Sharma. 2016. *Int. J. Vehicle Structures & Systems*, 8(1), 7-10
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.8.1.02

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Evaluation of Passenger Ride Comfort of Indian Rail and Road Vehicles with ISO 2631-1 Standards: Part 2 - Simulation

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ABSTRACT:
In this paper ride comfort of Indian road and rail vehicle is evaluated using ISO 2631-1 comfort specifications. A three wheel vehicle, light four wheel vehicle and general sleeper ICF coach of Indian railway have been evaluated on the basis of 1 hr, 2.5 hrs, 4 hrs and 8 hrs ISO 2631 comfort specifications in seated position as these are the normal duration for passengers. An insight to comfortable ride duration for these vehicles is presented in this paper.

KEYWORDS:
Ride comfort; ISO 2631; Weighted RMS acceleration; Vehicle model; Frequency weightings

CITATION:
R.C. Sharma. 2016. Evaluation of Passenger Ride Comfort of Indian Rail and Road Vehicles with ISO 2631-1 Standards: Part 2 - Simulation, *Int. J. Vehicle Structures & Systems*, 8(1), 7-10. doi:10.4273/ijvss.8.1.02.

1. Introduction

In different countries, a variety of standards or criteria are used to evaluate the ride comfort of rail and road vehicles because it is extremely difficult to establish a single universally applicable international standard for the ride comfort. In this paper, the long-term ride comfort of rail and road vehicles is evaluated using ISO 2631-1 criteria [12]. ISO 2631, which is proposed and revised by the International Organization for Standardization (ISO), has been initiated to evaluate human exposure to whole-body vibration which specifies a RMS based method of evaluation. As per ISO 2631 specifications, the human body is sensitive to shocks and vibrations are different in various frequency range. Therefore different frequency weighting factors are multiplied in RMS acceleration value at each frequency from 0.1 to 100 Hz. These frequency weighting factors are dominant in the frequency range of around 2 to 20 Hz because of human body sensitivity in this frequency range. The overall weighted RMS acceleration is determined in the vertical and lateral direction independently.

In this study, the ride comfort of the roadway vehicles i.e. three wheel vehicle & light four wheel vehicle and general sleeper ICF coach of Indian railway have been evaluated on the basis of 1 hr, 2.5 hrs, 4 hrs and 8 hrs ISO 2631 comfort specifications in seated position as these are the normal duration for passengers. All the vehicles have been modelled to move on the straight track with the speed 80 km/hr (rail), 40 km/hr (three wheeler) and 60 km/hr (four wheeler). In this study, the ride comfort is evaluated by utilising the coupled vertical-lateral model of these vehicles which is formulated using Lagrangian dynamics. In the past coupled vertical-lateral rail and road vehicles have been formulated using Lagrangian dynamics by different researchers [6-11]. However ride comfort evaluation is not carried by all the researchers. In the past, the author has carried out ride comfort, stability and sensitivity analysis of general sleeper/Rajdhani coach i.e. rail vehicle [1-5] and present study is extended to road vehicles.

2. ISO 2631-1 ride comfort criteria

In brief, as per ISO 2631-1 [12], it is specified that weightings factors are applicable in vertical and lateral directions for seating, standing and recumbent passengers. ISO 2631-1 considers RMS acceleration as the basic measure of vibration evaluation and ride comfort may be evaluated through overall frequency weighted RMS acceleration using,

$$a_W = \sqrt{\sum \left(W_f\, a_i\right)^2} \tag{1}$$

Where W_f and a_i are the frequency weighting factor and RMS acceleration in the f^{th} octave frequency band. Guidelines on applicable frequency weightings for comfort as per ISO 2631-1 criteria are given in Table 1. Sensitivity of these weightings for different frequencies are shown in Fig. 1 and basicentric axes of the human body is shown in Fig. 2. The overall frequency weighted RMS acceleration value is calculated in both vertical and lateral directions and combined overall frequency weighted RMS acceleration a is obtained using,

$$a = \sqrt{k_x\left(a_W\right)_x^2 + k_y\left(a_W\right)_y^2 + k_z\left(a_W\right)_z^2} \tag{2}$$

Where k_x, k_y and k_z are the multiplying factors in longitudinal, lateral and vertical direction respectively. Their values as per ISO 2631-1 are 1.4, 1.4 and 1 respectively. The ride comfort index of rail and road vehicles is evaluated as per Table 2.

