

Rail Vehicle Suspensions and Components

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Overview

- Rail Car Types.
- Rail Car Suspensions: **Why are suspensions important; reasons for suspension design choices; freight vs. passenger designs.**
- Rail Car 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>

Different commodities have had specialized cars developed for them to:

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



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



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



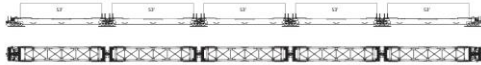
Freight Car Types



<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.
 - Under 40,000 pounds (container car, tank car, box car, flat car and ...) to over 100,000 pounds (autorack).
- **Gross Rail Load (GRL):** maximum loaded weight.
 - 263,000 to 286,000 pounds, or lower!
 - Depends on commodity (density).
 - Example: autorack GRL of ~ 200,000 pounds.



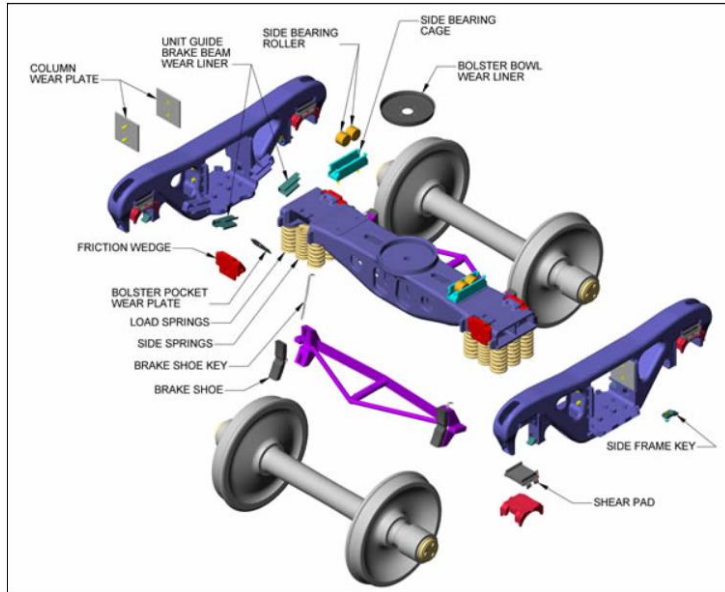
Car Types

- **GRL to LW ratio**
 - **Passenger: ~1.5 to 2**
 - **Autorack: ~ 1.8 to 2**
 - **5-pack container: ~4**
 - **Ore car: ~5.5 to 6**

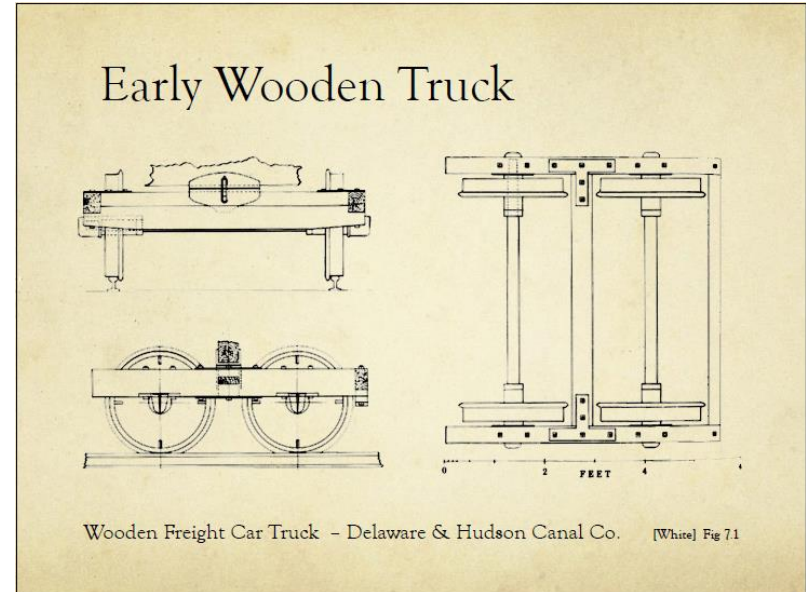
- **How do rail car suspensions handle this difference between empty and loaded weights?**



Freight Car Trucks



<http://www.sctco.com/products.html>



http://sld-nmra.ca/freight_car/ref_material/freight_car_trucks_long.pdf



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.



