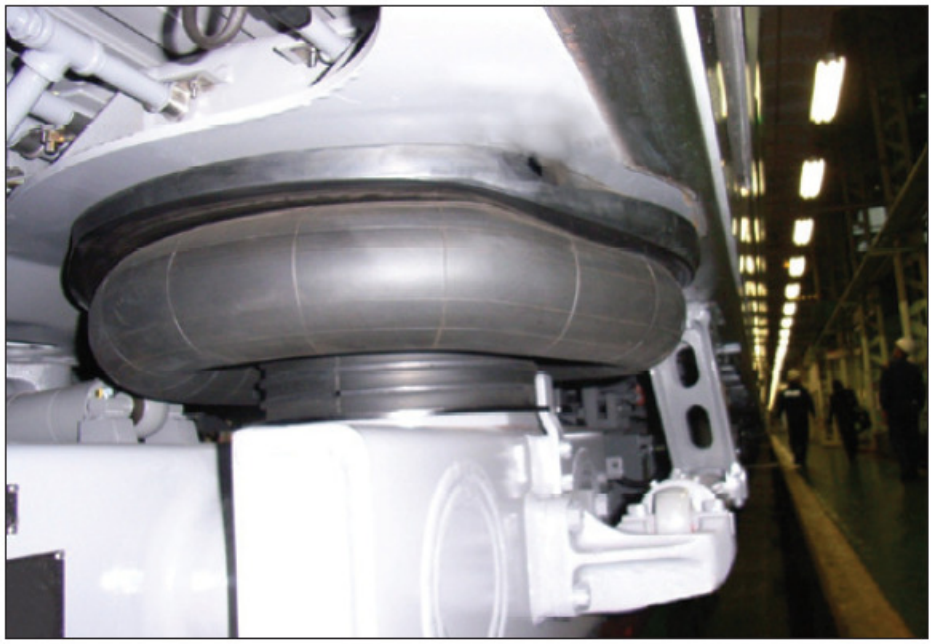


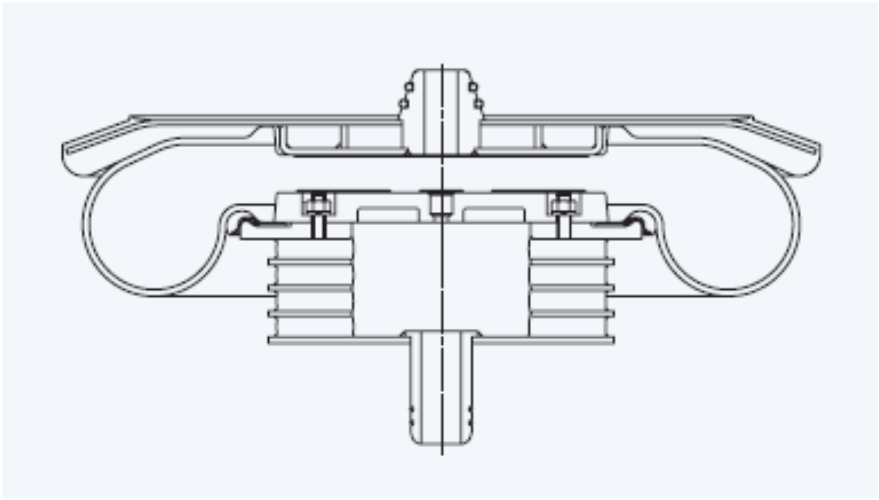
FIGURE 3.11 Schematic showing the operation of a typical air suspension: (a) Equilibrium position; (b) Upstroke; (c) Downstroke.

Handbook of Railway Vehicle Dynamics. Iwnicki, 2006, CRC Press

- Contained gas can act as a spring, but with interesting properties!
- The stiffness is a function of the volume of contained gas, and the change in volume.
- Often used on passenger and light rail cars: empty and loaded stiffness can be adjusted.

Air Springs



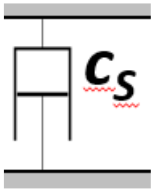


https://www.bridgestoneindustrial.eu/downloads/Air-Spring-EN.pdf

Air Springs

- Air Springs have some interesting properties:
  - Pre-loading the system allows for constant ride height and load leveling.
  - Suspension stations can be connected and interact:
    - Automated levelling; roll in curves.
    - Reduced pitch and roll response.

