Rock Til' You Drop: Investigating a Train's Harmonic Rock and Roll

Introduction / Background

•Train derailments happen when on-track equipment leaves the rail for reasons other than collisions or impacts, with the FRA recording 742 incidents in 2023.

•Equipment failure has been the leading cause of derailments, because of damaged suspension systems with faulty springs.

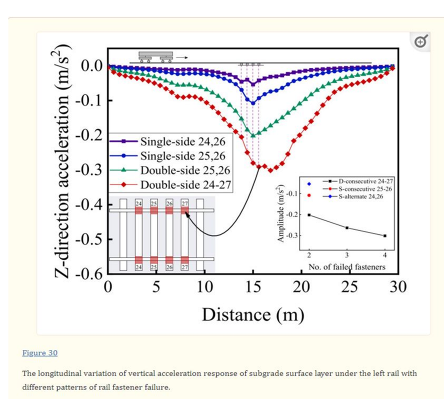
•Proper design of spring rate is necessary for effective load distribution; incorrect rates can lead to poor support that cause excessive vibrations.

•Unbalanced loads and worn-out springs increase the risk of derailments, emphasizing the significance of proper maintenance and fitting of suspension springs.

Review of Literature

Effects of Track Support Failures on Dynamic Response of High-Speed Tracks

Xiao, X. B., Wen, Z. F., Jin, X. S., and Sheg, X. Z., 2007, "Effects of Track Support Failures on Dynamic Response of High Speed Tracks," Int. J. Nonlinear Sci. Numer. Simul., 8(4), pp. 615–630. International Journal of Nonlinear Sciences and Numerical Simulation



International Journal of Nonlinear Sciences and Numerical Simulation
https://doi.org/10.1515/IJNSNS.2007.8.4.615

Goal: To investigate the effect of track support failures on the dynamic response of high-speed tracks.

Finding: A bad suspension system and unkempt train tracks will have a negative impact when acceleration is applied with an uneven load.

Free Vibrations…under moving Loads

Museros P, Moliner E, Martinez-Rodrigo MD. Free vibrations of simply-supported beam bridges under moving loads: maximum resonance, cancellation and resonant vertical acceleration. J Sound Vibr 2013; 332:326–45.

Goals: Investigate bridge movement with addition of loads; determine when shaking strongest and stopping point; correlation of horizontal bridge movement to load.

Findings: Maximum shaking varies by load speed, potentially cancelling or increasing unusual "bounce".

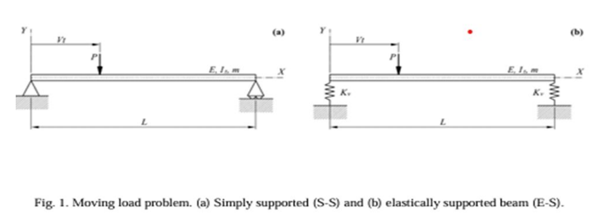


Fig. 1. Moving load problem. (a) Simply supported (S-S) and (b) elastically supported beam (E-S).

Free vibrations of simply-supported beam bridges under moving loads: maximum resonance, cancellation and resonant vertical acceleration.
Citation Section, Figure 1

A Look at Freight Railroads' Average Speed

A Look at Freight Railroads' Average Speed for the First Week of May – Railfanning.org. (2024). Railfanning.org

Goals: Determine average train speeds with various variables and cargo.

Findings: In a 7 years period with 7 load variables measured, average speed is 25.4 mph. Speed varies based on load weight, between average of 33.1 and 22.3 mph.

Railroad	Measure	Variable	5/3/2017	5/2/2018	5/1/2019	5/6/2020	5/5/2021	5/4/2022	5/3/2023
BNSF	Average Train Speed (MPH)	Intermodal	33.3	33.3	32.3	37.1	30.6	31.2	34.0
BNSF	Average Train Speed (MPH)	Automotive unit	25.8	26.1	24.6	31.1	24.1	25.2	26.0
BNSF	Average Train Speed (MPH)	System	25.7	24.9	23.6	28.6	24.7	25.0	25.7
BNSF	Average Train Speed (MPH)	Ethanol unit	24.0	21.1	20.9	25.2	21.3	20.6	23.0
BNSF	Average Train Speed (MPH)	Coal unit	23.8	22.4	20.0	25.8	22.5	24.1	24.6
BNSF	Average Train Speed (MPH)	Grain unit	22.8	21.9	22.5	25.6	23.4	23.9	25.4
BNSF	Average Train Speed (MPH)	Crude oil unit	21.9	22.3	22.8	27.5	22.5	24.7	25.3

BNSF Railway Snippet Data Chart

Problem Statements

•Limited research has been made on how different compression spring stiffness levels can have an impact on train steadiness and performance during resonance situations.

