Whole body vibration of the midibus driver with different seating condition

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Abstract. The current study focused on the vibration through the seat of the midibus with different seating conditions to evaluate the comfort of the driver. The vibration dose value (VDV) was the parameter studied with different anthropometric characteristics (mass, stature and BMI) of six male drivers. The seating conditions considered for the study were no backrest (NB), backrest with 90° (B90), backrest with 110° (B110) and backrest with 130° (B130). The test was conducted on a typical highway segment at a constant speed of 40kmph. The VDV on the seat and backrest in all directions (x, y & z) were calculated based on the vibration signal. The statistical significance of VDV of the seat and backrest was carried out using a statistical tool - "Wilcoxon signed rank" test. The correlation of anthropometric data with VDV was evaluated using a “Karl Pearson” correlation technique. The experimental results showed that at B130, the dynamic response of the body to vibration was severe in the x-direction as the resonance frequency varied from 0.92Hz (at NB) to 2 Hz (at B130). It was found that at B90 the ride comfort was good with the lesser VDV of as 3.12m/sec¹.⁷₅ when compared to the B110 and B130.

1. Introduction

Midibus transit operators represent one of the largest working populations in the transportation sections in India and have substantial occupational exposures to Whole Body Vibration (WBV). Nevertheless, very limited data were available on WBV levels experienced by the drivers and passengers of midibus. WBV is the motion transmitted to the human body through the supporting surfaces, i.e. Feet, buttock and back. The effect of WBV depends on the magnitude of vibration, transmission part of the body, vibration frequency, direction and duration. To study the effect of the vibration exposed to the human body many international and national standards is available. The main standard ISO 2631-1 (1997) was used in this research to evaluate the human responses to vibrations.

Though several laboratory studies on whole body vibration were available to study the bio dynamic response at various excitation frequency ranges and magnitudes for seated human bodies with and without backrest, those to study on real road conditions were few. In actual conditions the road excited vibration has shocks and impulsive velocity changes.

The bio dynamic apparent mass response of 12 males and females in the laboratory with the inputs of the white noise vertical vibration of 0.25, 0.5 and 1.0m/s² acceleration in the frequency range 0.5–40Hz on different automotive postures were studied by Rakheja et al., [8] with hands in lap (passengers) and hands on the steering wheel (drivers) postures.

Nawayseh et al., [2], [4] studied the forces in the vertical, fore and aft and lateral direction of
the seat at 4 sitting postures. They found that the backrest reduced forces on the seat at low frequencies and however, forces got increased at higher frequencies. Further, in another similar work, Nawayseh [3] investigated the effect of seat surface angles (i.e. 0°, 5°, 10°, 15°). At all seat angles, both with and without backrest the resonance frequency in the vertical apparent mass was greater than the resonance frequency in the fore and aft cross axis apparent mass. Wang et al., [9] studied in 13 male and 14 female subjects for vertical vibration and the white noise random excitations in the frequency of 0.5-40Hz range with the total rms acceleration values of 0.5 and 1.0m/s² as an input to the exciter. Measurements were performed for a total of 36 different sitting postural configurations viz., 2 hand positions, 3 seat heights, 2 seat pad orientation, 3 back support conditions. Hands in lap posture yielded a larger primary resonant frequency than the hands on the steering wheel posture, when the back is supported with an inclined backrest.

Nawayseh [5] studied the effect of different seating conditions on the transmission of vibration through a sedan car seat. 10 males sat in the passenger seat of a sedan car driven at 60kmph with 6 different seating conditions. The parameters measured were VDV on the seat and backrest which was proved to be more sensitive to the peaks. The VDV is the suitable measurement in road excited vibration assessment. It is calculated by the fourth root of the integral with respect to the time of the fourth power of the acceleration after it has been weighted. Because of the fourth power it is more sensitive to the vibration peaks. Through literature study, it was understood that none of the work considered the effect of seats vibration with and without backrest inclination for midibus drivers. Midibus driver drives the vehicle around 8hrs maximum inside the city on an average speed of 40kmph, in Indian city conditions.

Compare to other countries Indian preferred road laying material has for long been bitumen. It is proven that the resistance of bitumen surfaces and their strength deteriorates rapidly under the influence of aggressive climate and usage conditions. The life of the road condition was very less. There are lot of small and medium size potholes, will create the health issue to the drivers and passenger.

In the current study the urban midibus having the specification of about 5000mm wheel base and commonly used for shuttle services within the city as well as for school services is considered. The objective of this study is to investigate the effect of different seating conditions on the vibrations received by the driver from the seat pad and seat back rest in midi bus and VDV is used to assess the bio dynamic response under the road excited vibration at actual conditions.