Damping



- **What is "Damping"?**
  - **Energy loss in the system, through friction.**
  - **In an automobile, typically an oil-filled "shock absorber"**
    - **Pushing the oil through a hole involves friction**
  - **But any form of friction works – metal-on-metal sliding can be used as a form of damping**

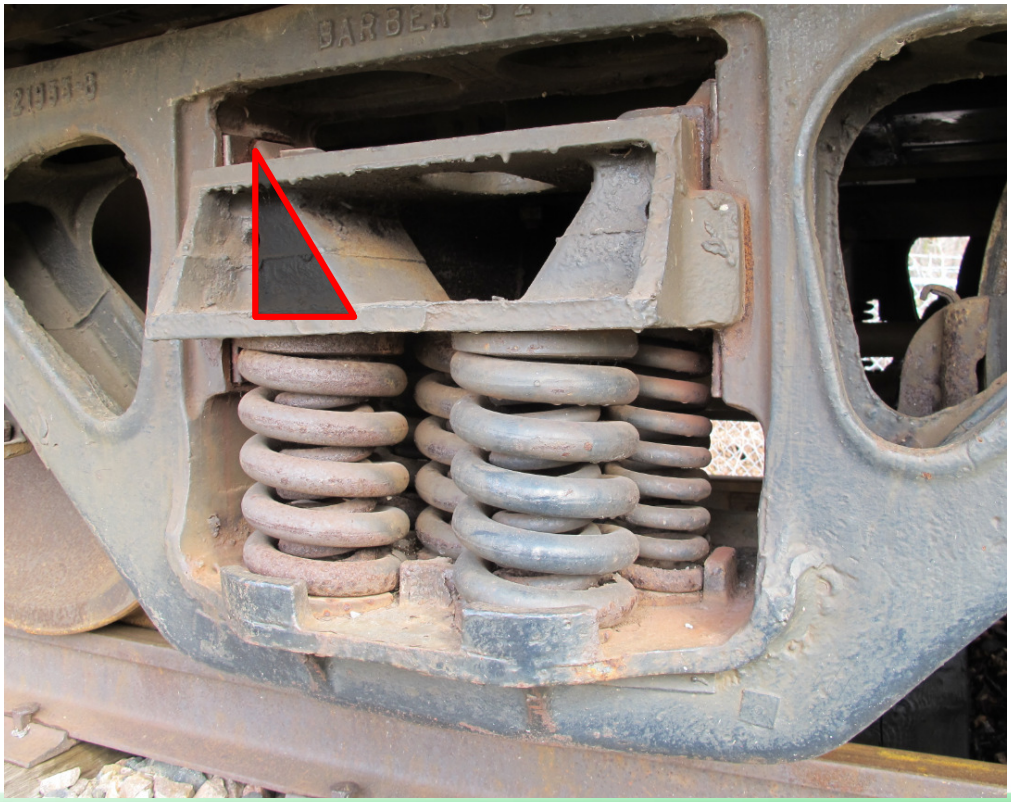
Damping

- **Freight rail cars:**
  - **Almost universally use surface friction for damping**
  - **“Friction Wedges” in the truck design.**
- **Passenger rail cars:**
  - **Hydraulic is often used.**