•Many studies overlook the relationship between weight distribution and spring characteristics, which fail to provide an understanding of what the derailment risks are if combined.

Engineering Goals

•Investigate how suspension compression spring stiffness affects train performance to understand its role in preventing derailments.

•Study the effects of different weight distributions on the suspension system to identify possible threats and improve safety measures.

Hypothesis

•If a train's level of compression spring stiffness varies, then weaker compression springs will less steady and more likely to become unstable during acceleration and high vibrations.

•If weight dispersal and spring characteristics are combined in an accelerating train, then an uneven load with weak springs will increase.

Hypothesis 1 and 2 are based on the theory that a good working suspension system can effectively absorb shocks and maintain stability, preventing excessive vibrations while moving.

Materials & Methodology

Materials: XPS, track, G Scale train, compression springs, computer, student created program

Controlled variables: railcar model and weights; independent variables: spring stiffness and mass distribution; dependent variable: acceleration at resonance measured with sensors.

•Completed summer internship in railway safety at the *University Transportation Center for Railway Safety, College of Engineering UTRGV*
- •Monitored computer data on daily basis for 8 hours/day and assist mentor in design and building bearing testers
- •Investigated two possible causes for Ohio derailment [unbalanced load or faulty suspension system] while studying train bearings and pressure limits
- •Designed and created train track model

•Cut and constructed 10 feet of extruder polystyrene [XPS] foam boards
- •Measured, designed and constructed various springs to simulate suspension stiffness using Hooke's Law ($F = -kx$)
- •Two springs, spaced every 4 inches along XPS track, taking corrosion and viability into account

•Designed and built miniature railcar (G-Scale) suspension system with 8 springs per section under XPS to test coil spring stiffness.

•Built and coded Arduino accelerometer to measure vibrations and track spring handled pressure.

•Tested different weight distributions in railcars to see how uneven loads affected the suspension using track system, computer, train and accelerometer.

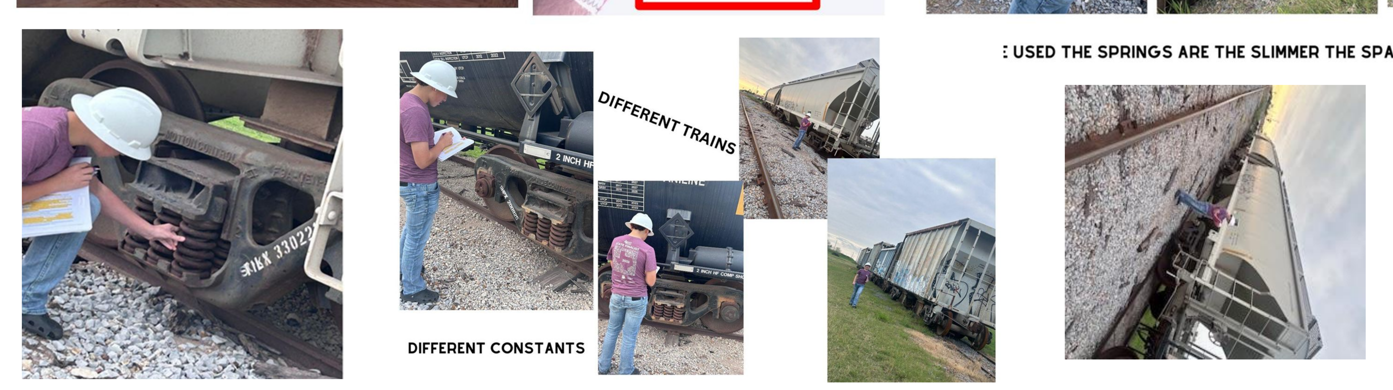
⅔ of the trials the train derailed during unbalanced load testing.