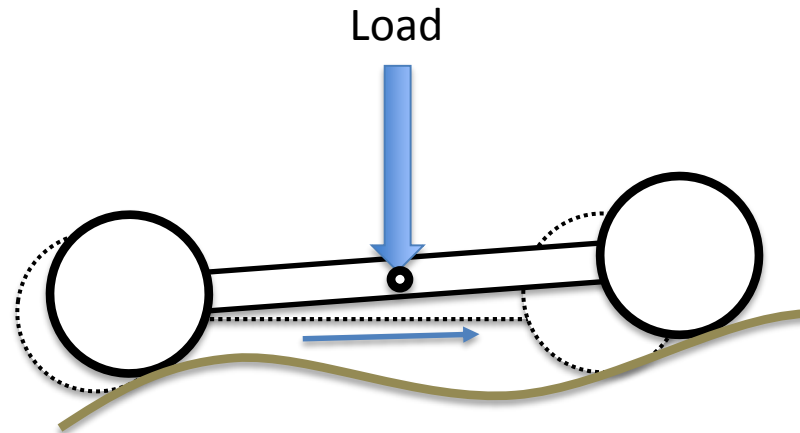
Load Equalization

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.



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.**

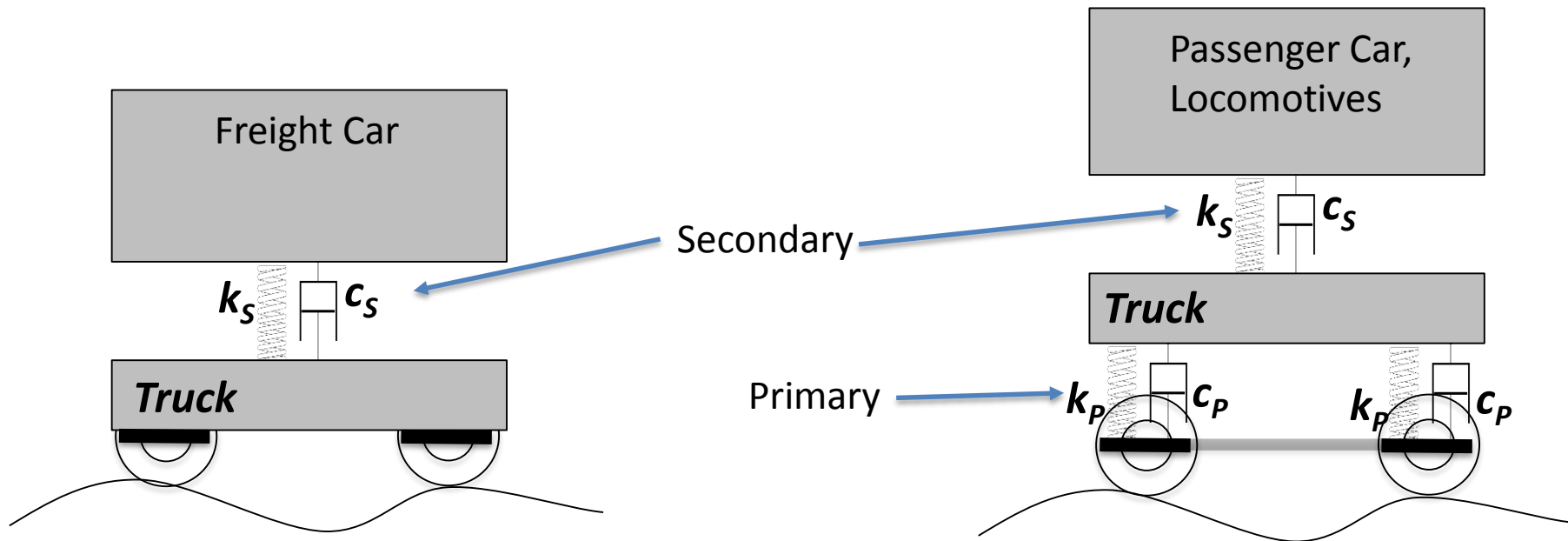


Primary and Secondary Suspension

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

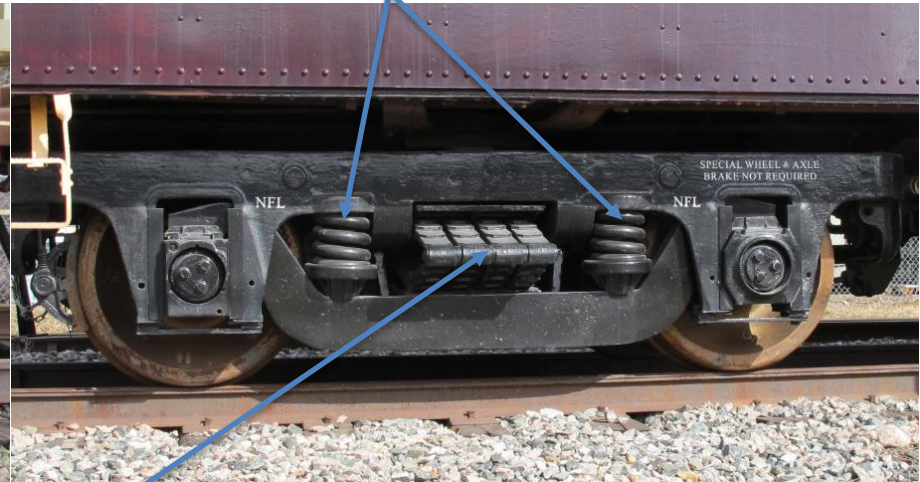