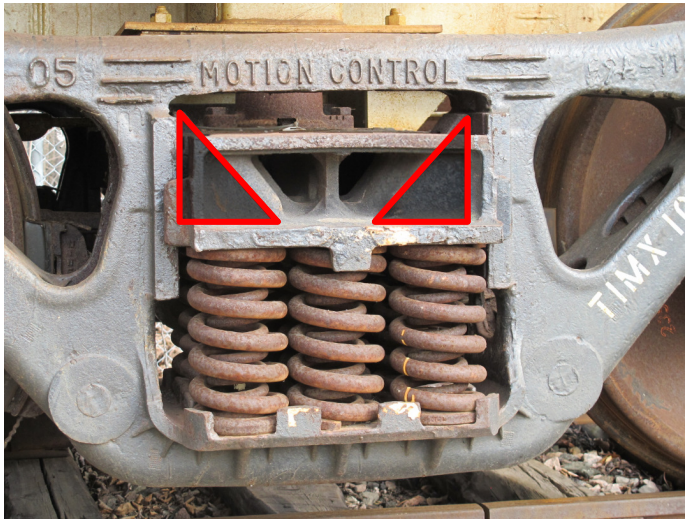
Friction Wedges

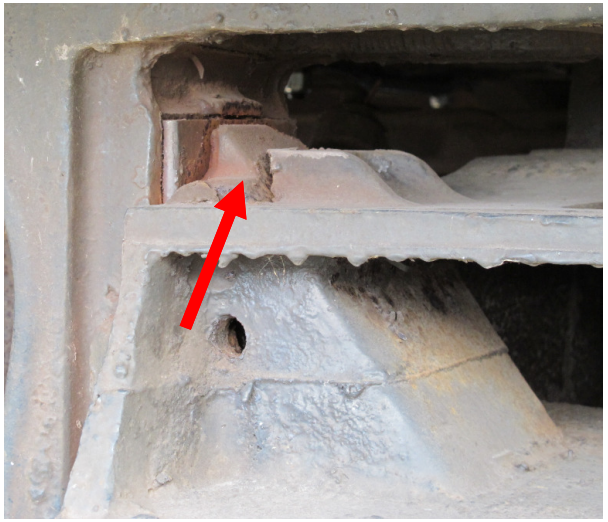
- Main form of damping in freight cars.
  - Vertical, but also lateral.
- Wedges are also key in keeping the truck square and stiff.
  - a requirement for high speed performance and better wheel life.

