Analysis of Passengers Ride Comfort Based on Smartphone Vibration Measurement for Chengdu Metro

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Abstract— Whole-body vibration transmission influences comfort, performance, and long-term health of the metro passengers. Here in Chengdu, Metro is a major transportation system which is why this study has an objective of, analyzing ride comfort level passengers based on international standard ISO 2631-1 (1997). Transmission of vibration on passengers was measure in three lines (line 3, 4 and 7) using a smart phone application called Digital Metro. The application is used to collected acceleration data from different location of the train and passengers sitting location and position. According to ISO 2631-1 (1997), results indicate that, passengers are not likely to be uncomfortable during all trip except two locations that were found to be fairly uncomfortable in line seven and line four routes, which is, the vector sum result were 0.659 m/sec^2 and 0.516 m/sec^2 respectively on a seat-pan location. It also shows that the vibration acceleration value is much higher on seat-pan location compered to floor location and vibration transmitted along mainly the vertical direction. Also it can be seen that the highest values of the acceleration were found from the z-axis, it reaches up to 0.381 m/sec^2.

Keywords— Ride comfort; Vibration transmission; whole body vibration; Acceleration root mean square; vibration dose value.

I. INTRODUCTION

Trains are becoming an important part of the passenger's in day to day life activities. Information concerning the response of passengers to a train has become gradually important for use in the development of new transportation system. Train offers a safe and fast way of transportation. Because of high demand for quality service, railway companies are forced to meet more restrictive and severe specifications to meet the demand of passengers. Passengers ride comfort using rail vehicles is determined by the collective effects of vibration, noise, temperature, humidity, light, seat texture, height of ceiling, view, ventilation, etc. Accordingly, studies on ride comfort can be categorized into the measurement of physical quantities that affect ride comfort, and the measurement of human reactions and consciousness. In latter cases, it is very challenging to evaluate ride comfort quantitatively by in view of all factors, since the feelings of each passenger along with various factors that affected ride comfort were dissimilar. Therefore, vibration accelerations are generally effective in evaluating ride comfort of railway vehicles. [1]

Vibration is complex because it is containing many frequency and effect of whole body vibration exposure causes a complex distribution of oscillatory motion and forces within the body that led to discomfort sensation and health effect [2]. Usually WBV occurs in seated postures while people are driving the vehicle or passenger were used transportation system [3]. Its appears that locomotive engineers and conductors are working in a unique environment with likely exposure to significant WBV and shocks depending on locomotive design, train speeds, and operational tasks [4] [5]. WBV gained by human body increased when the duration of vibration exposure and total train trips experienced by the subject enlarged [6]. As the speed of the train increases the vibration magnitudes will also increase. Reducing the train speed can decrease the vibration exposure of the persons in the train but this will result in an escalation in the travel time. Neither the railway line nor the passengers will like it [7].

Ride comfort is a dynamic performance characteristic of railway vehicle and its affected by a variety of elements such as temperature, noise, humidity, smell, and visual stimuli and vibrational however it's challenging to consider all component simultaneously S [8]. The passenger comfort related to vibrations is vital importance among the variety factors concerned in comfort evaluation. The quantity that is relevant to the vibration aspect of ride comfort is the acceleration that uncovered to the passenger throughout the motion of railway vehicle. (Abqari et al., n.d.) [9]

According to Griffin & Erdreich [10] when magnitude of vibration is increased, there is possibility growing in discomfort. In addition, at low frequencies the force that acting on the human body is proportionally with the input of acceleration transmitted to the entire body.

Simonyi et al. [12] says the "smartphone-world" is expanding with an relatively speedy pace; in 2012 already about 80% of the world's population owned some type of an intelligent device according to Go-Gulf web-application and development website (2012). Smartphone-world, therefore, is a huge market and facilitates practical measurements and data collection based on the built-in sensors on a range of scales. The built-in sensors, which currently can be observed in most smartphones include among others GPS sensors and accelerometers. used smartphones equipped with built-in accelerometers for recognizing easily daily activities of subjects. [13] [14]

This study analysis passengers comfort through the general evaluation of Whole body vibration for passengers, based on ISO 2631-1-1997 focusing on through calculating the root mean square value for the three orthogonal directions and the vector sum as well as vibration dose value.

II. MATERIALS AND METHODS

A. Whole Body Vibration Measurements

There are now accepted international standards for evaluation of human exposure to vehicle vibrations. ISO2631-1 (1997) standard defines measurement methods for measuring periodic, random and transient vibration affecting the human body as a whole. And it also defines measurement methods and provides health risk prediction in case of the multiple shocks. These standards summarize factors that determine separately or in combination the degree to which a vibration exposure will be acceptable for humans. [2]

WBV that absorbed by human body will improved when the magnitude of vibration exposure experienced by passenger is increased. Moreover, generally vibration factors from train cause by indelicate track passed via train, train operation fashion and speed of the train [11].

Vibration measurements were done according to the measuring procedure outlined in ISO 2631-1 (1997). Acceleration levels were measured on the passenger seat and on the floor beneath the seat, in three perpendicular directions (x - longitudinal, y - transverse, z – vertical, (see Fig. 1).