Primary and Secondary Suspension

No Primary Springs: “Hard” Connection



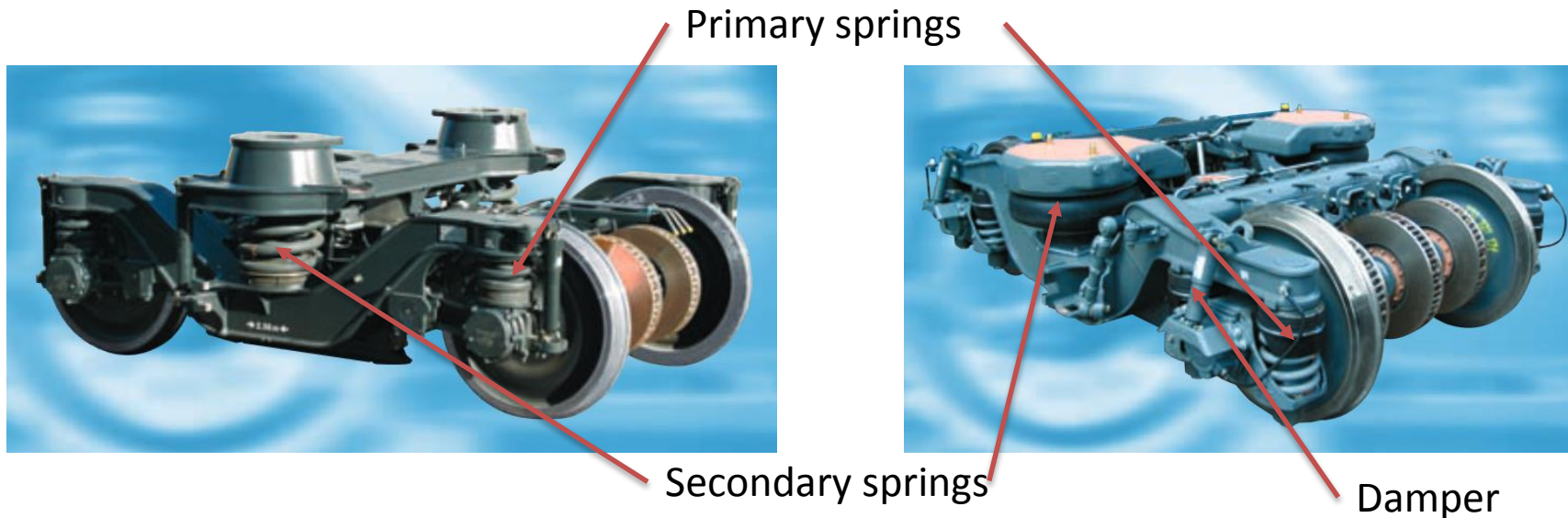
Primary springs



Secondary springs



Passenger Car Truck



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

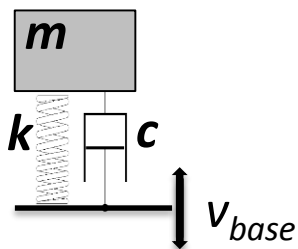
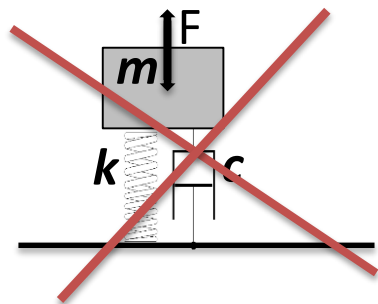