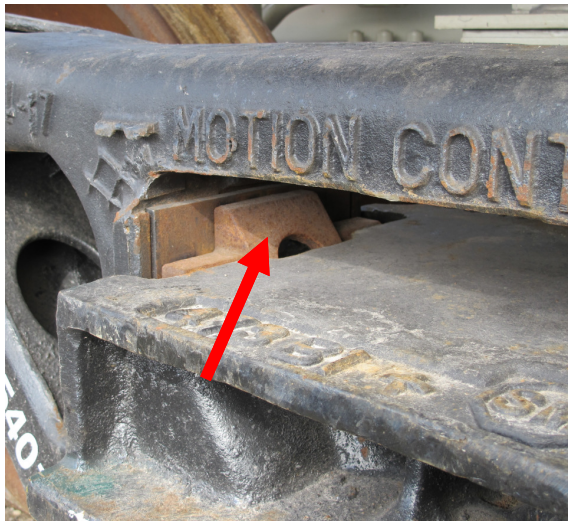
Freight Truck Friction Wedges



Freight Truck Friction Wedges

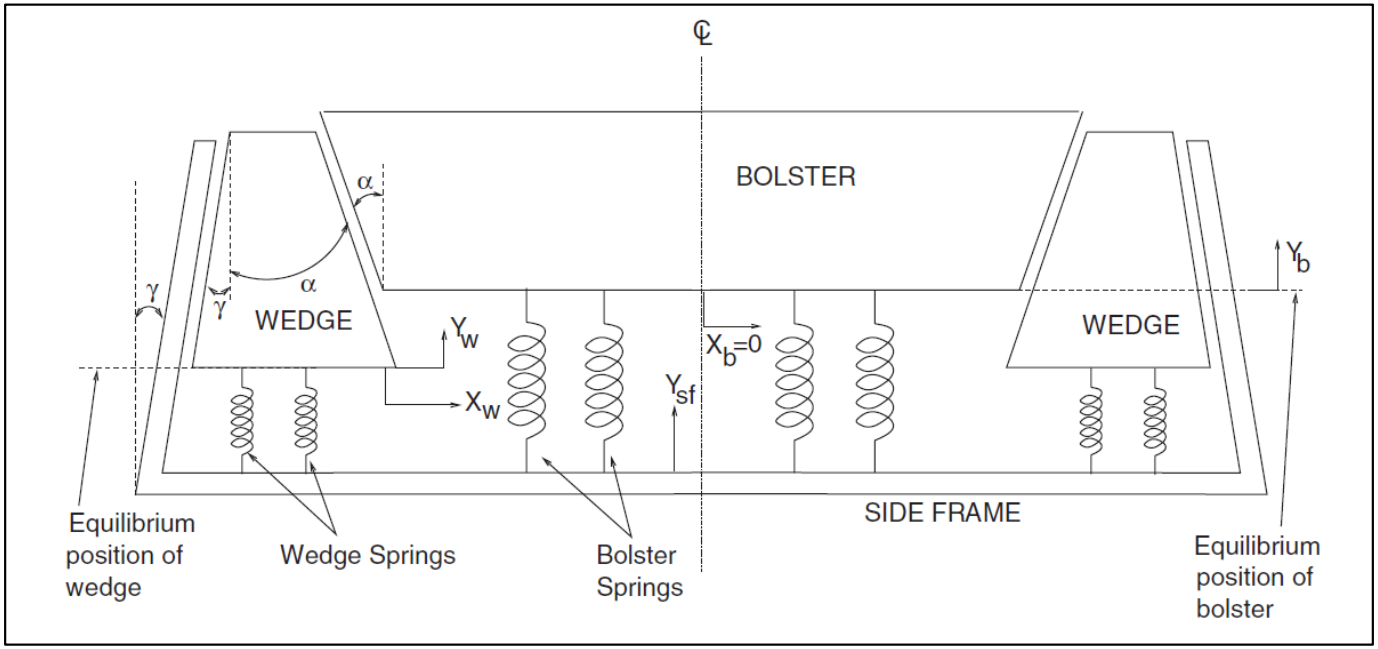






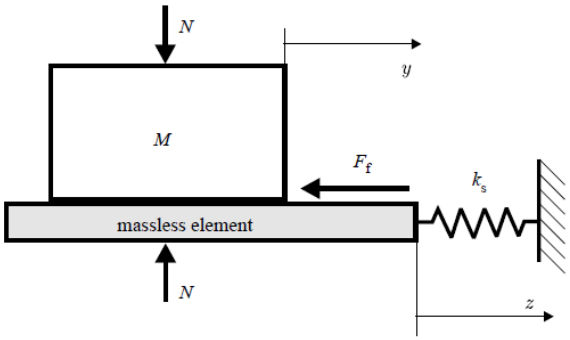
The wedge slides against a vertical wear plate on the side frame, while moving with the bolster as it moves.

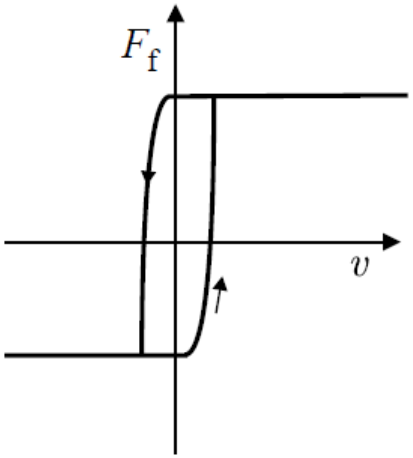
Friction Wedges

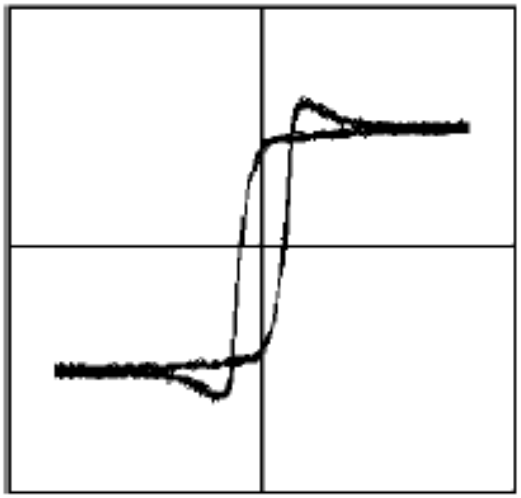


Experimental study of stick-slip dynamics in a friction wedge damper. N.K. Chandiramani, K. Srinivasan, J. Nagendra. Journal of Sound and Vibration 291 (2006) 1–18

