Comfort analysis on vertical Rail Suspension

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Reference research material

1. Dumitriu, Mădălina. "Influence of the suspension damping on ride comfort of passenger railway vehicles." *UPB Scientific Bulletin, Series D: Mechanical Engineering* 74.4 (2012): 75-90.
2. Graa, Mortadha, et al. "Modeling and Simulation for Vertical Rail Vehicle Dynamic Vibration with Comfort Evaluation." *Multiphysics Modelling and Simulation for Systems Design and Monitoring*. Springer International Publishing, 2015. 47-57.

Abstract

- We focused mainly on the comfort analysis and how velocity of the vehicle and ride index comfort determine the comfort of the passenger in the vehicle for a frequency within 30Hz.
- Suspension system is key for the comfort analysis.
- Two factors determine comfort. One of them is train properties such as type of suspension, wheel and bogy materials, etc.
- The second factor is track irregularities. We considered this factor in our analysis.

Analysis performed

- Understanding railway suspension.
- CAD modeling of individual parts of rail suspension.
- CAD assembly of rail suspension.
- MATLAB analysis and finding ride comfort factor.
- Results and comparisons.

Rail suspension components

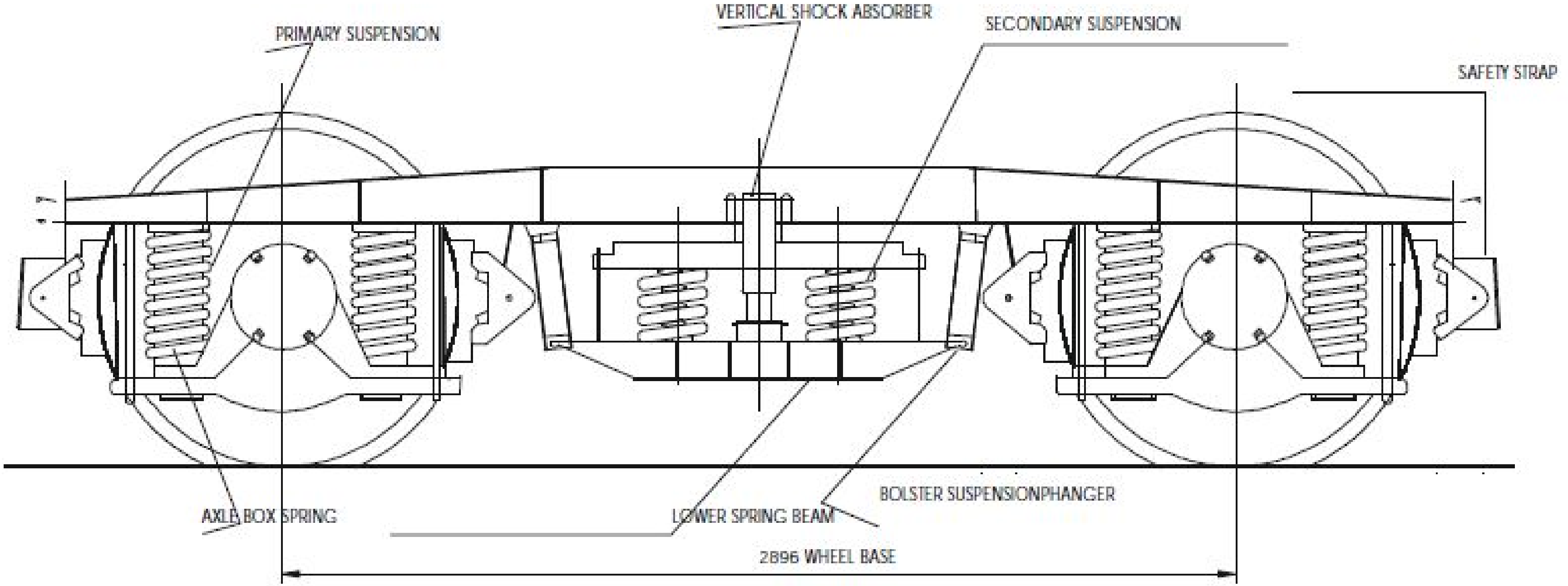
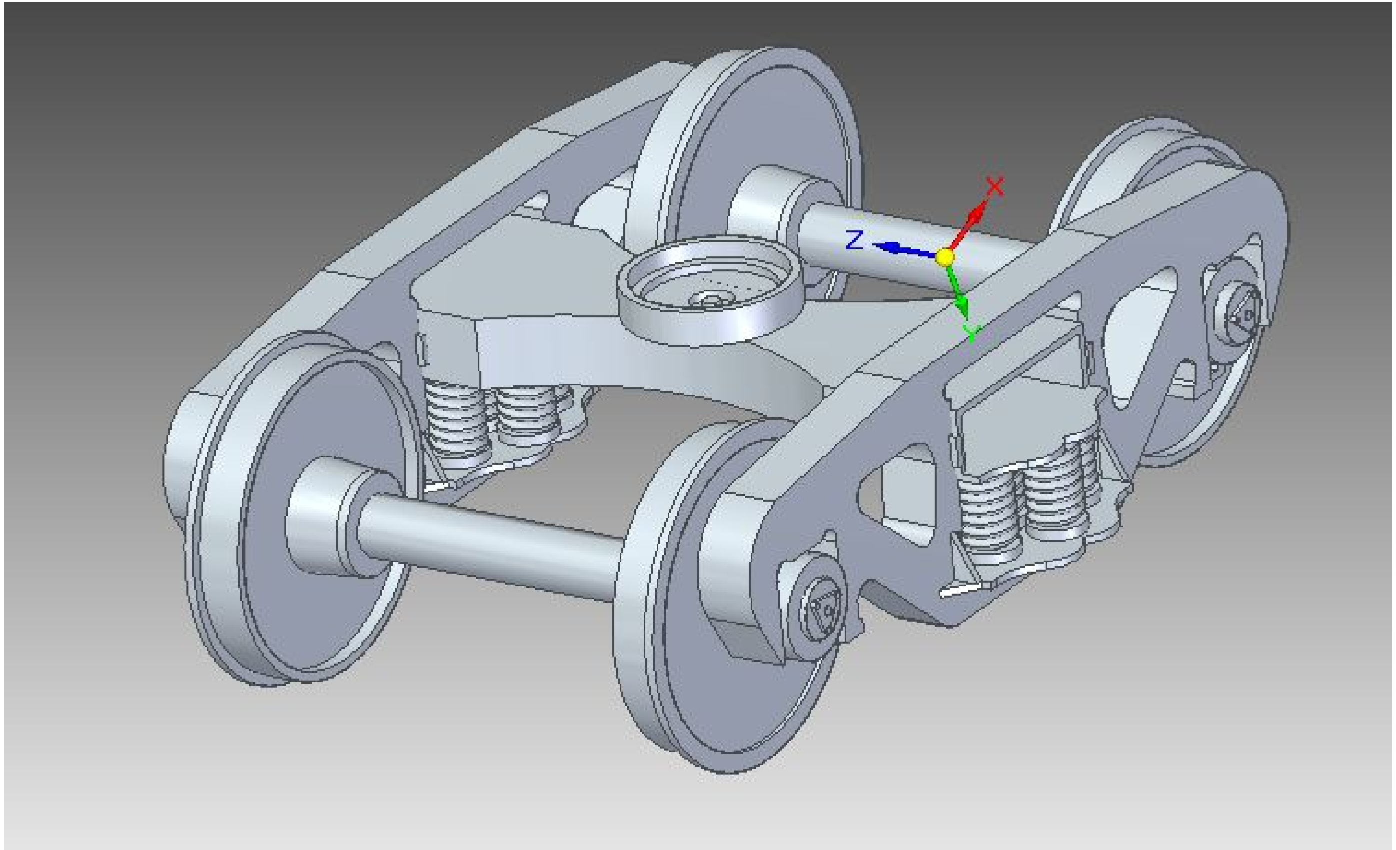
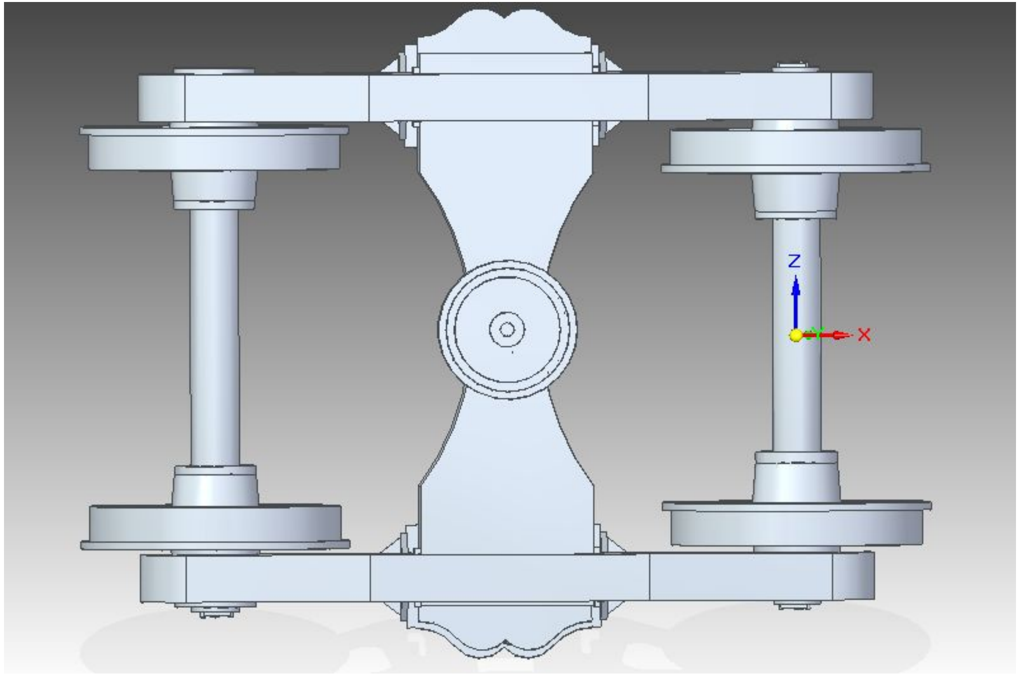