Table 1: Guidelines to application of frequency weightings with different positions of passengers

Frequency weighting	Comfort
W_k	z - axis, seat surface z - axis, standing vertical recumbent (except head) x -, y -, z - axis, feet (sitting)
W_d	x -, y - axis, seat surface x -, y - axis, standing horizontal recumbent y -, z - axis, seat-back
W_c	x - axis, seat-back
W_e	r_x-, r_y-, r_z- axis, seat surface
W_j	Vertical recumbent (head)

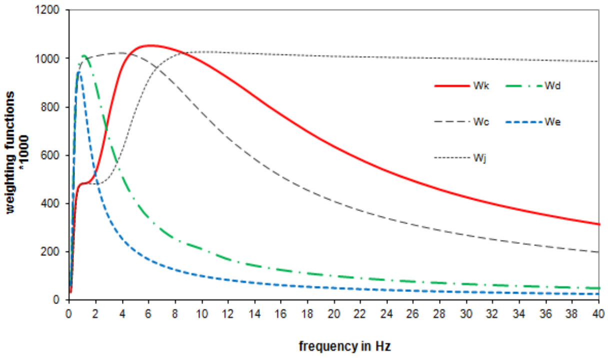

Fig. 1: Sensitivity of frequency weightings with frequency

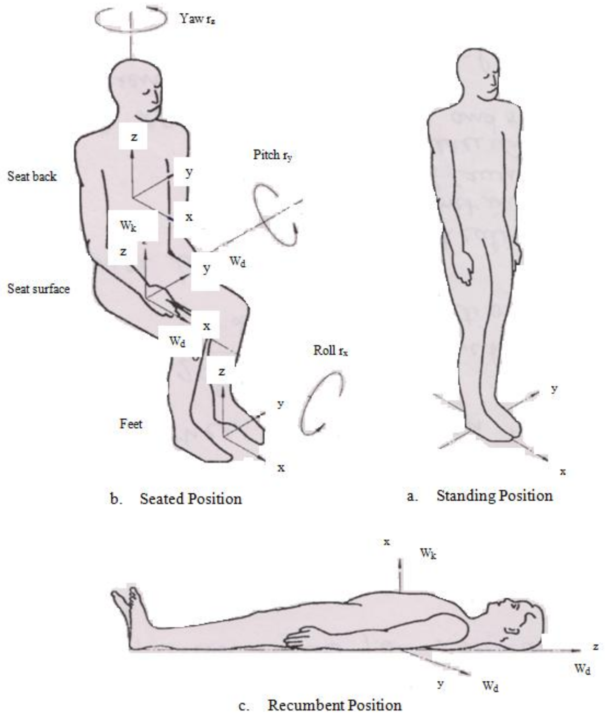

Fig. 2: Basicentric axes of the human body [13]

Table 2: Ride comfort of rail and road vehicle

Vibration	Reaction
Less than $0.315 m/s^2$	Not comfortable
$0.315 m/s^2$ to $0.63 m/s^2$	A little uncomfortable
$0.5 m/s^2$ to $1 m/s^2$	Fairly uncomfortable
$0.8 m/s^2$ to $1.6 m/s^2$	Uncomfortable
$1.25 m/s^2$ to $2.5 m/s^2$	Very uncomfortable
Greater than $2 m/s^2$	Extremely uncomfortable

3. Ride comfort of rail vehicle

The weighted RMS accelerations of loaded car body were obtained by mathematical modeling in vertical and lateral directions. The rail vehicle is considered to be moving at a constant speed of 80 km/hr on a straight track. Since the ride comfort of rail vehicle is evaluated for sitting passengers who normally travel for short journeys. It will be sufficient for the purpose of ride comfort, to consider ISO fatigue decreased proficiency (FDP) boundary from 1 to 8 hrs duration only as this is normally the maximum duration of travel time in a seated posture. With the existing suspension parameters, the overall weighted vertical and lateral RMS accelerations for the frequency range from 1 to 80 Hz are $1.94 m/s^2$ and $1.1 m/s^2$ respectively. The result of weighted vertical RMS acceleration response (Fig. 3) indicates that the response of loaded GS coach lies well within the ISO-2631 comfort criteria except for frequency range from 4 to 18 Hz for 8 hrs comfort. Vertical ride lies in discomfort for frequency range from 5 to 11.5 Hz for 4 hrs comfort and from 8.5 to 10 Hz for 2.5 hrs comfort. Vertical ride is well within the comfort range for 1 hr comfort.