Vibration Isolation

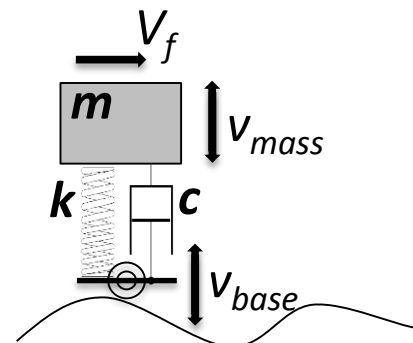
- 1. As car speeds increase, vibration isolation becomes important – the suspension isolates the car from the changing forces of the wheels on the rails.**
- 2. The car and the suspension form a spring-mass system.**
- 3. A car with no suspension would move up-down with every undulation on the track.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



Spring-Mass-Damper System



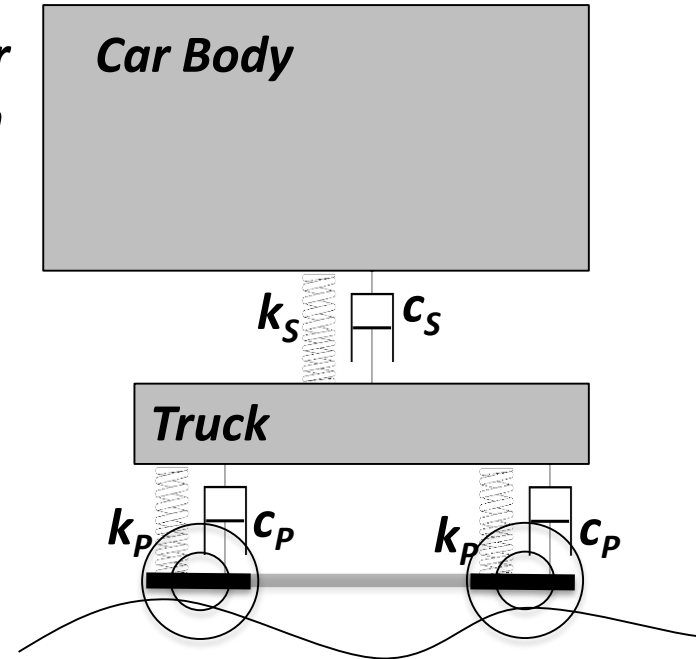
“Quarter Car Model”



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

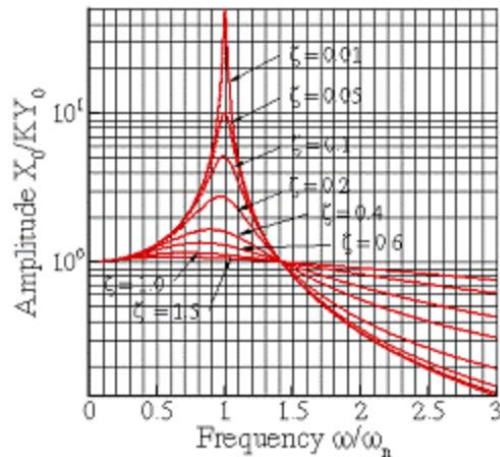
“Quarter Car Model” with Primary and Secondary Suspension