Image courtesy: http://www.scr.indianrailways.gov.in/uploads/files/1341833527005-Bogies.PDF

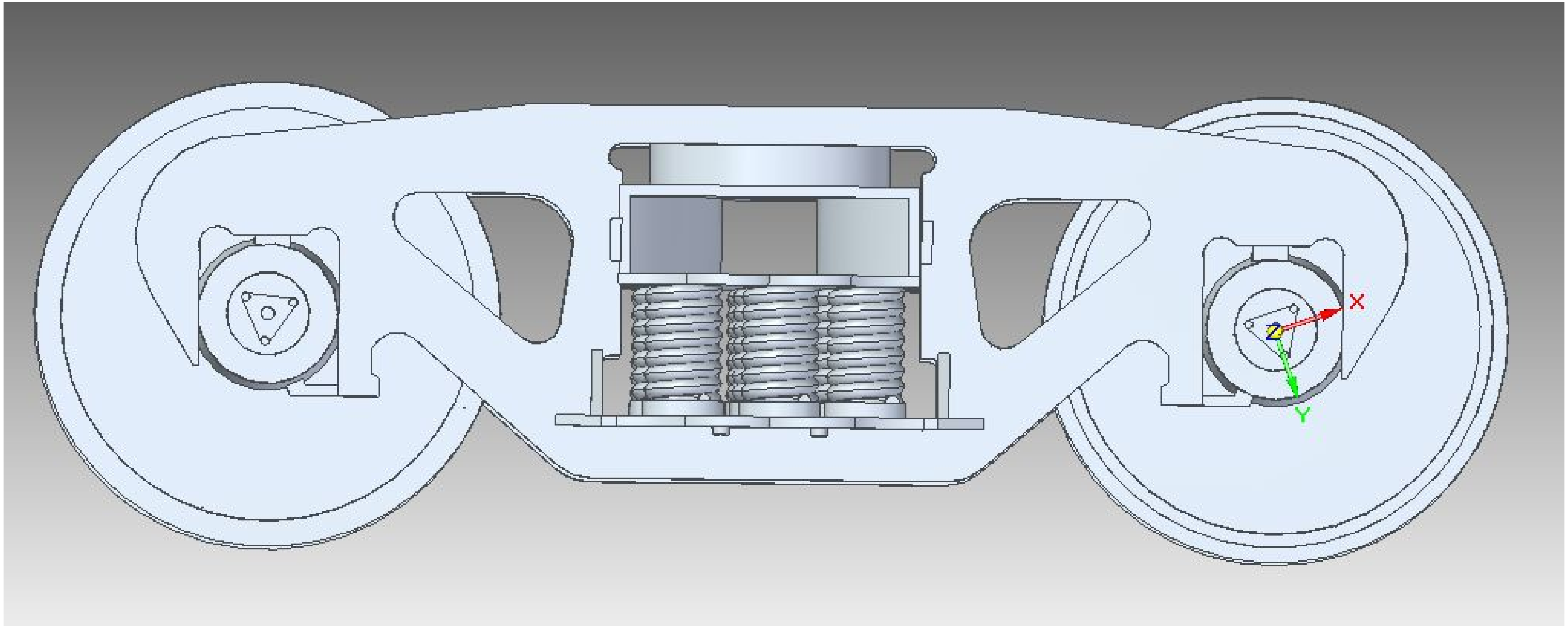
CAD modeling of suspension system



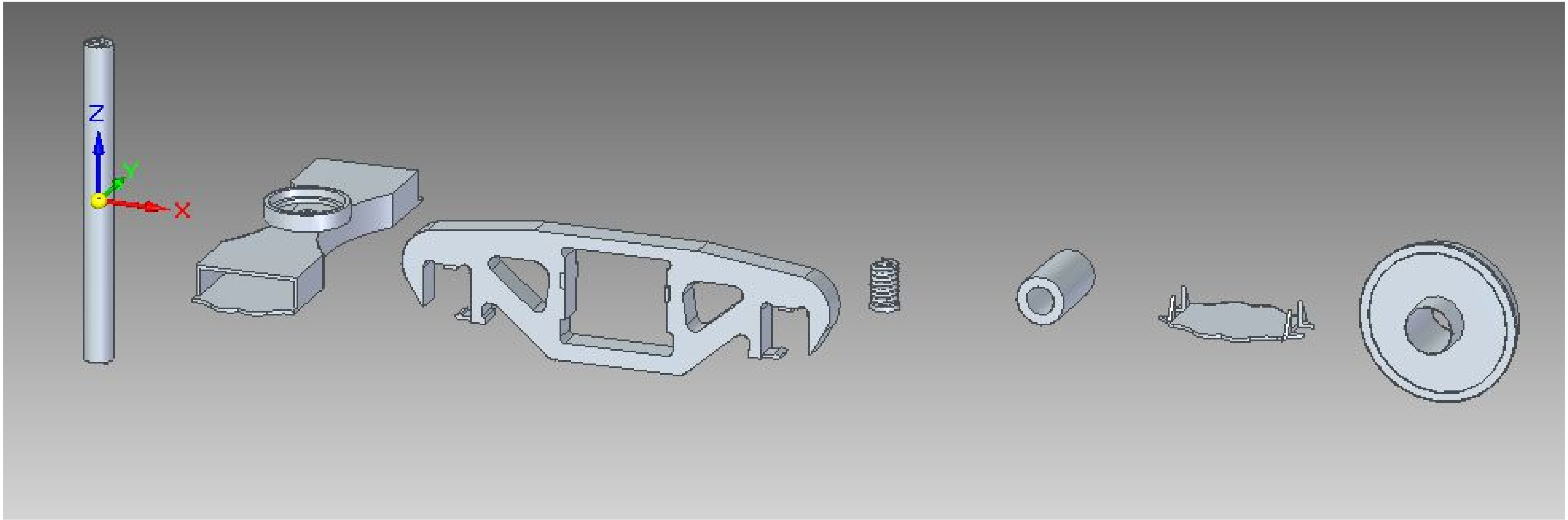
Top view



Side view



Individual Parts



Ride comfort

- Human beings are most sensitive in the frequency range of 4 to 12.5 Hz.
- First of all, we quantify ride comfort by defining ride comfort index and the Sperling Index.
- Besides other factors, the ride comfort primarily depends on the vibration behaviour to which the vehicle is subjected.
- Despite of the favourable results, the active suspension is not a widespread operational solution, due to the fact that the price of implementing and maintenance of this system is too high versus the benefits
- In order to evaluate the ride comfort, there are various international standards, namely ISO 2631 [8], BS 6841 [9], Index Sperling Ride [10, 11], ENV-12999 [12] and UIC 513 [13] – generally speaking, they assess the vibration level in terms of comfort based on the frequency-weighted acceleration.