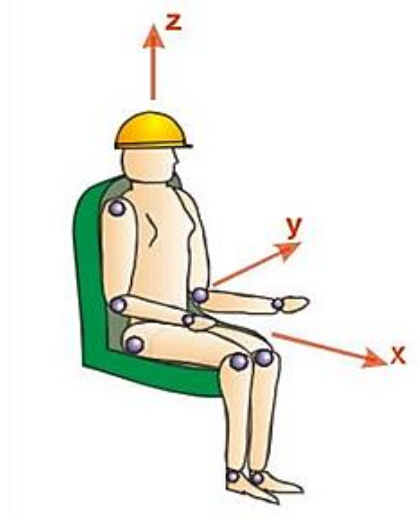


Fig. 1 Sitting position Griffin & Erdreich, 1991 [10]

B. Test Route

For the purpose of this study, three randomly selected routes were used to measure and evaluate the whole body vibration. The measurement was conducted during non-peak hours.

First route that is used for whole body vibration measurement was metro line 7. This metro line was open for public service in December 6/2017. It is the first circular metro line running across the central areas of Chengdu, it is also the longest among all metro station have been opened containing 31 stations it stretches 38.6 kilometers circularly between the second and the third ring roads. The measuring time for the first route test took about 20 minute and the total stations covered on this rout was 11 station.

The second route used for whole body measurement was Chengdu metro line 3. This metro line stretching in the southwest-northeast direction is a trunk line of the local subway system. It passes the core area of the city's CBD (Central Business District) and mainly serves the Shuangliu, Wuhou, Jinjiang, Chenghua, Jinniu and Xindu Districts. The whole line will connect the Shuangliu West High-speed Railway Station and Xindu East Railway Station. The operating route, which is the phase one of Chengdu metro line 3, passes 17 stations for a distance of 12 miles (20 kilometers). It runs between Taipingyuan and Military General Hospital with the cost of CNY2-4. The phase two and three of line 3 are expected to serve the public in early 2019.

The measuring time for the second route and the total stations covered for the measurement of whole body vibration was about 17 minute and 9 station respectively.
Extending in the east-west direction, Chengdu metro line 4 was the third route used for whole body vibration test. It is the third metro in the city following line 1 and line 2. It covers a distance of 40 km (25 mi) and passes 30 stations, linking Wannianchang and Intangible Cultural Heritage Park. Passengers can easily transfer to metro line 1, line 2 and line 3, respectively at stations of Luomashi, Chengdu University of TCM & Provincial People's Hospital and 2nd People's Hospital. Chengdu subway line 4 passes West Railway Station, Luomashi Commercial Zone, and several attractions such as Wide and Narrow Alley, Cultural Park, Sichuan Museum and Intangible Cultural Heritage Park. The measuring time for the third route and the total stations covered for the measurement of whole body vibration was about 15 minute and 8 station respectively.

C. Data Acquisition Recording

Data acquisition was performed using smartphone application that is named Digital Metro specifically developed to measure vibration in all three orthogonal directions (x, y, z) for both locations, seat pan and floor location.
According to ISO 2631-1 (1997) the duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed [2] There for the duration of the measurement for route one, route two and route three were about 20 min, 17 min and 15 min respectively (see Table 3.1)

D. Digital Metro Smartphone Application

Digital Metro is a smartphone application that is specifically designed and developed to measure noise and vibration on trains (see Fig 3.4 & 3.5). This application was developed by team of PhD and MSc students in Civil Engineering department majoring in High speed railway in southwest Jiaotong University.

The application can only be installed using Smartphones equipped with GPS and accelerometer sensors. Also, the smartphone must be android operating system as well as it is expected to have enough memory and good capacity of ram for best applicability. For this study six Xiaomi smartphones were used to measure the vibration. Each selected carriage has two smartphones to measure and collect the vibration data from seat-pan and floor for a seated passenger. The smartphones were fixed on the seat-pan and floor of the passenger's seat in each of selected carriages. Three students were willing to participate in the measuring process and they were also being part of passengers. Adhesive tape was used at the back of the smartphone to firmly fix the smartphone on the floor for feet location and on the surface of the seat to avoid any unnecessary movement that could occur during the travel.

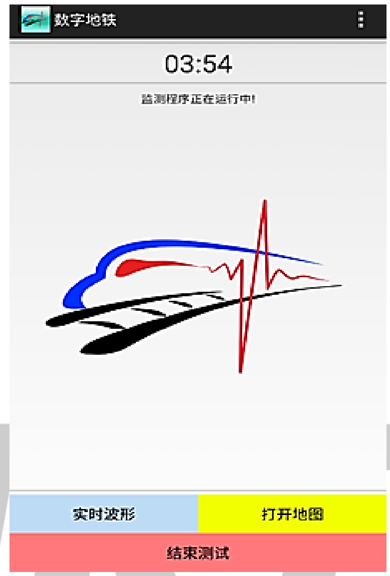


Fig. 2. Digital Metro

During measurements it is assumed that the smartphone will always be lying on its back with the z axis facing upwards, and the x axis facing to the direction or position of passenger seating and y axis towards the direction train movement (see Fig 3). For the readings to be reasonably accurate in this assemblage, the smartphone has to be firmly placed on the seats and floor of passenger's seat on each of selected carriages.