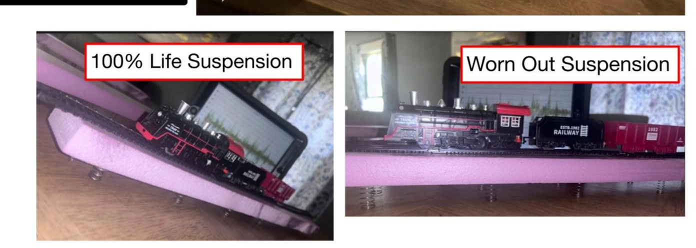
Unbalanced load ONLY continued successfully with the new shocks.

Suspension springs held to support the weight of the train carriages, and are designed to compress and expand in order to absorb shocks and vibrations caused by bumps or irregularities in the track.

I USED THE SPRINGS ARE THE SLIMMER THE SPACE BETWEEN THE COILS!

The impact of the imbalance of mass on the railcar and the spring stiffness of the railcar suspension on acceleration at resonance will always vary depending on the specific circumstances and system dynamics.





Results / Discussion / Analysis

Results

- Springs with lower spring constants (k) showed more vibrations and were not able to support the weight, leading to more frequent derailments.
- The weakest (end-of-life) springs produced the highest vibrations and shakiness.
- The Arduino accelerometer tracked increased oscillations (vibrations) as spring stiffness decreased.
- Uneven weight distribution in the railcar contributed significantly to instability and intensified derailment risks when combined with weaker springs.

Discussion

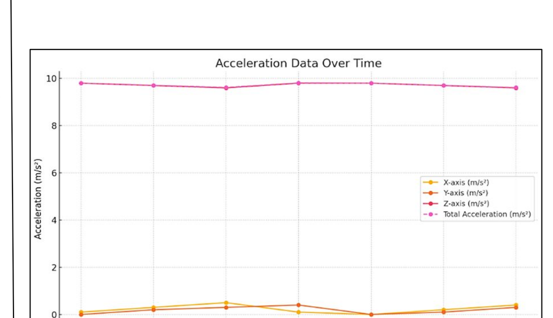
- The results demonstrate that spring stiffness is a critical factor in maintaining railcar stability. Springs with a lower k constant (weaker springs) could not absorb forces effectively, which led to dangerous vibrations during acceleration.
- Weight distribution also played a role. Even with midlife or stiff springs, uneven weight loads caused additional tension, making the railcar more likely to derail.
- The combination of a weak suspension system and uneven weight distribution is dangerous, as it mixes both issues and increases the likelihood of a derailment.
- These findings align with Hooke's Law ($F = -kx$), where springs that lose stiffness (lower k values) cannot counterbalance the forces acting on the railcar.

Analysis

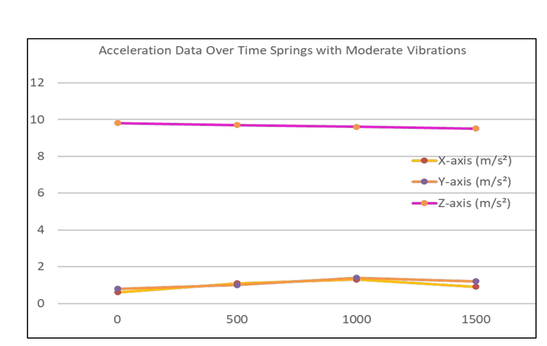
- The tests suggests that spring stiffness and weight distribution significantly affect railcar stability. While weak springs directly led to higher vibrations and derailments, uneven mass distribution stressed the system even more, worsening the problem.
- **Spring Stiffness:** Suspension systems with higher stiffness provided better support and fewer vibrations, making them safer for railcar operation. This emphasized the need for more frequent suspension spring maintenance to ensure springs maintain their k-value.
- **Mass Distribution:** Evenly distributed loads were less likely to cause derailment, but any added strain (especially with older or weaker suspension systems) increased the risk. This showed the importance of careful cargo loading and weight management in real-world railcar operations.
- Fndings suggest railway engineers consider suspension quality and load distribution for safer train travel, especially at resonance where small changes can have significant effects.