Friction Wedges





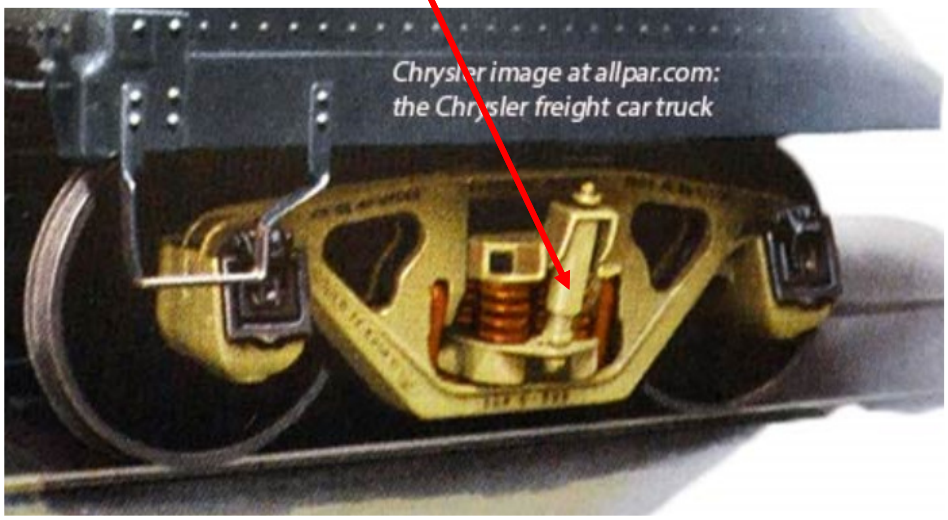


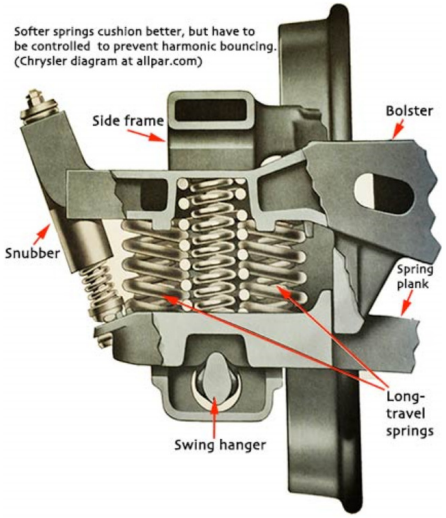
Phil. Trans. R. Soc. A (2008) 366, 747–765
doi:10.1098/rsta.2007.2125
Published online 18 October 2007

Friction is not a simple to model as it is to use in practice!

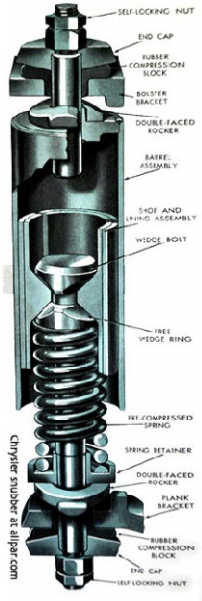
Friction Dampers

Chrysler truck design (1950s) – not current but a very interesting design!
External "friction snubber" is friction based, not hydraulic.





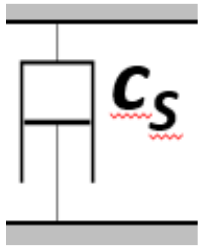
https://www.allpar.com/corporate/railroads.html

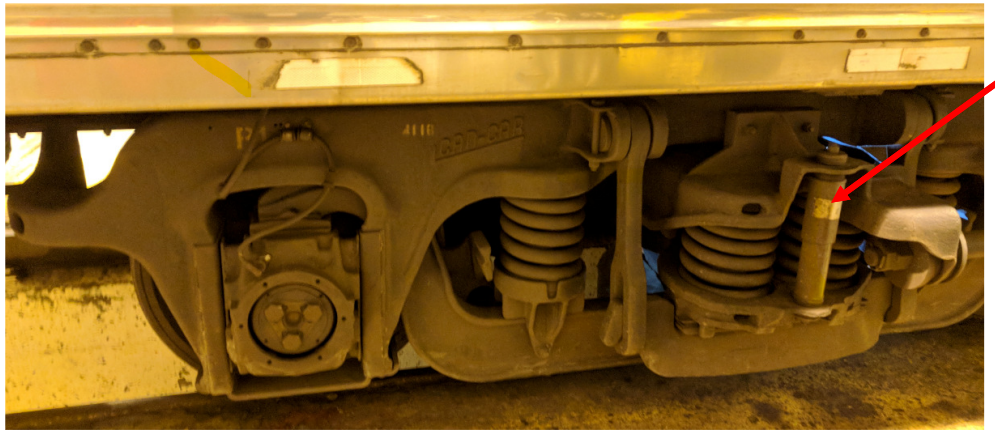


https://www.allpar.com/corporate/railroads.html

Hydraulic Dampers

- **Typically, damping force is proportional to velocity.**
- **Design details can be adjusted to result in non-linear response to velocity, include “blow off” force limits, and other useful design features.**