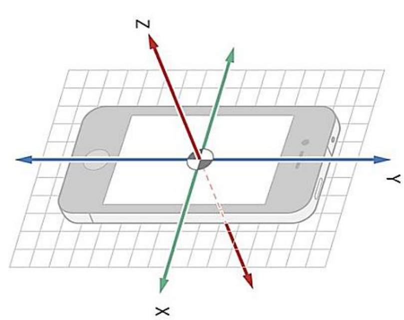


Fig. 3. The coordinate system used in acceleration measurement

ISO 2631-1 1997 standard requires that a device that is used for the purpose of measuring vibration, should be able to measure up to 80 Hz. For this study the Digital Metro application have the capacity to measure vibration up to 100 Hz. As well as measure the acceleration vibration on three orthogonal direction x, y, and z axes. [2]

E. International Standard Parameters

Ride comfort of all the passenger trains were evaluated with respect to ISO 2631 (1997). ISO 2631 provides basic and additional evaluation methods for whole body vibration measurement. Weighted R.M.S acceleration and fourth power vibration dose method is the basic evaluation method to measure passenger's exposure level to vehicle vibration for ride comfort. Guidance with respect to the use of evaluation methods and frequency weightings for comfort provided table 3.3. since this study is focused on whole body vibration form comfort perspective [2] . Basic evaluation method uses frequency weighted R.M.S. accelerations and is defined by:

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}} \qquad (2.1)$$

where, a_w (t) is the weighted acceleration as a function of time in meters per second square (m/s^2) and T is the duration of the measurement, in seconds. The standard defines the total vibration value of acceleration R.M.S for all directions in respective position. As per ISO-2631,

Table 1 gives approximate indications of likely reactions to various magnitudes of overall vibration values in public transport. When evaluating comfort, it is recommended that the combined vibration of the three axes be used including multiplying factors. (See table 3.3).

Table 1. Perception of ride comfort according to ISO263 1[2]

Perception	R.M.S vibration Level
Not uncomfortable	Less than 0.315m/s^2
A little uncomfortable	0.315 m/s^2 to 0.63 m/s^2
Fairly uncomfortable	0.5 m/s^2 to 1 m/s^2
uncomfortable	0.8 m/s^2 to 1.6 m/s^2
Very uncomfortable	1.25 m/s^2 to 2.5 m/s^2
Extremely uncomfortable	Greater than 2 m/s^2

F. Data Analysis

After the measurements were completed, the collected data manually uploaded to the smartphone storage, from there, the collected data were transferred from the smartphone using USB cable to a laptop computer. There for the acceleration Root Mean Square (R.M.S) and vibration dose value (VDV) where calculated based on ISO 2631 MATLAB software and the vector sum of axis Microsoft Office Excel 2016.

A MATLAB script that was prepared as per ISO 2631-1 (1997) for acceleration time history data was used for calculating acceleration RMS and VDV values for each axis.

The time required for fitting the smartphone and the data acquisition system was less than 30 seconds and as it was mentioned above for measuring the acceleration data from 15 to 20 minutes for all routes.

As suggested by Mansfield and Atkinson [3] a minimum of 10 minutes is required to record data. All the data time histories were recorded in m/s2 in acceleration form file format.

Generally, the procedures and methodologies in the computation of parameters in the ISO 2631-1 (1997) standards were outlined and the parameters were also properly defined.

In RMS acceleration assessment showing vector sum of acceleration during assessment period, the triple axes were mixed/ combined to one another with calculating the second root of total acceleration squares.

This combination is calculated with equation (2.3) for RMS acceleration amounts with the use of ISO 2631 method;

$$a_{xyz} = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \qquad (2.2)$$

In this equation: a xyz: is the root of total weighed-frequency squares, and a show the weighed accelerations in x, y, and z axes, respectively; kx, ky, and kz, also show the relevant coefficient for a seated person emphasizing comfort, which is, for x, y and z axes, multiplying factor is 1 in seat pan location, and 0.25 for x and y axes, 0.4 for z axis in floor (feet) location.

III. RESULTS

a) First Route Result

As Table 2 show, the first route calculated results for Line 7, the Vector sum RMS measurements in seat pan and floor location for first carriage equals 0.444 m/sec2 and 0.171 m/sec2, for middle carriage the seat pan and feet location RMS amounts are,0.417 m/s2 and 0.172 m/sec2 respectively also the RMS result for last carriage is 0.659 m/sec2 for seat pan location and 0.174 m/sec2 for floor location. Also, vibration dose value (VDV) was calculated for each of axes in each location to provide an alternative measure for vibration.