Ride comfort

- Among them, a simple and widely used method is the Sperling's, *Index Sperling Ride,* which stands out by the fact that its implementation leads in a number with a precise signification that may be easily interpreted, in dependence of the action of different elements in the vehicle vibrant system.
- Here, only the carbody bending modes have been considered for both generality and simplicity.
- The hypothesis of rigid track is adopted because the track rigidity is much higher than the one of the vehicle suspension and the frequencies of wheelsets on the track are much higher than the vehicle's. Therefore, the vertical wheelset displacement equals the corresponding irregularity.

Mathematical formulation

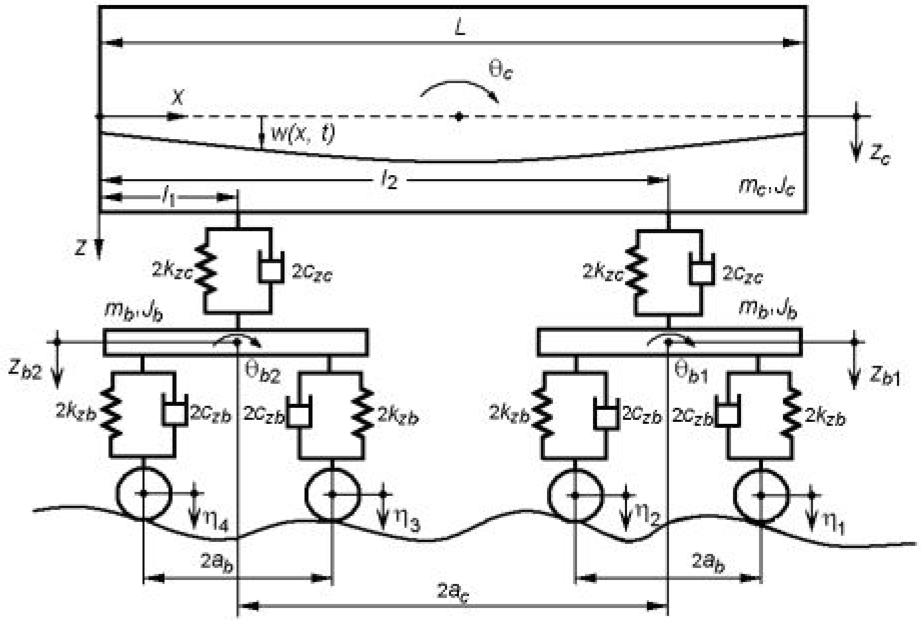


Fig. 1. The vehicle mechanical model.