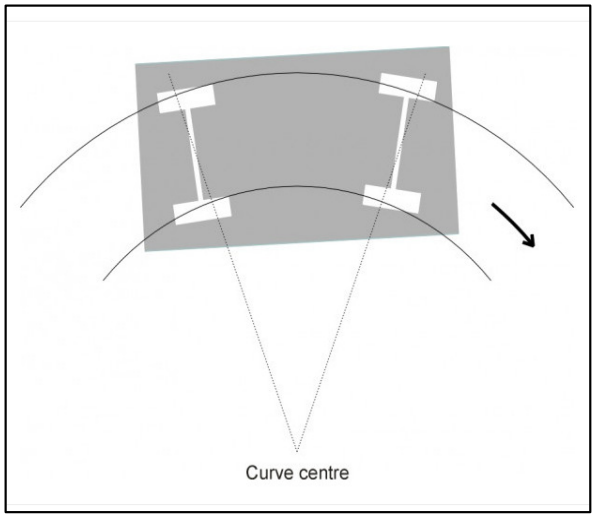
Overall Truck Design Properties

- Looked at the main components of the rail car suspension.
  - 3-piece freight truck
  - Rigid frame passenger car bogies
  - The “job” of the suspension
    - Springs
    - Dampers
  - Easy!

….But there’s more….

The wheels have to get through the curves, sometimes at pretty high speeds!

Freight Truck Curving



http://the-contact-patch.com/book/rail/r0415-curving

- How do you get solid axle wheelsets, mounted to a truck frame, to go around a curve?
- The truck frame must allow some relative motion of the wheelsets, either with controlled stiffness, or clearances.
- Side effect of being able to negotiate curves is that lateral stability is affected.
- At high speeds the truck may begin “hunting”.

Dynamic Stability

- Systems often have regions of operation that are ‘unstable’ – e.g. the wobbly shopping cart wheel.
- Aircraft, motorcycles, cars: all have design elements to maintain stability.
- Rail cars have the same limitations with stability and speed.

Dynamic Stability

- **The hunting problem was so important, that in the 1950s a competition was held to find a solution.**
  - **de Possel, Boutefoy, and Matsudaira (1960) described and analyzed the problem.**
  - **similarities to aero-elasticity problems in high speed aircraft.**

Dynamic Stability

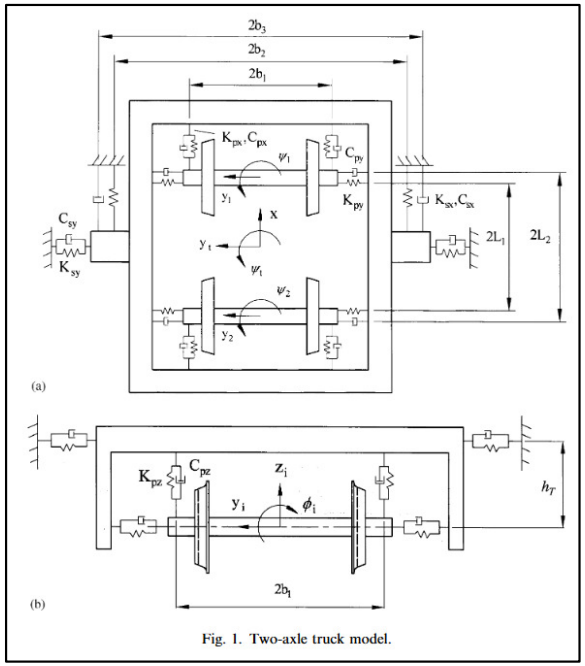
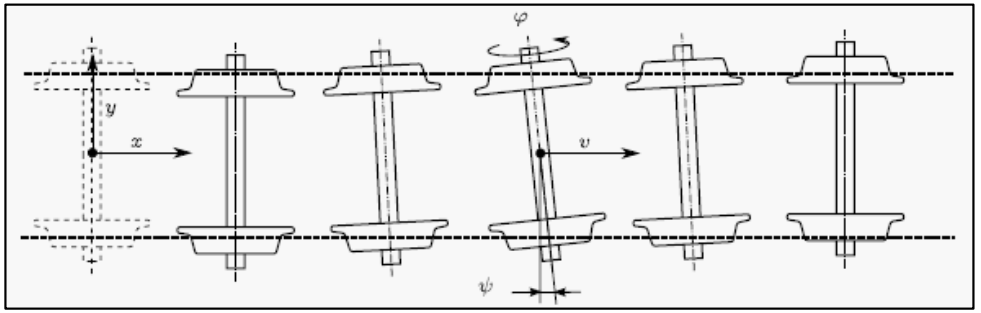