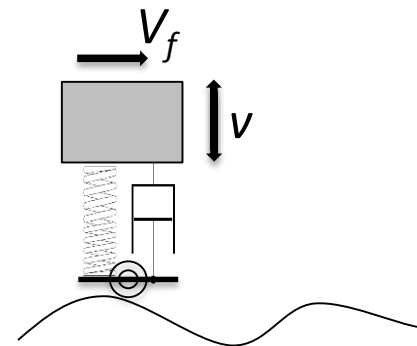
Vibration Isolation

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

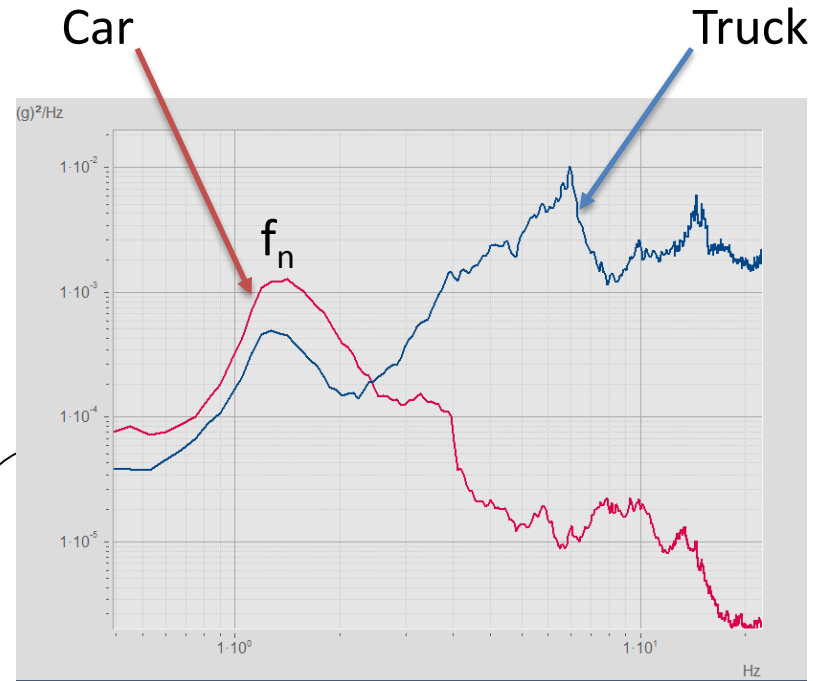
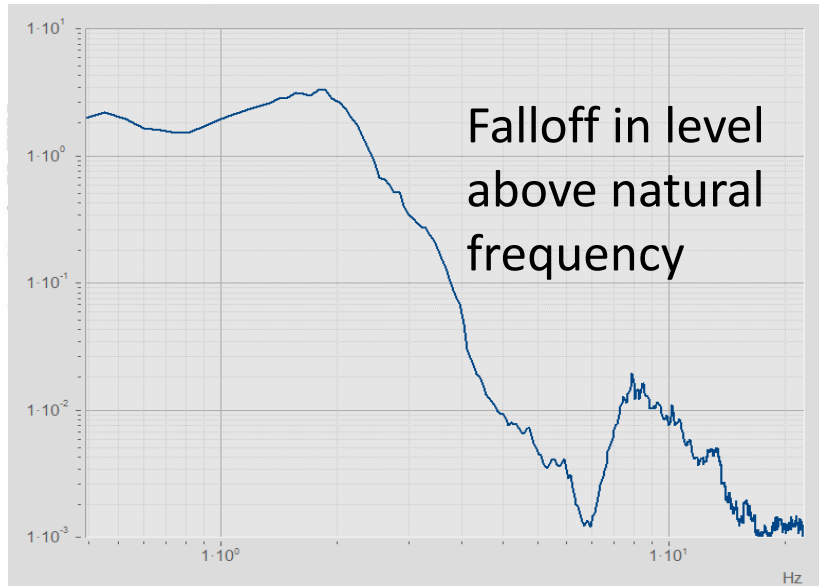


Spring-Mass-Damper System

- 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

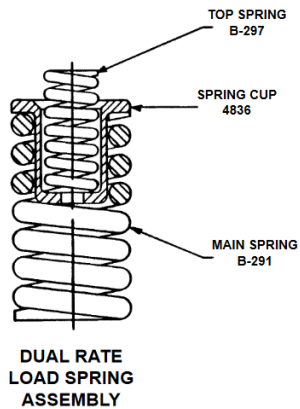
- Freight typically use coil springs. Passenger; coil or air.
- Freight car “spring groups” are designed to keep the freight car suspension effective when the car is empty and loaded.
 - Concentric springs with different heights.
 - Built up in groups to achieve desired empty and loaded stiffness.
 -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

DOUBLE SIDE SPRING DESIGN

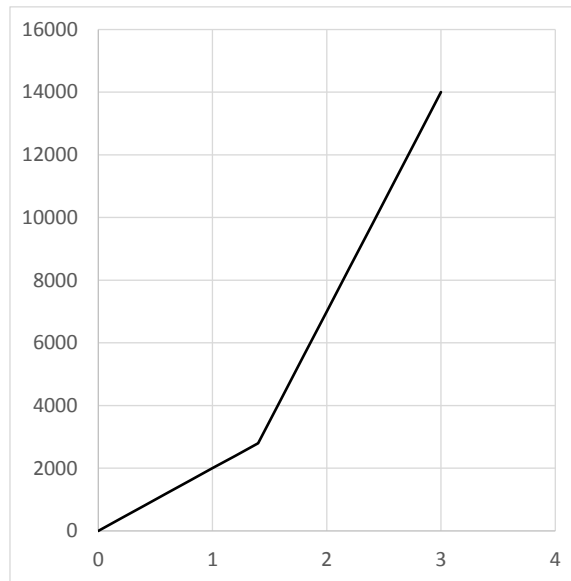
	S-2-A	S-2-B	S-2-C
SPRING TRAVEL	2 1/2"	3 1/16"	3 11/16"
FREE HEIGHT <small>(CENTER GROUP)</small>	9 1/16"	9 5/8"	10 1/4" (OUTER COIL)
SOLID HEIGHT	6 9/16"	6 9/16"	6 9/16"
6" X 11" BEARING SIZE			
220,000 LBS. MAX RAIL LOAD	5 OUTERS D-3 4 INNERS D-5 2 OUTER SIDE B-421 2 INNER SIDE B-422	7 OUTERS D-4 3 INNERS D-4 2 OUTER SIDE B-422 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