In order to calculate the average root, mean square value, from comfort perspective, ISO 2136-1 1997 specifies that, the results that are collected from each axis should be used to calculate using the coefficient or multiplying factors for each of axis (see eq. 2.1).

These multiplying factors are, multiplying factor 1 should be used in all orthogonal axis for a seat surface but for a floor surface in a setting position, 0.25 for x and y axis and 0.4 in z axis are the multiplying factors.

Also, ISO 2136-1 1997 suggests that, the average root mean square should only be calculated using eq. 4.1, if there is no a dominant axis from the three orthogonal axes. In this study there is no a dominant axis as mentioned above, all the measurement results are used to calculate the average root mean square. This applies for each of routes in this study.

The largest Root mean square acceleration results in the first carriage is found to be, 0.327 m/sec2 for seat-pan location in z-axis and 0.39 m/sec2 for floor location in y-axis. For middle carriage, 0.327 m/sec2 and 0.345 m/sec2 are the largest results for both seat pan and feet location in z and y axis respectively.

For end carriage, for seat pan location x-axis result is the highest which is, 0.529 m/sec2 and for feet location y-axis was the highest which is, 0.437 m/sec2 (see table 2).

The maximum vibration dose value for the first rout in the first carriage is found to be in z-axis on a seat pan location and also z-axis has maximum result on feet location (0.779 m/sec2 and 0.821 m/sec2) respectively.

For middle carriage, 0.772 m/sec2 and 0.814 m/sec2 is the highest for both seat pan and feet location. For end carriage, x and z-axis has the highest result for both seat pan and floor location which is 0.971 m/sec2 and 0.783 m/sec2 respectively. (see Table 2

Table 2. Results of calculated vibration for route one line 7

					RMS			**TOTAL**	**VDV**		
	No.	**Carriage**	**Location**	**Measuring Time**	**X**	**Y**	**Z**	**A_{Xyz}**	**X**	**Y**	**Z**
LINE SEVEN	1	First Carriage	Floor	20	0.082	0.39	0.347	0.17	0.218	0.51	0.82
	2	First Carriage	Seat Pan	20	0.281	0.107	0.327	0.44	0.576	0.11	0.78
	3	Middle Carriage	Floor	20	0.054	0.407	0.345	0.17	0.093	0.54	0.81
	4	Middle Carriage	Seat Pan	20	0.231	0.118	0.327	0.42	0.454	0.17	0.77
	5	End Carriage	Floor	20	0.075	0.437	0.334	0.17	0.192	0.69	0.78
	6	End Carriage	Seat Pan	20	0.529	0.101	0.381	0.66	0.971	0.13	0.78

Table 3. Results of calculated vibration for route one line 3

					RMS			TOTAL	VDV		
LINE THREE	**NO.**	**Carriage**	**Location**	**Measuring Time**	**X**	**Y**	**Z**	**A $_{Xyz}$**	**X**	**Y**	**Z**
	1	First Carriage	Floor	17	0.122	0.376	0.35	0.171	0.392	0.479	0.79
	2	First Carriage	Seat Pan	17	0.332	0.095	0.337	0.482	0.65	0.119	0.76
	3	Middle Carriage	Floor	17	0.072	0.383	0.351	0.170	0.145	0.494	0.8
	4	Middle Carriage	Seat Pan	17	0.275	0.103	0.333	0.443	0.52	0.135	0.75
	5	End Carriage	Floor	17	0.0085	0.38	0.339	0.165	0.16	0.505	0.78
	6	End Carriage	Seat Pan	17	1.80E-06	0.108	0.344	0.360	0.0003	0.147	0.76

Table 4. Results of calculated vibration for route one line 4

					RMS			TOTAL	VDV		
LINE FOUR	**No.**	**Carriage**	**Location**	**Measuring Time**	**X**	**Y**	**Z**	**A $_{Xyz}$**	**X**	**Y**	**Z**
	1	First Carriage	Floor	15	0.153	0.134	0.355	0.151	0.34	0.22	0.75
	2	First Carriage	Seat Pan	15	0.162	0.155	0.332	0.401	0.29 1	0.28	0.7
	3	Middle Carriage	Floor	15	0.076	0.105	0.365	0.15	0.13 2	0.14	0.77
	4	Middle Carriage	Seat Pan	15	0.1	0.37	0.346	0.516	0.12 7	0.66	0.73
	5	End Carriage	Floor	15	0.025	0.099	0.354	0.144	0.04	0.13	0.74
	6	End Carriage	Seat Pan	15	0.21	0.116	0.352	0.426	0.38 6	0.19	0.74

b) Second Route Result

Table 3 show, the results of second route Line 3. Vector sum root mean square calculation results in seat pan and feet location for first carriage equals 0.482 m/s2 and 0.171 m/s2, for middle carriage the seat pan and feet location RMS amounts are, 0.444 m/s2 and 0.171 m/s2 respectively also the acceleration RMS result for end carriage is 0.361m/s2 for seat pan location and 0.166m/s2.

