Analysis of WBV on standing and seated passengers during off-peak operation in KL monorail

K Hasnan1, Q Bakhsh1, A Ahmed1, D Ali1, A R Jamali1
1Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor-Malaysia

Email: qadirquest@gmail.com

Abstract. In this study, the Whole-Body Vibration (WBV) was analyzed on the standing and seated passenger during off-peak operating hours when train was on the track. The experiments were conducted on two car train at one constant location (bogie-1, which is near to driver’s cabin) during downward direction from KL sentral station towards Titiwangsa station. The aim of this study was to analyze that, in which posture of passenger’s exposes the maximum level of WBV. Since, one passenger was performed the whole journey in standing posture whereas, the other passenger was in seated posture. The result obtained from experiments for the RMS accelerations ($A_{rms}$), maximum acceleration ($A_{max}$) and minimum acceleration ($A_{min}$) during the trip. As per standard ISO 2631-1, the daily vibration exposure ($A_d$), Vibration Dose value (VDV) and Crest Factor (CF) of this trip for both standing and sitting orientations were calculated. Results shows that the seated passenger was exposed to longer periods of continuous vibration as compared to the standing passenger. Whereas, the Vibration Dose value (VDV) value was greater than the action value as per ISO 2631-1 and within the limit values. The study concluded that whole body vibration transmitted towards both passengers either standing or seated during their journey. But in overall results comparison of both orientations, the seated passengers gained higher vibration than the standing one.

Keywords. Vibration, Monorail, Whole Body Vibration, Crest Factor, RMS acceleration

1. Introduction
In the field of railway engineering, the monorail is one of well famous transportation system in the field of railway, usually it is used in urban cities. The mono means one and rail means track or beam because it is a rail based transportation system, which is operated on a single rail or beam. In its design, the monorail considered as noiseless and more comfortable ride than the other trains or steel wheeled trains [1]. The monorails have no any road traffic interactions because usually they operated at elevated tracks or beams. Monorails are small or portable, it has the number of cars (2 to 8 cars) are coupled together in a series [2]. In monorail, each car contains two bogies at its front and rear axles. Each bogie equipped with the set of rubber wheels such as; load wheels used for propulsion, brake and guider wheels, which are used to hold or grip the train with track [3].

There are many factors that effects passenger ride comfort, in which the vibration is the fundamental or primary factor [4]. Many people are faced the whole-body vibration (WBV) in their occupational life, specially the drivers and passengers of various vehicles, such as trucks, cars, trains and buses [5]. In whole-body vibration the human body experienced with complex distribution of oscillatory waves and forces. It usually affects the human performance capability by discomfort or annoyance, influences a health and safety risk [6]. In vehicles like car, buses, trucks, trains and airplanes the persons sitting on seat either drivers or passengers are exposed to WBV and exposed to local acceleration at the hand, feet,
back and head [7]. Usually, in vehicles they are drivers, passengers while riding on uneven surfaces and in case of machines they are operators. Also, the human body posture plays an important role in the magnitude of vibration transmission to their body [8]. The WBV usually cause health and safety risk such as; ride discomfort, badly disturb their performance, back pain, shoulder pain, nausea and other health conditions [9]. WBV also effects on many health risks to the human body such as; physiological system, psychomotor and psychological system [10]. Whenever, there is vibration transmission to whole body of human by means of the vibration source matting with the bottom back or feet of human is always considered as whole-body vibration [11].

In WBV, the humans are experienced with the six (6) type of different vibrational motions in three main orthogonal axes x, y, and z-axis, also the rotational motions around x, y, and z directions with the combination of individual motions [12]. Mainly in whole-body vibration exposure, the human body gained the vibration, which transmitted in their body from the seat or floor on that they are standing, or the contact between the machine and the operator from the driver seat [13]. When the drivers or passengers are seated on a fixed seat, the acceleration from the source then be will transmitted from the seat of that the body [14]. Among longitudinal and lateral vibrations, the vertical vibrations (in z-axis directions) are mainly affects the human body in case of WBV. These vertical vibrations are transmitted from the seat or floor to the buttocks and back of the persons along the vertebral axis through the seat pan and back [15]. The continues or long-term exposure to high amplitude WBV is strongly connected with the successive growth of lower back pain in human body [16].

In this study, the experiment was conducted to measure the whole-body vibration behavior for passengers in standing and sitting orientation during peak operation hours. The Human Vibration Meter (HVM-100) with accelerometer pad was used to record the vibration transmission from monorail to human body.