Fig. 1. Two-axle truck model.

Journal of Sound and Vibration 282 (2005) 881–898, Hunting stability analysis of high-speed railway vehicle trucks on tangent tracks. Sen-Yung Lee, Yung-Chang Cheng

- **Solution: Control lateral and longitudinal stiffness of the axle-truck system => control hunting.**

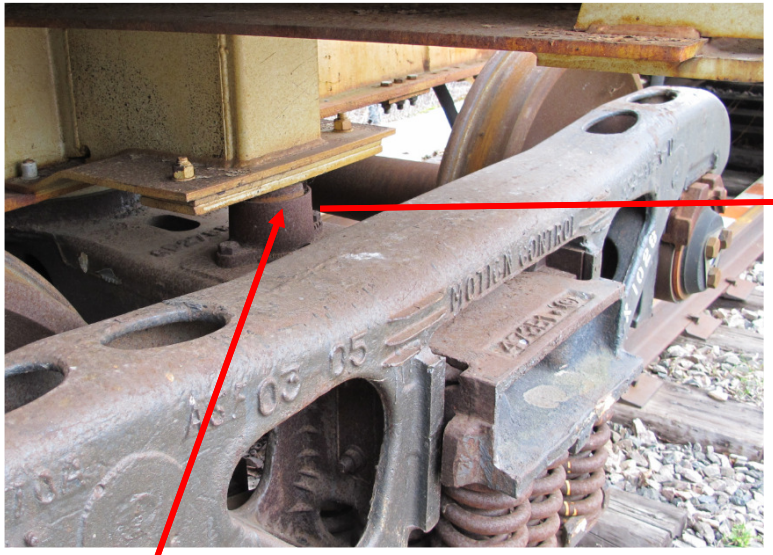


Multibody System Dynamics, July 2015, Volume 34, Issue 3, pp 259–274, Kinematic oscillations of railway wheelsets. Mate Antali, Gabor Stepan, S. John Hogan

Dynamic Stability

- **Freight Car Trucks:**
  - **Wedge designs to improve warp stiffness.**
  - **Constant-contact side bearings to provide damping.**
  - **Bearing adapter inserts: elastomeric pads to control longitudinal and lateral stiffness, improve curving performance.**
  - **Special truck designs.**

Dynamic Stability



Constant contact side bearing

https://www.amstedrail.com/sites/default/files/sales-collateral-files/field-inspection-pocket-guide.pdf

Bearing adapter: Adapter Plus Steering Pad System

Dynamic Stability

- **Passenger Car Trucks: Primary suspension elements are designed with controlled lateral and longitudinal stiffness values, to allow for steering in curves but also to control hunting at high speeds.**
- **Lateral dampers and car body-bolster side bearings may also be incorporated.**

Suspensions for Freight Cars

- **Each car type will have a truck design, spring group, friction wedge design, and side bearing each selected to be optimized for that particular car.**
  - **Optimal curving performance; low drag, low wheel wear.**
  - **Prevent hunting when empty (and loaded).**
  - **Traverse demanding track conditions, switches, crossovers,**
  - ***Cost effective to operate and maintain from a system-wide standpoint.***

Suspensions for Passenger Cars

- **Each passenger car design will have a truck design with primary and secondary suspension spring and dampers selected to be optimized for that particular car.**
  - **Optimal curving performance; low drag, low wheel wear.**
  - **Prevent hunting at all operational speeds.**
  - **Isolate passengers from vibrations.**
  - **Traverse demanding track conditions, switches, crossovers.**

Thank You