Mathematical formulation

- Track irregularities are quantified as power spectral density, G which depends on the angular frequency.

$$G(\omega) = \frac{A\Omega_c^2 V^3}{[\omega^2 + (V\Omega_c)^2][\omega^2 + (V\Omega_r)^2]}$$

- But we need to consider acceleration power spectral density G(x,w).

$$G_c(x,\omega) = \omega^4 G(\omega) \left| \overline{H}_c(x,\omega) \right|^2 .$$

Mathematical formulation

- Rate index comfort, Wz is defined as the vehicle's ability to stay within the limits that will not disturb comfort.
- The mathematical expression given by Sperling is as follows

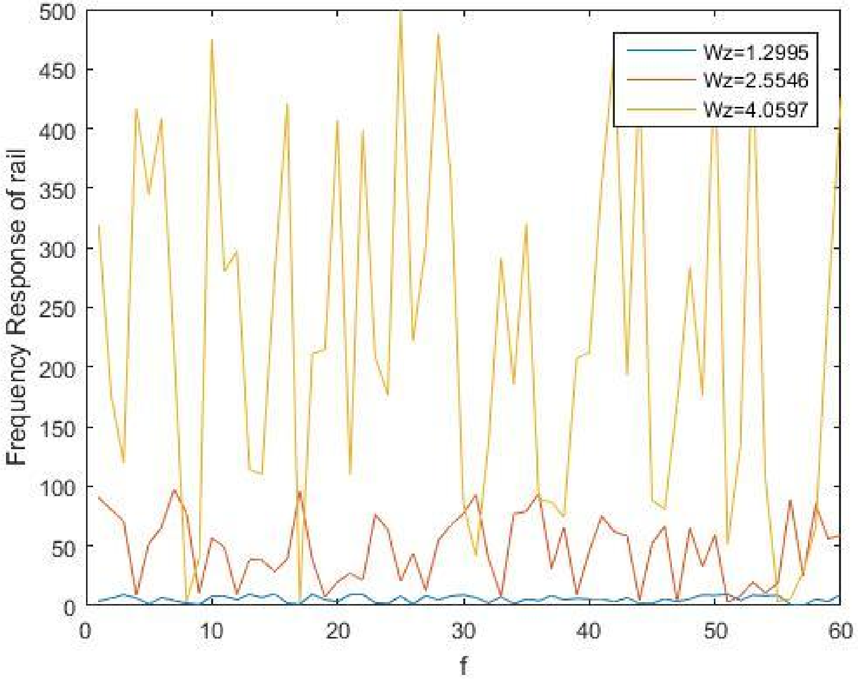
$$Wz = \left(2 \int_{0.4}^{30} G_c(f) B^2(f) \mathrm{d}f \right)^{(1/6.67)}$$

Where

$$B(f) = 0.588 \sqrt{\frac{1.911 f^2 + (0.25 f^2)^2}{(1 - 0.277 f^2)^2 + (1.563 f - 0.0368 f^3)^2}} \; .$$

MATLAB Analysis

Here, we assumed the train's frequency Response signal as 10*rand(1,length(f)), 100*rand(1,length(f)) and 500*rand(1,length(f)) and Comfort index is calculated as shown in the plot.