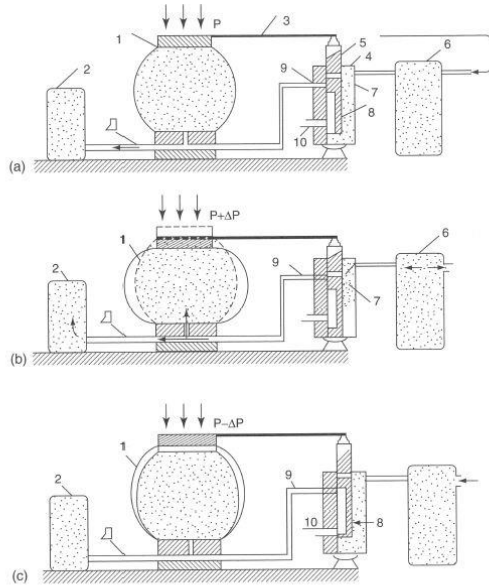


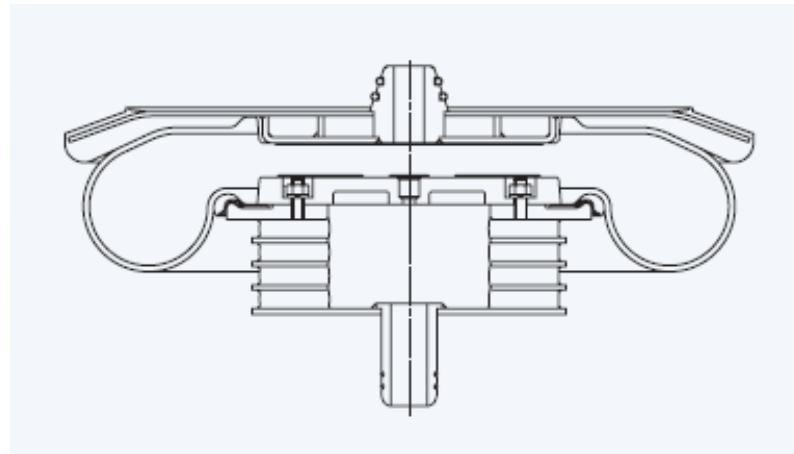
FIGURE 3.11 Schematic showing the operation of a typical air suspension: (a) Equilibrium position; (b) Upstroke; (c) Downstroke.

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.



Damping

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



Friction Wedges

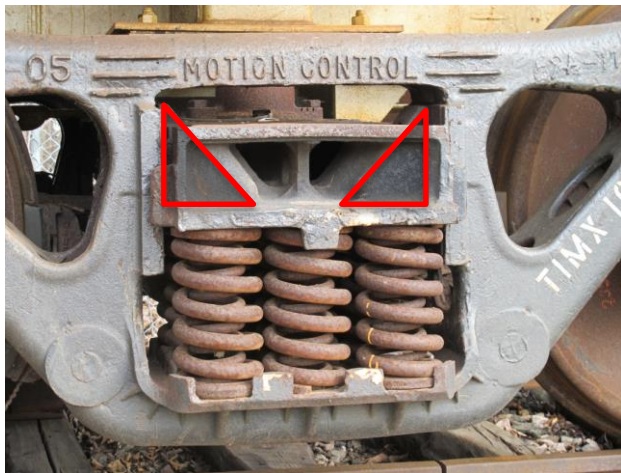
- Main form of damping in freight cars.
 - Vertical, but also lateral.
- Wedges are also key in keeping the truck square and stiff.
 - a requirement for high speed performance and better wheel life.