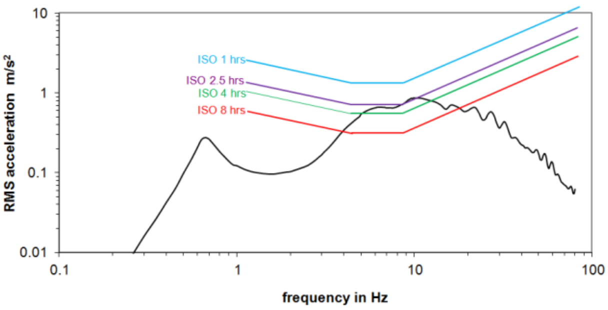

Fig. 3: Weighted vertical RMS acceleration of loaded GS coach

The result of weighted lateral RMS acceleration response (Fig. 4) indicates that the response of loaded GS coach lies well within the ISO comfort criteria except for frequency at nearly 4 Hz for 4 hrs comfort, where the peak value is obtained. After 8 hrs, lateral ride becomes discomfort for frequency range from nearly 3.95 to 4.05 Hz. Lateral RMS acceleration value just reaches the 2.5 hrs comfort boundary at nearly 4 Hz and well within the comfort boundary for 1 hr comfort. Therefore it may be concluded on the basis of present analysis that for Indian railway GS coach discomfort frequency range lies from 4 to 11.5 Hz and improvements in the suspension design are required for 4 hrs comfort. The ride is comfortable for 1 hr ride for all frequency range as per ISO-2631 comfort criteria.

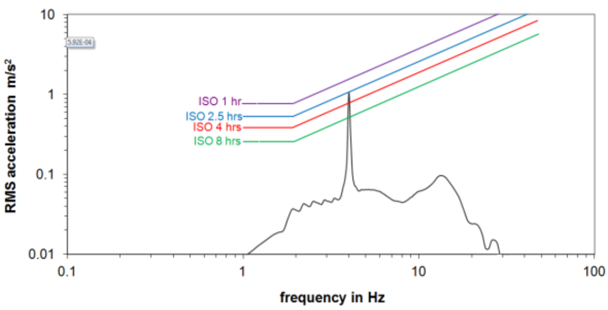

Fig. 4: Weighted lateral RMS acceleration of loaded GS coach

4. Ride comfort of three wheel vehicle

The weighted RMS accelerations of sprung mass of three wheel vehicle were obtained by mathematical modeling in vertical and lateral directions. The vehicle is considered to be moving at a constant speed of 40 km/hr on a straight track. The overall weighted vertical and lateral RMS accelerations of the three wheel vehicle for the frequency range from 1 to 80 Hz obtained from the present analysis are 2.63 m/s^2 and 0.81 m/s^2 respectively. The result of weighted vertical RMS acceleration response (Fig. 5) indicates that the response of three wheeler lies well within the ISO-2631 comfort criteria except for frequency range from 1.8 to 7 Hz and from 8 to 9 Hz for 8 hrs comfort. Vertical ride lies in discomfort for frequency range from 2 to 6.9 Hz for 4 hrs comfort and from 2.2 to 6.7 Hz for 2.5 hrs comfort. Vertical ride is well within the comfort range for 1 hr comfort except for frequency range from 2.5 to 4.1 Hz and 5.5 to 6.1 Hz. The result of weighted lateral RMS acceleration response (Fig. 6) indicates that the response of three wheeler lies well within the ISO comfort criteria except for frequency at nearly from 2.5 to 4.1 Hz for 8 hrs comfort, from 2.8 to 3.1 Hz for 4 hrs comfort. For 2.5 hrs and 1 hr lateral ride lies in comfort range. Therefore it may be concluded on the basis of present analysis that the lateral ride of three wheel vehicle is comfortable in all frequency range up to 2.5 hrs travel.