The largest Root mean square acceleration results in the first carriage is found to be, 0.337 m/sec2 for seat-pan location in z-axis and 0.376 m/sec2 for floor location in y-axis. For middle carriage, 0.333 m/sec2 and 0.383 m/sec2 are the largest results for both seat pan and feet location in z and y axis respectively. For end carriage, for seat pan location z-axis result is the highest which is, 0.344 m/sec2 and for feet location y-axis was the highest which is, 0.38 m/sec2. (see table 3)

The maximum vibration dose value for the first rout in the first carriage is found to be in z-axis on a seat pan location and also z-axis has maximum result on feet location (0.79 m/sec2 and 0.76 m/sec2) respectively.

For middle carriage, 0.75 m/sec2 and 0.8 m/sec2 is the highest for both seat pan and feet location. For end carriage, x and z-axis has the highest result for both seat pan and floor location which is 0.76 m/sec2 and 0.78 m/sec2 respectively. (see Table 3)

c) Third Route Result

Table 4.3 show, the Vector sum root mean square results for the third route which is Line 3 are, 0.400 m/s2 and 0.150 m/s2 in seat pan and feet location for first carriage respectively, for middle carriage the seat pan and feet location RMS amounts are, 0.516 m/s2 and 0.149 m/s2 last but not least acceleration root mean square result for end carriage is 0.426 m/s2 for seat pan location and 0.144 m/s2. The largest Root mean square acceleration results in the first carriage are found to be, 0.332 m/sec2 for seat-pan location in z-axis and 0.355 m/sec2 for floor location in z-axis. For middle carriage, 0.37 m/sec2 and 0.365 m/sec2 are the largest results for both seat pan and feet location in y and z-axis respectively. For end carriage, for seat pan location z-axis result is the highest which is, 0.352 m/sec2 and for feet location z-axis was the highest which is, 0.354 m/sec2. (see table 4)

The maximum vibration dose value for the first rout in the first carriage is found to be in z-axis on a seat pan location and also z-axis has maximum result on feet location (0.7 m/sec2 and 0.75 m/sec2) respectively. For middle carriage, 0.73 m/sec2 and 0.77 m/sec2 is the highest for both seat pan and feet location. For end carriage, x and z-axis has the highest result for both seat pan and floor location which is 0.74 m/sec2 and 0.74 m/sec2 respectively. (see Table 4)

IV. DISCUSSION

Measurement durations pertaining to the data collection process were divided into three routes. The ISO standard instructs that the dominant axis may be used to compare for vibration exposures to statutory limits. If no dominate axis is present, the vector sum may be used in order to evaluate exposure. Even though z-axis is the dominant axis for third route which a line 4 (see table 4), it cannot be said same for the first route and second route line 7 and line 3 because there is a result that shows y-axis was dominate (see table 2 and 3). Therefor there was no maximal WBV was obtained in any of axes, the data obtained from all axis was assessed and used to calculate the obtained vector sum parameters.

Passengers comfort is evaluated based on the above parameters, not uncomfortable, little uncomfortable, fairly uncomfortable, uncomfortable, very uncomfortable and extremely uncomfortable based on ISO 2631-1 (1997). The evaluation parameters depend on the calculation results of vector sum of acceleration root mean square of all axis. ISO 2631-1 (1997) implies that comfort reaction depends on passenger’s expectation with regard to trip duration and the type of activities passengers expect to accomplish (e.g. reading, eating, writing, etc.) there for ISO gives approximate indications to evaluate passengers comfort reaction (see table 4). Based on this idea table 5 shows that passengers comfort reaction for each of tested routes in both locations. Most the vector sum root mean square result shows, passengers are not likely to be uncomfortable during the all trip except two locations that were found to be fairly uncomfortable in line seven and line four routes, although it also shows that the vibration acceleration value is much higher on seat-pan location than floor location and vibration transmitted along mainly the vertical direction. Also, it can be seen that the highest values of the acceleration were found for the z-axis, up to 0.381 m/sec2.

a) Comparison of results based on Carriage

As mansion above the whole-body vibration measurement was done in three specific carriages for each of routes. The reason this carriage was selected was simply to evaluate whether the severity of vibration transmission to the passengers’ body reaches to the extent where it gets to be uncomfortable in different carriages. Chengdu metro train have six carriages, therefor for the purpose of this study three carriage was selected throughout the entire trip, these carriages are: first carriage, middle carriage and End carriage. According to the calculated results of acceleration root mean square and vibration dose value for each axis and the vector sum, there is no a significant difference in result between the selected carriages. Therefor it can be concluded that passengers cannot be affected by sever vibration transmission for using a specific location of carriage during travel.

b) Comparison of Results Based on Testing Location

ISO 2136-1 (1997) suggests three basic testing locations to evaluate whole body vibration specifically for a seated person. These locations are: seat-pan, back rest and floor (feet) location. In this study, seat-pan and floor location was used to evaluate transmission of vibration for passengers in each of routes. Generally, if the vector sum of each axis is evaluated there is a clear difference of vibration transmission between seat-pan and floor (feet) location. Table 6 shows that passengers are unlikely to feel uncomfortable from high amount of vibration from floor (feet) location. On this location, the comment for all results shows not uncomfortable. Since the heaviest part of the human body is placed on the surface of the seat, it is expected that the seat-pan location to have a higher vector sum of root mean square acceleration. Therefor the highest RMS of vector sum was found to be on a seat-pan location for eac of testing routes in each carriage. Even though most of the comments says a little uncomfortable, there was a couple of fairly uncomfortable results in this location.