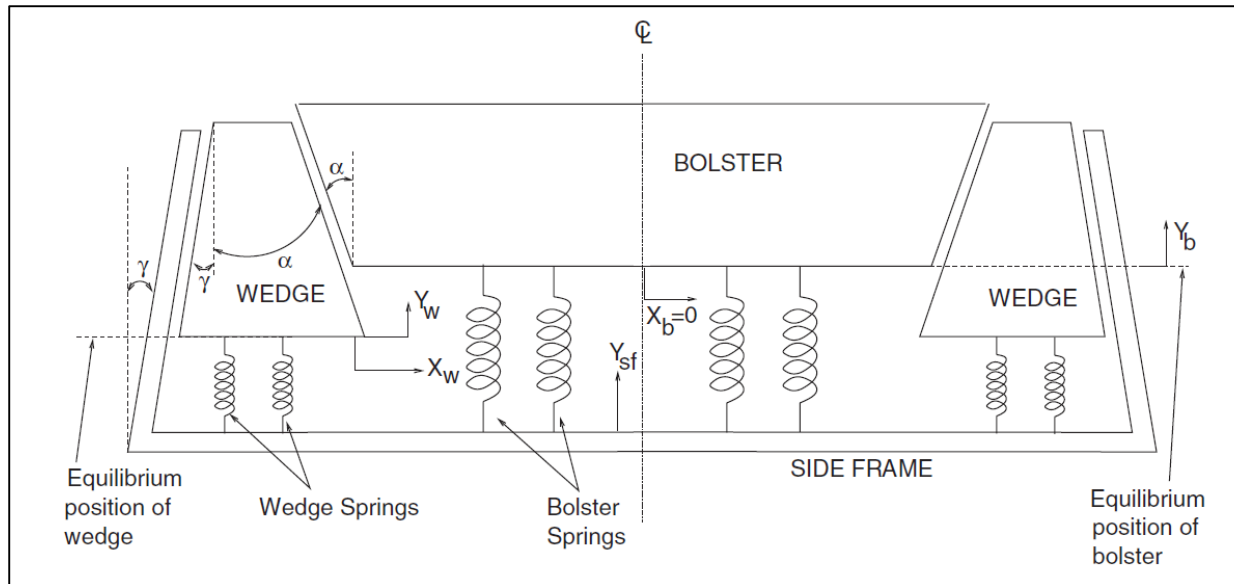
Friction Wedges



Friction Wedges



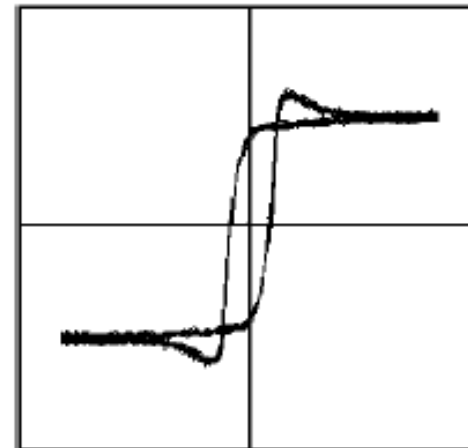
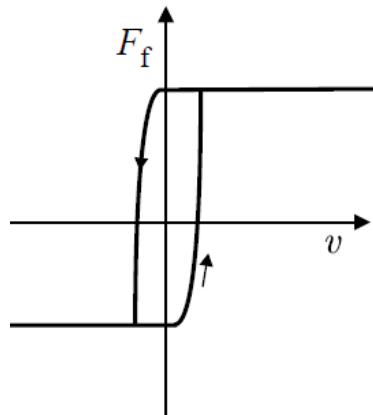
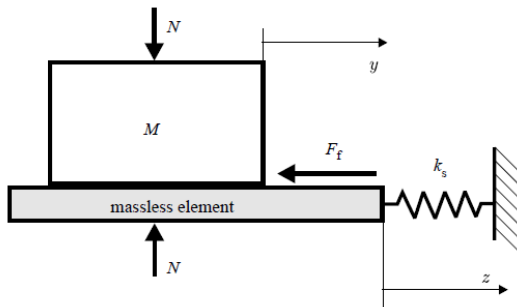
Friction Wedges