2. Design of experiment
In 2003, SCOMI launched their very first successful project so called KL Monorail with 2 car trains as the Malaysian first monorail system [17]. In its infrastructure and layout, 8.6 km long elevated track was built for KL monorail track with eleven (11) stations in total, which starts from Kuala Lumpur Sentral (KL Sentral) to Titiwangsa [18]. The experiment starts from KL sentral towards the last station Titiwangsa, this whole monorail line was divided into sections. The distance between the stations were named as section, therefore in eleven stations, total ten sections were designed as shown in Figure 1. As per KL monorail operating division, the peak operation hours are 6.30 AM to 9.00 AM and similarly in the evening 4.00 PM to 7.00 PM. Except these peak hours, the remaining all operating hours are Off-peak operation hours.

![Figure 1. KL monorail stations, their subsections and location Bogie-1](image)

2.1. Sitting on seat above bogie
In Figure 1, at position (1) the accelerometer pad was placed on the pan of seat and the passenger was seated on the accelerometer pad during the experiments.
2.2. **Standing above bogie**

In Figure 1, at position (2) the accelerometer pad was placed on the floor and the passenger was standing on it.

3. **Results and Discussion**

3.1. **RMS Acceleration** ($A_{rms}$)

The Root Mean Square Acceleration ($A_{rms}$) was in peak value in standing position during MT to CK stations was obtained 0.389 m/s$^2$ in section D9, while during station RC and BN in the sitting position it was 0.418 m/s$^2$ in section D7. Moreover, the least Arms of this trip was generated 0.222 m/s$^2$ at section D6 in the standing position, whereas in sitting position it was 0.26 m/s$^2$ at section D6 from station BB to RC. The comparative results show that the seated passenger gained high vibration than the standing passenger as shown in Figure 2(a).

3.2. **Maximum Acceleration** ($A_{max}$)

The maximum acceleration ($A_{max}$) during standing position was generated 1.06 m/s$^2$ in section D9, while, in the sitting position it was 1.25 m/s$^2$ at section D10. Furthermore, during the standing position the lowest acceleration was generated 0.538 m/s$^2$ in section D6, since, in the seated passenger it was 0.598 m/s$^2$ in section D4. The comparison of both orientations is shown in Figure 2(b), in which it is clearly noticed that the seated passenger gained high vibration throughout the trip than the standing passenger except only in one section D1.

3.3. **Minimum Acceleration** ($A_{min}$)

The lowest minimum acceleration ($A_{min}$) 0.000772 m/s$^2$ was transmitted to the standing passenger at section D6, while, 0.00042 m/s$^2$ to seated passenger during section D6. Since, the highest Amin was developed during standing position 0.0355 m/s$^2$ at section D7 and in seated passenger it was 0.0271 m/s$^2$ at section D10. Figure 2(c) shows the comparison of both standing and sitting positions, in which the standing passenger gained highest vibration during eight sections (D1 to D8) than the seated passenger.

3.4. **Daily vibration exposure** ($A_8$)

According to the equation:

$$A_8 = kA_w \left[ \frac{\tau}{T_0} \right]^{1/2}$$

the daily vibration exposure ‘$A_8$’ was calculated for all sections during standing and sitting position passengers, the comparative results are shown in Figure 2(d). The maximum $A_8$ value in standing position was measured 0.0244 m/s$^2$ in section D9 and in seated passenger the daily vibration exposure was 0.026 m/s$^2$ in section D9.

3.5. **Vibration Dose Value** (VDV)

The VDV was calculated by the equation

$$VDV = \left[ \int_0^T a^4(t)dt \right]^{1/3}$$

for the standing and sitting position. The maximum VDV in standing position was obtained 1.95 m/s$^1.75$ in section D2, while in sitting orientation, it was 2.05 m/s$^1.75$ in section D10. Similarly, the highest vibration is transmitted to the seated passenger than the standing one as shown in comparative graph in Figure 2(e).