Table 5 Comments on vector sum of each route

Route	Carriage	Location	Total RMS	Comment on Comfort
Line Seven	First Carriage	Seat-pan	0.444	Little Uncomfortable
		Floor	0.171	Not Uncomfortable
	Middle Carriage	Seat-pan	0.417	Little Uncomfortable
		Floor	0.172	Not Uncomfortable
	End Carriage	Seat-pan	0.659	Fairly uncomfortable
		Floor	0.174	Not Uncomfortable
Line Three	First Carriage	Seat-pan	0.482	Little Uncomfortable
		Floor	0.171	Not Uncomfortable
	Middle Carriage	Seat-pan	0.443	Little Uncomfortable
		Floor	0.171	Not Uncomfortable
	End Carriage	Seat-pan	0.36	Little Uncomfortable
		Floor	0.166	Not Uncomfortable
Line Four	First Carriage	Seat-pan	0.4	Little Uncomfortable
		Floor	0.151	Not Uncomfortable
	Middle Carriage	Seat-pan	0.516	Fairly uncomfortable
		Floor	0.149	Not Uncomfortable
	End Carriage	Seat-pan	0.426	Little Uncomfortable
		Floor	0.144	Not Uncomfortable

a) Comparison of Results Based on Routes

The measurement results that are found in each of routes shows there is no much of difference between routes even though line four is the oldest and line three and seven are the newest metro line in Chengdu. The vibration transmission form z-axis set be higher than x & y axes for each route. Although line four the x and y axis results are the lowest acceleration root mean square compare to line three and line seven (see table 2 to 3). Which means passengers are likely to experience less vibration on x and y axis in line four. Generally, there is no visible difference that circles a danger zone for passengers' comfort between line seven, line three and line four. It is possible for passengers to have almost same vibration perception in most cases.