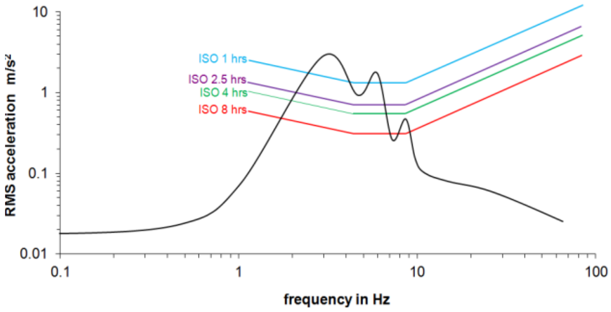

Fig. 5: Weighted vertical RMS acceleration of three wheeler

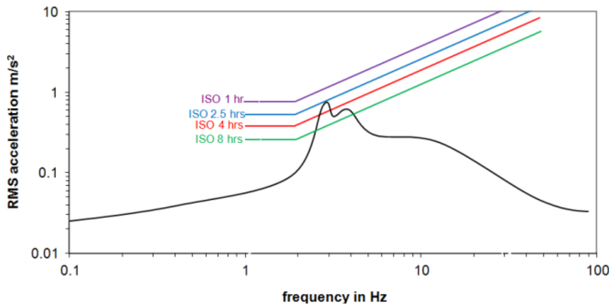

Fig. 6: Weighted lateral RMS acceleration of three wheeler

5. Ride comfort of light four wheel vehicle

The weighted RMS accelerations of sprung mass of four wheel vehicle obtained by mathematical modeling in vertical and lateral directions are shown in Fig. 7 and Fig. 8 respectively. The vehicle is considered to be moving at a constant speed of 60 km/hr on a straight track. The overall weighted vertical and lateral RMS accelerations of the four wheel vehicle for the frequency range from 1 to 80 Hz obtained from the present analysis are 2.33 m/s^2 and 0.61 m/s^2 respectively. The result of weighted vertical RMS acceleration response (Fig. 7) indicates that the response of light four wheeler lies well within the ISO-2631 comfort criteria except for frequency range from 1.5 to 10 Hz for 8 hrs comfort. Vertical ride lies in discomfort for frequency range from 1.8 to 7.1 Hz for 4 hrs comfort and from 1.85 to 6 Hz for 2.5 hrs comfort. Vertical ride is well within the comfort range for 1 hr ride except for frequency range from 1.9 to 2.5 Hz. The result of weighted lateral RMS acceleration response (Fig. 8) indicates that the response of light four wheeler lies well within the ISO comfort criteria except for frequency from 2.9 to 3.1 Hz for 4 hrs comfort and from 2.75 to 3.25 Hz for 8 hrs comfort. For 1 hrs and 2.5 hrs rides, lateral acceleration lies in the comfort range. Therefore it may be concluded that the lateral ride of four wheel vehicle is comfortable in all frequency range up to 2.5 hrs.

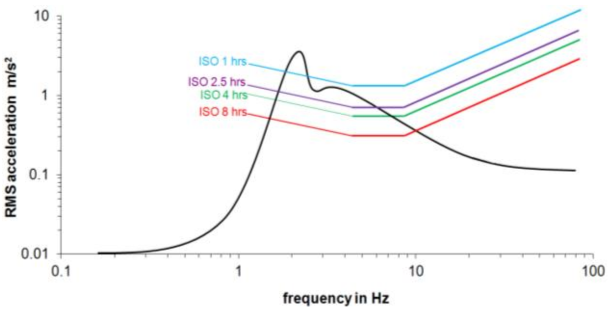

Fig. 7: Weighted vertical RMS acceleration of light four wheeler

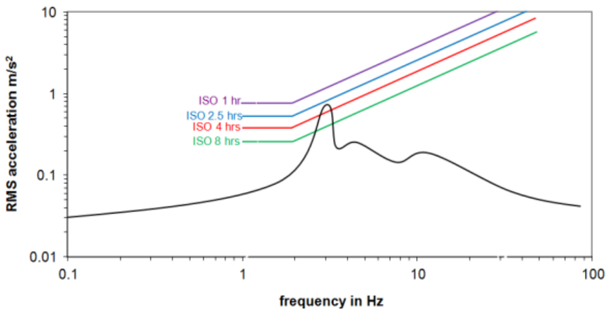

Fig. 8: Weighted lateral RMS acceleration of light four wheeler

6. Results

The overall weighted vertical and lateral RMS accelerations a of the rail vehicle for the frequency range from 1 to 80 Hz obtained from the present analysis are 1.94 m/s^2 and 1.1 m/s^2 respectively. All the vehicles analysed in present analysis are considered to move at constant speed therefore longitudinal ride is not investigated. The ride comfort index obtained for the rail vehicle is 2.336 which indicate the ride is in ‘extremely uncomfortable’ range as per ISO 2631-1 criteria. The three wheeler’s overall weighted vertical and lateral RMS accelerations as obtained from the present analysis are 2.63 m/s^2 and 0.81 m/s^2 respectively. The ride comfort index obtained for the three wheeler is 2.8 which indicates that the ride is in ‘extremely uncomfortable’ range as per ISO 2631-1 criteria. The four wheeler’s overall weighted vertical and lateral RMS accelerations obtained from the present analysis is 2.33 m/s^2 and 0.61 m/s^2 respectively. The ride comfort index obtained for the four wheeler is 2.44 which indicate the ride is in ‘extremely uncomfortable’ range.