Data Tables

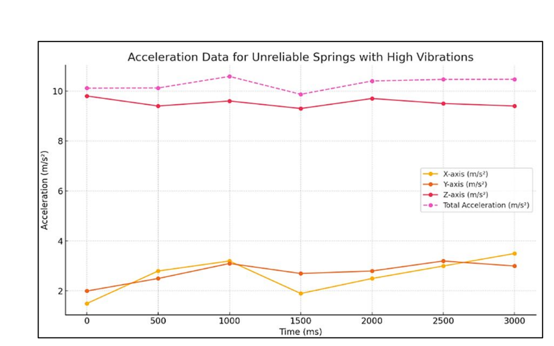
Beginning Of Life Springs

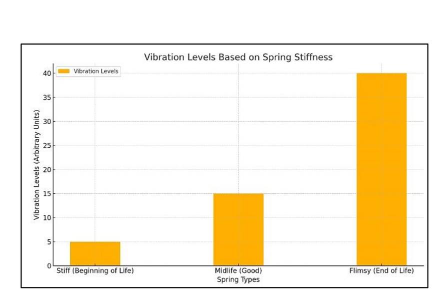


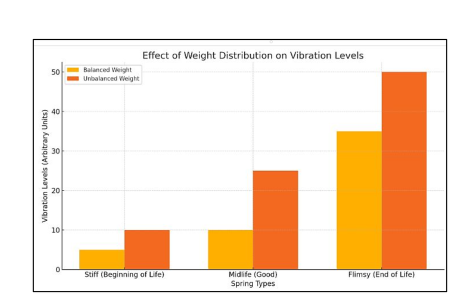
Middle of Life Springs



End Of Life Springs







Practical Applications

- Improved railcar design: Findings can lead to better suspension systems that enhance stability and safety while in motion.
- Enhanced maintenance practices: Data on spring performance will help keep a maintenance schedule to help prevent derailments.
- Safety regulations: Research can inform railway operators to keep a watchful eye on suspension systems.
- Training for railway engineers: Information can be used to train and to emphasize the importance of suspension systems and load distribution to keep a train on its tracks.
- Emergency response strategies: Understanding how suspension failures contribute to derailments can help develop more effective emergency response plans for incidents involving trains

Future Investigations

The next phase will involve testing train derailments under varying environmental factors, to observe their effects on resonance behavior and acceleration responses. Factors include:

- Temperature
- Weather
- Track conditions (track near oceans, dry areas, and riverbanks)

Conclusion

Suspension compression spring stiffness

- When the springs have a low k constant [flimsy], train vibration and bounce increases
- If the springs have a higher k constant [stiff], train vibration and bounce decreases.
- Averaging bounce and weight, the numbers get smaller by half. The weight and springiness have a similar effect on how much it bounces through the vibrations and likeliness to derail.

Weight distributions on the suspension system

- The springs are more important than weight in making the train shake less.
- Both the weight and the springs affect how much the railcar vibrates.
- The springs in the suspension system are crucial for making the car ride smoothly.
- The weight must be balanced, and springs the right stiffness, to ensure a safe ride from point A to point B.

Application/Implication

•Proper spring stiffness in railcar suspensions plays an important role in preventing derailments.

•Railway personnel should maintain and balance mass distribution while selecting appropriate suspension stiffness to ensure a stable railcar performance.

Works Cited/Photographs

- Museros P, Moliner E, Martinez-Rodrigo MD. Free vibrations of simply-supported beam bridges under moving loads: maximum resonance, cancellation and resonant vertical acceleration. J Sound Vibr 2013; 332:326–45.
- Sun YQ (2018) Mitigating Train Derailments Due to Sharp Curve and Overspeed. Front. Mech. Eng. 4:8. doi: 10.3389/fmech.2018.00008
- USAFacts. (2023, October 25). Are train derailments becoming more common in the US? https://usafacts.org/articles/are-train-derailments-becoming-more-common/#:~:text=How%20many%20trains%20have%20derailed,people%20at%20the%20crossicr%20site.
- X. Liu, M.R. Saat and C.P.L. Barkan, Analysis of causes of major train derailment and their effect on accident rates. Transportation Research Record Vol2289, 154-163, 2012.
- Xiao, X. B., Wen, Z. F., Jin, X. S., and Sheg, X. Z., 2007, "Effects of Track Support Failures on Dynamic Response of High Speed Tracks," Int. J. Nonlinear Sci. Numer. Simul., 8(4), pp. 615–630.

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