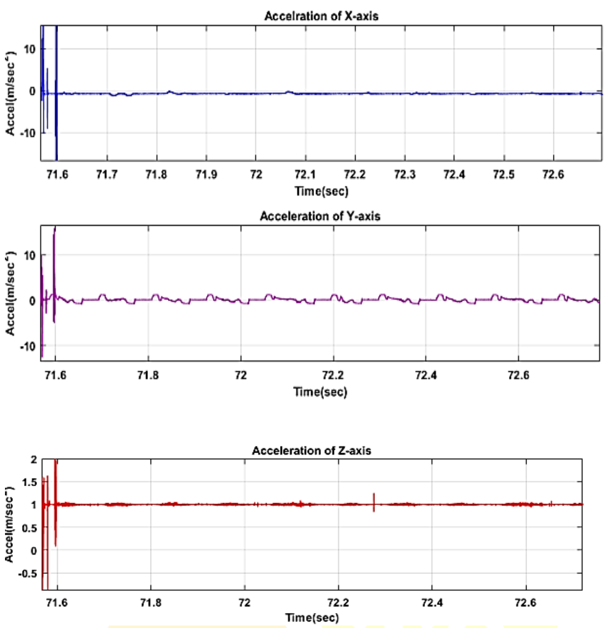


Figure 4 Acceleration for the First carriage seat-pan location in first route

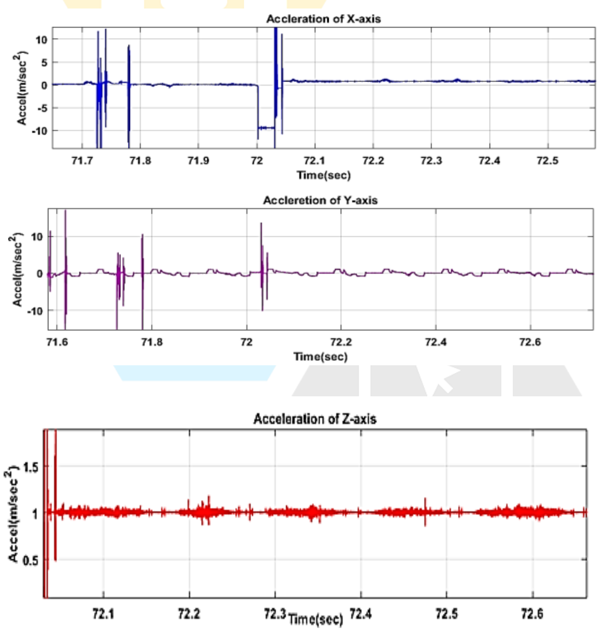


Figure 5 Acceleration for the middle carriage seat-pan location in first route

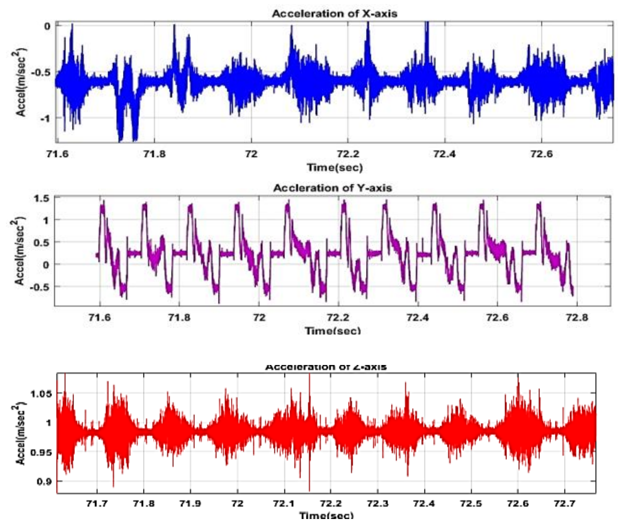


Figure 6 Acceleration for the end carriage seat-pan location in first route

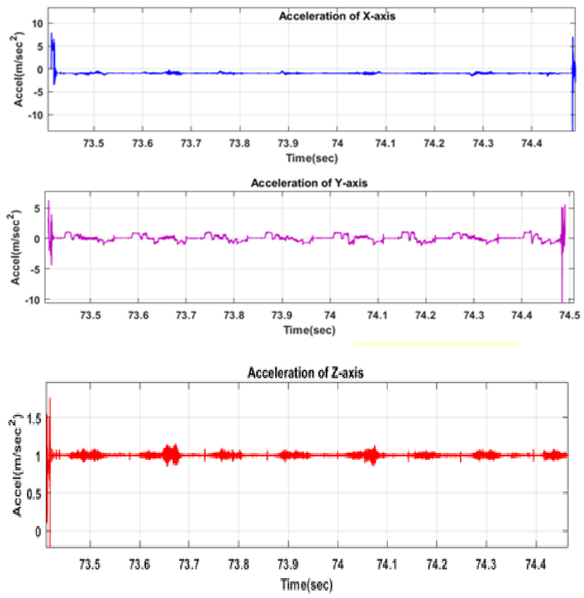
Figure 4 to 6 Graphically summarize the time history plot of acceleration in each axis for seat-pan location for the first route. According to ISO 2136-1(1997), the major measuring location of whole body vibration for a seated person is As well as the measurement As results of this study shows vibration transmission in seat-pan location is much higher than floor location.

V. CONCLUTION

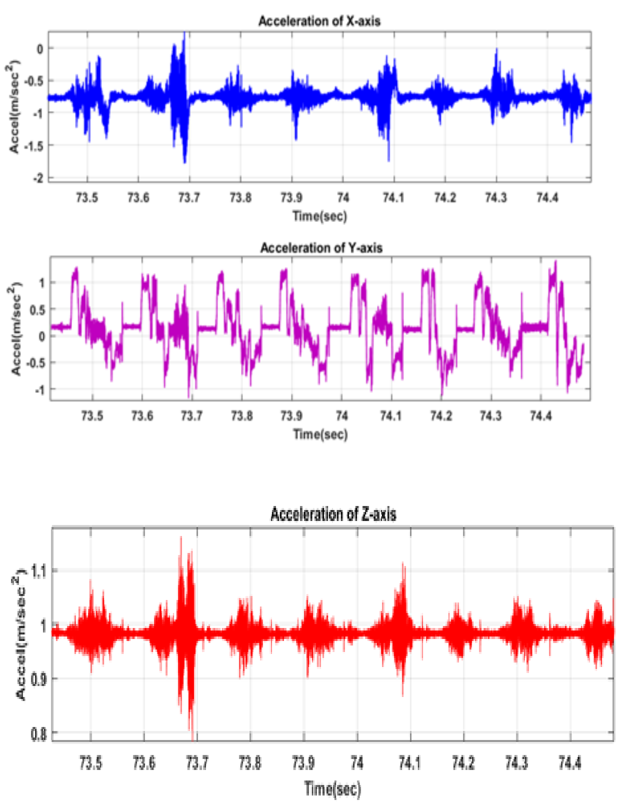
- The techniques that are discussed in this study show a method to calculate expected passenger's comfort from the vibration magnitudes measured.
- Generally, to conclude in this study, it was found that most results of each axis RMS acceleration and their vector sum, Chengdu metro passengers were not within high discomfort zone according to ISO 2136-1 (1997).
- Metro passengers were clearly not exposed to serious magnitudes of whole-body vibration. Although results from seat-pan location are considerably higher compare to floor location means it could occasionally cause some discomfort.