7. Conclusions

The ride comfort index of the rail and road vehicles considered in the present analysis lies in 'extremely uncomfortable' range. The rail vehicle ride is comfortable upto 2.5 hrs travel in seating position as comfort boundaries are just crossing weighted vertical RMS acceleration values for this duration. The peak weighted lateral RMS acceleration value is attained at a sharp frequency of 4 Hz therefore lateral ride is not critical as compared to vertical ride. The three wheeler ride is comfortable within 1 hr travel in seating position as comfort boundaries are crossing weighted vertical RMS acceleration values for 1 hr for considerable frequency range for this duration of travel. The light four wheeler is comfortable up to 1 hr travel in seating position as comfort boundaries are crossing weighted vertical RMS acceleration values for 2.5 hrs for wider frequency range as compared to 1 hr duration. In this case, the vertical ride is critical whilst the lateral ride is comfortable for 2.5 hrs travel.

REFERENCES:

[1] R.C. Sharma. 2013. Sensitivity analysis of ride behaviour of Indian Railway Rajdhani coach using Lagrangian dynamics, *Int. J. Vehicle Structures & Systems*, 5(3-4), 84-89. http://dx.doi.org/10.4273/ijvss.5.3-4.02.

[2] R.C. Sharma. 2013. Stability and eigenvalue analysis of an Indian railway general sleeper coach using Lagrangian dynamics, *Int. J. Vehicle Structures & Systems*, 5(1), 9-14. http://dx.doi.org/10.4273/ijvss.5.1.02.

[3] R.C. Sharma. 2012. Recent advances in railway vehicle dynamics, *Int. J. Vehicle Structures & Systems*, 4(2), 52-63. http://dx.doi.org/10.4273/ijvss.4.2.04.

[4] R.C. Sharma. 2011. Parametric analysis of rail vehicle parameters influencing ride behaviour, *Int. J. Engg. Sci. & Tech.*, 3(8), 54-65.

[5] R.C. Sharma. 2011. Ride analysis of an Indian railway coach using Lagrangian dynamics, *Int. J. Vehicle Structures & Systems*, 3(4), 219-224. http://dx.doi.org/10.4273/ijvss.3.4.02.

[6] W.M. Zhai, K. Wang and C. Cai. 2009. Fundamentals of vehicle-track coupled dynamics, *Vehicle System Dynamics*, 47(11), 1349-1376. http://dx.doi.org/10.1080/00423110802621561.

[7] W.M. Zhai, C.B. Cai and S.Z. Guo. 1996. Coupling Model of vertical and lateral vehicle/track interactions, *Vehicle System Dynamics*, 26 (1), 61-79. http://dx.doi.org/10.1080/00423119608969302.

[8] N.S. Nathoo and A.J. Healey. 1978. Coupled vertical-lateral dynamics of a pneumatic tired vehicle: Part 1- A mathematical model, *J. Dynamic System Measurement and Control*, 100(4), 311-318. http://dx.doi.org/10.1115/1.3426383.

[9] N.S. Nathoo and A.J. Healey. 1978. Coupled vertical-lateral dynamics of a pneumatic tired vehicle: Part 2- Simulated versus Experimental data, *J. Dynamic System Measurement and Control*, 100(4), 319-325. http://dx.doi.org/10.1115/1.3426384.

[10] K. Ramji. 2004. *Coupled Vertical-Lateral Dynamics of Three-Wheeled Motor Vehicles*, Ph.D. Dissertation, Dept. of Mech. and Indus. Engg., I.I.T. Roorkee.

[11] K. Ramji and V.K. Goel. 2001. Coupled vertical-lateral dynamics of three-wheeled motor vehicles, *Proc. 17th IAVSD Symposium*, Technical University, Denmark.

[12] ISO 2631. 1997. *Mechanical Vibration and Shock Evaluation of Human Exposure to Whole Body Vibrations - Part 1: General requirements.*

[13] M.J. Grifin. 1990. *Handbook of Human Vibration*, Academic Press, New York.