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



Hydraulic Dampers

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

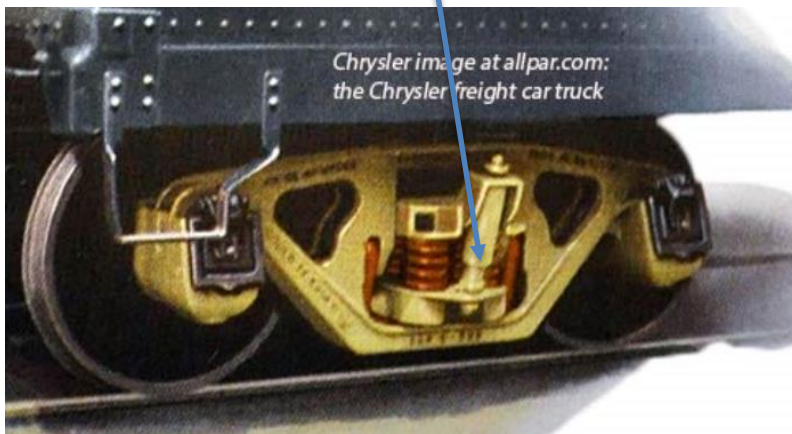


Damper

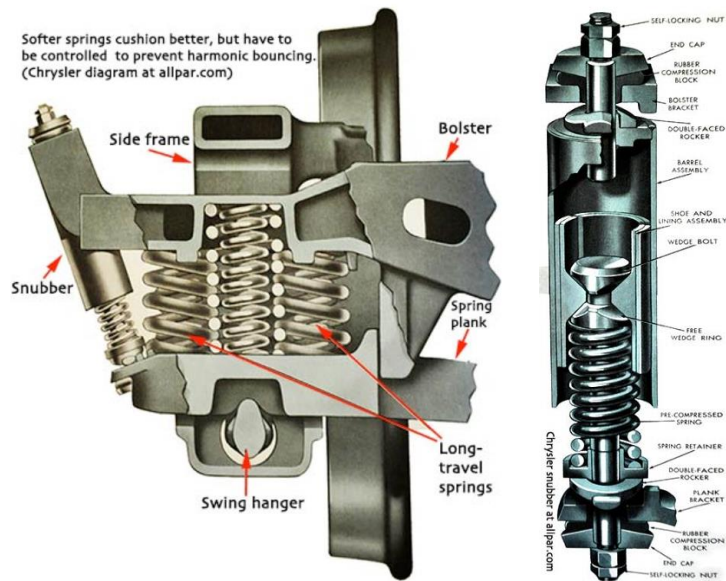


Friction Dampers

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



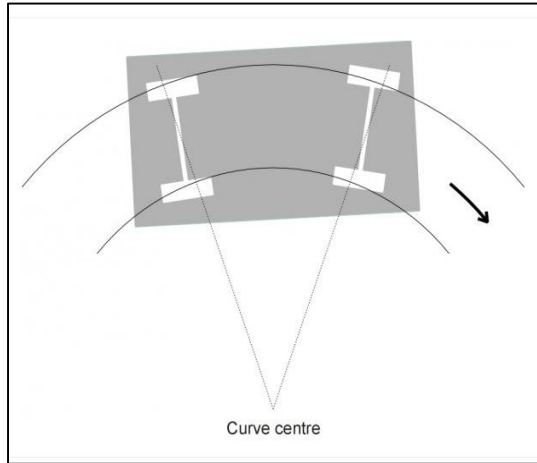
<https://www.allpar.com/corporate/railroads.html>



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



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.

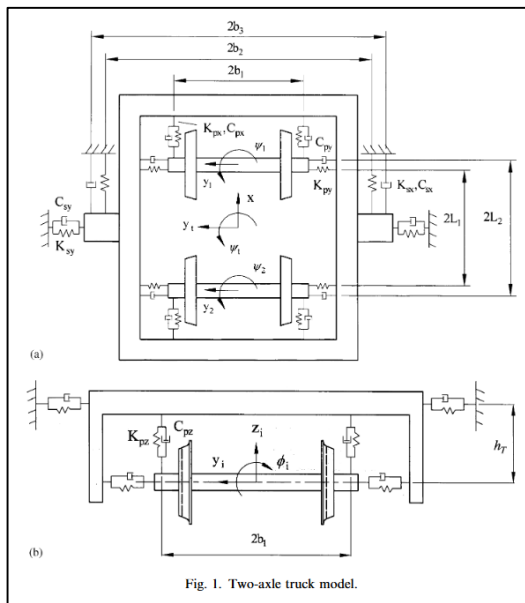


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<https://commons.wikimedia.org/w/index.php?curid=5161741>

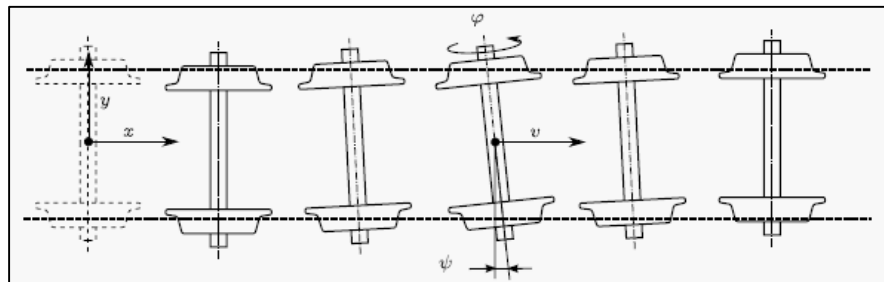


Dynamic Stability

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



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



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

- 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.



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>



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