VI. APPENDIX

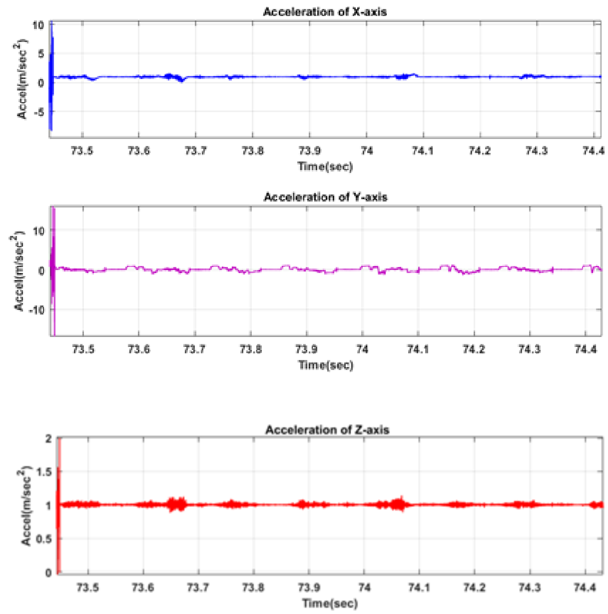
a). Time history of acceleration for x, y & z second route seat-pan location for first carriage



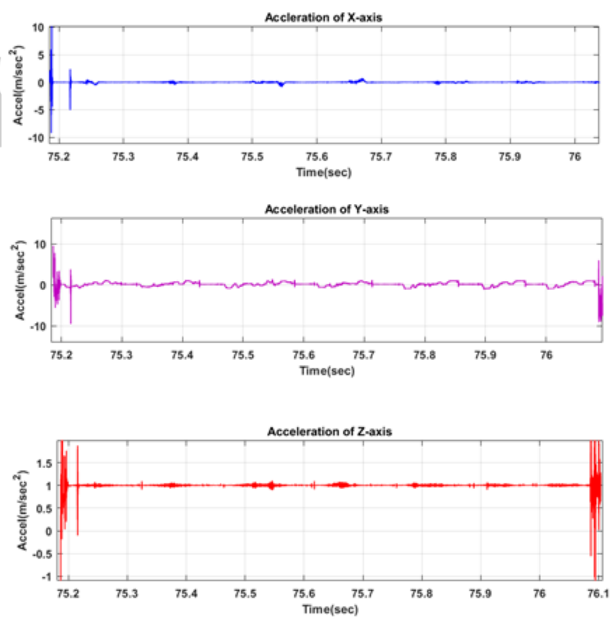
. b). Time history of acceleration for x, y & z second route seat-pan location for second route middle carriage



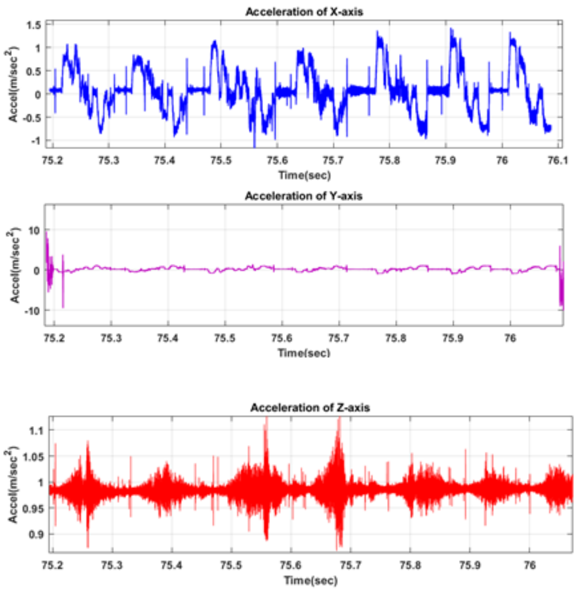
c). Time history of acceleration for x, y & z second route seat-pan location for end carriage



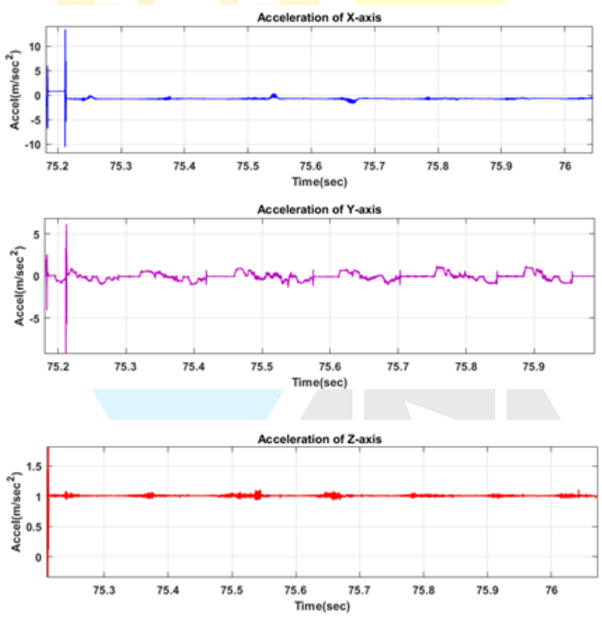
d). Time history of acceleration for x, y & z third route seat-pan location for first carriage



e). Time history of acceleration for x, y & z third route seat-pan location for middel carriage



f). Time history of acceleration for x, y & z third route seat-pan location for end carriage



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