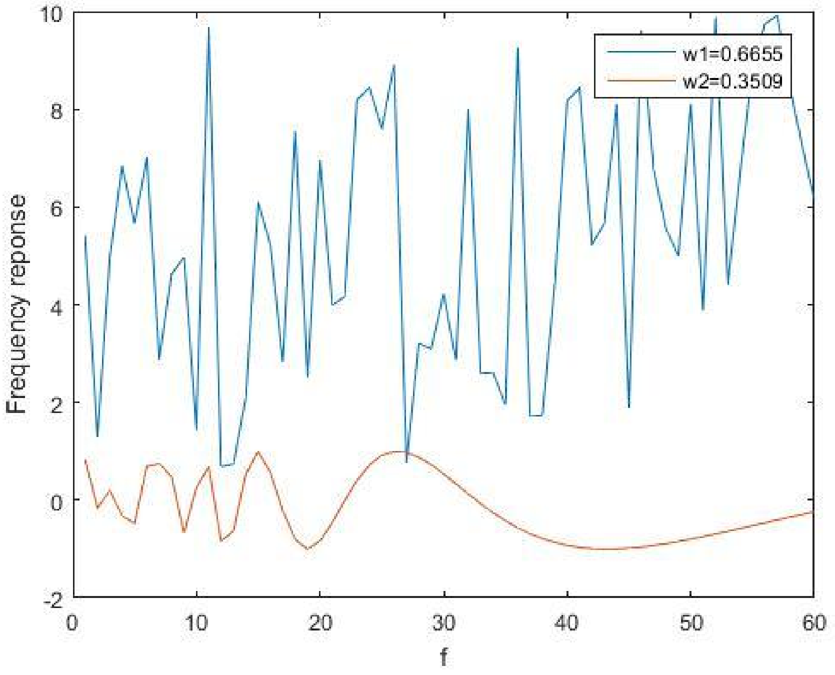
Wz.m

```matlab
f=0.4:0.01:30;
V=60;
A=4.032e-7;
Omegac=0.8246;
Omegar=0.0206;
omega=2*pi*f;
Omega=omega/V;
G=A*Omegac^2*(V^3)./((omega.^2+(V*Omega).^2).*(omega.^2+(V*Omegar.^2)));
H=1*rand(1,length(f));
Gc=(omega.^4).*G.*(H.^2);
B=0.588*sqrt((1.911*f.^2+(0.025*f.^2).^2)./((1-0.277*f.^2).^2+(1.563*f-0.0368*f.^3).^2));
df=f(2)-f(1);

for i=1:length(f)
    if i==1
        W=2*Gc(i)*B(i)^2*df;
    else
        W=W+2*Gc(i)*B(i)^2*df;
    end
end
(W)^(1/6.67)
```

MATLAB Analysis

Here, we assumed the train's frequency response signal as 10*rand(1,length(f)) corresponding to w1 and sin(100./f) corresponding to w2.



MATLAB Analysis

With a response of 10*rand(1,length(f)) and changing the speed of train the value of comfort index is measured

Velocity(Kmph)	Wz
15	1.33
30	1.818
60	2.488
100	3.1246
200	4.2675

Conclusions

- We analysed the value of ride comfort index with velocity and frequency response of the car as parameters
- As velocity increases, it’s observed that the value of Wz increases.
- As road irregularities increase, which would intrinsically increase the disturbance in frequency and it’s observed that Wz increases.
- We inferred from our plots and tables that for better comfort, Wz should be within 2.5.

References

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- http://www.railway-technical.com/suspen.shtml
- https://books.google.co.in/books?id=1mXSBQAAQBAJ&pg=PA62&lpg=PA62&dq=simulation%20of%20railway%20suspension%20system&source=bl&ots=FdOEDwhzty&sig=tzF8xGkrffAkCp3Ul51MmTxDl48&hl=en&sa=X&ved=0ahUKEwjXgvDEg5DMAhWJHZQKHdllApcQ6AEIODAG#v=onepage&q=simulation%20of%20railway%20suspension%20system&f=false
- https://en.wikipedia.org/wiki/Suspension_(vehicle)

Thank you