3.6. **Crest Factor** (CF)

The CF for standing and seated passengers was calculated by equation

$$CF = \frac{a_{peak}}{a_{rms}}$$

the comparison graph is given in Figure 2(f). The maximum CF was obtained 5.718085 for standing passengers in section D8 and the for seated passengers the maximum CF value was 5.831325 during section D8. In both orientations the maximum crest factor value is less than 6, it means the ride was comfort as per standard.
4. Conclusion

The passengers who are seated on seat have experience of high vibration magnitudes because during the sitting condition the area in contact is high. While, in the case of the standing passengers the vibration transmission is less. Therefore, the results show that there is a difference in standing and sitting orientations. This is all because of the contact surface between the passangers and monorail body. Since, the overall daily vibration exposure of both orientations has difference but both values are under exposure limit value as per standard. In this study, the overall trip vibration exposure ‘A8’ was obtained during the sitting position 0.204 m/s² while, during the standing position it was 0.1819 m/s². As per the standard, VDV limit and action values should be 9.1 m/s¹/² and 21.0 m/s¹/², whereas in this study, the overall trip vibration dose value was 15.05 m/s¹/² during standing position, and in sitting it was 16.81 m/s¹/². Moreover, the crest factor value as per standard if exceeded from 6 that means the ride during that location or trip was not comfort. Therefore, it is concluded here in this study, that on same location (at bogie-1), same route (from KLS to TW station) and same operation hours (off-peak) the whole-body vibration magnitude that transferred to the passengers during sitting orientation is more than the standing orientation. Thus, it is concluded that the standing passengers has less exposure of WBV on their body as compared to the seated passengers.
5. Acknowledgement
The Authors would like to thank the Universiti Tun Hussein Onn Malaysia for financially supporting of this study.

6. References
[1] Kennedy R R 2010 Monorail Rapid Transit Considering Monorail Rapid Transit for North American Cities.
[2] Wang B 2003 Constructability Analysis of Monorail Project Pre-Project Planning & Constructability Analysis.
[3] Lee C H, Kim C W, Kawatani M, Nishimura N and Kamizono T 2005 Dynamic response analysis of monorail bridges under moving trains and riding comfort of trains J. Engineering Structures, 27(14), 1999–2013.
[4] Kim Y G, Choi S, Kim S W, Kim Y M and Park T W 2009 An Experimental Study on the Ride Comfort of the Korean High-Speed Train J. Experimental Techniques, 33(December), 30–37.
[5] Đumić M, Lučić J and Milić Ž 2002 Some Aspects of the Investigation of Random Vibration Influence on Ride Comfort J. Sound Vib; 253(1):109–28.
[6] ISO 1997 Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1 International Standard Organization (ISO).
[7] Griffin M J 1990 Handbook of Human Vibration Elsevier Science Academic press UK.
[8] Ismail A R, Nuawi M Z, How C W, Kamaruddin N F, Nor M J M and Makhtar N K 2010 Whole Body Vibration Exposure to Train Passenger American Journal of Applied Sciences 7(3), 352-359.
[9] Mcphee B, Foster G and Long A 2001 A handbook on whole body vibration and exposure in mining The Joint Coal Board Health & Safety Trust Sydney, Australia.
[10] Sayed M E, Habashy S and Adawy M E 2012 Evaluation of Whole-Body-Vibration Exposure to Cairo Subway (Metro) Passengers Global Advanced Research Journal of Engineering, Technology and Innovation, 1(7), 168–178.
[11] Sylvester A A 2009 Evaluation operator whole body vibration and shock exposure in South African open cast mine University of Pretoria. MS Thesis.
[12] Rao S S 2010 Mechanical Vibrations Pearson Education, (Fifth edition).
[13] Farhana L 2008 The Effect of Whole Body Horizontal Vibration in Position Sense and Dynamic Stability of the Spine University of Kansas. MS Thesis.
[14] Falou W E, Duchêne ., Grabisch M, Hewson D, Langeron Y and Lino F 2003 Evaluation of driver discomfort during long-duration car driving J. Applied ergonomics, 34(3), 249-255.
[15] Cann A P, Salomoni A W and Eger T 2004 Predictors of whole-body vibration exposure by highway transport truck operators J. Ergonomics, 47(13), 1432-1453.
[16] Limerick R B and Lynas D 2016 Long duration measurement of whole-body vibration exposures associated with surface coal mining equipment compared to previous short-duration measurements J. of Occupational and Environmental Hygiene 13, 339-345.
[17] Scomi 2017 About Monorail: Scomi Rail Retrieved March 26, 2017, from, http://www.scomirail.com.my/monorail.htm.
[18] Prasarana 2014 Maintenance manual, Technical manual of bogie Kuala Lumpur: Technology, Monorail Malaysia.