2. Instrumentation and Procedure

The study was conducted on an urban midi bus having 120hp engine as shown in the figure 1. Two numbers of ICP type tri axial seat pad accelerometers (Dytran Model 5313A) were used to measure the vibration at the driver’s seat and backrest. The accelerometers were firmly secured to the seat centre from vertical and horizontal direction, to measure accelerations in the fore-and-aft (x), lateral (y) and vertical directions (z). The seat dimensions are height is 856mm, width is 445mm and thickness is 160mm. The seat cushion characteristics are moulded polyurethane foam with density 50kg/m³. A 16-channel data acquisition system (Model: SC360 Make: LMS Scada’s System, Belgium), and a laptop with LMS Test Lab software module was employed for acquiring and analysing the acquired data. The acceleration was acquired in all three directions (x, y, and z) at the seat and backrest positions with a sampling rate of 10 kHz. The experimental setup is also shown in the figure 1.
Six male drivers with different weight (62 - 72kg), stature (158 - 176cm) and BMI (20-28kg/m$^2$) participated in these trials conducted for four conditions, namely no backrest (NB), Back rest at 90$^0$ (B90), Backrest at 110$^0$ (B110), and Backrest at 130$^0$ (B130). During the test the drivers drove the vehicle on the identified highway segment, and for 30-minute vibration measurement were logged during the drive. The driver fixed the height and distance from the ABC pedal, only changing the inclination of the backrest before going for the trial and vehicle speed was maintained at 40kmph, the city traffic speed limit.

Whole body vibration can be evaluated by the main standard i.e., ISO 2631 (1997). According to ISO 2631-1, the continuous WBV exposures include: (i) The weighted root mean square (rms) average weighted vibration ($A_w$) which is extrapolated to an 8-hour daily value $A_{(8)}$ (ms$^2$) and (ii) The VDV which is extrapolated to an 8-hour daily value VDV (8) (m/s$^{1.75}$).

VDV is calculated as given below

$$\text{VDV} = \left[ \int_{t=0}^{T} a_w^4(t) dt \right]^{1/4}$$

(1)

Where $a_w(t)$ is the frequency weighted acceleration and $T$ is the signal duration (60s in this study).

The grand total VDV can be calculated by

$$\text{VDV}_s = (\text{VDV}_{xs}^4 + \text{VDV}_{ys}^4 + \text{VDV}_{zs}^4)^{1/4}$$

(2)

$$\text{VDV}_{bs} = (\text{VDV}_{xbr}^4 + \text{VDV}_{ybr}^4 + \text{VDV}_{zbr}^4)^{1/4}$$

(3)

$$\text{VDV}_{\text{grand total}} = (\text{VDV}_s^4 + \text{VDV}_{br}^4)^{1/4}$$

(4)

Whereas $\text{VDV}_s$ is Vibration dose value on the seat and $\text{VDV}_{br}$ is Vibration dose value on backrest.

VDV measured on the seat and backrest with different backrest conditions are given in the table 1. It also shows the total and grand total VDV. Table 2 gives the average VDV on the seat and backrest in all backrest conditions and figure 2. shows the plots of VDV of seat at different backrest angles.
3. Whole body vibration analysis

3.1 Karl Pearson correlation Analysis

The degree of relationship of physical characteristics such as mass, stature and BMI with VDV can be measured using the well-known correlation analysis called “Karl Pearson correlation analysis. Minitab was used for this analysis. The correlation coefficient $r$ lies between the +1 and -1. If $r=0$, indicates that there is no correlation between the variables. If $r$ is near to +1 then the variables considered are said to be strongly positively correlated and if $r$ value is near to -1 then the variables considered are said to be strongly negatively correlated.

Table 1. VDV Values on the seat and backrest in x, y, and z direction.

| Driver | Condition | X     | Y     | Z     | X     | Y     | Z     | Seat Total | Backrest Total | Grand Total |
|--------|-----------|-------|-------|-------|-------|-------|-------|------------|----------------|-------------|
|        |           |       |       |       |       |       |       |            |                |             |
| 1      | NB        | 3.9   | 6.3   | 3.6   | 0     | 0     | 0     | 6.67       | 0              | 6.67        |
|        | B90       | 3.2   | 5.1   | 3     | 2.1   | 10    | 4.1   | 5.42       | 10.07         | 10.28       |
|        | B110      | 3.7   | 5.7   | 3.2   | 4.6   | 11.4  | 4.8   | 6.06       | 11.56         | 11.77       |
|        | B130      | 4     | 5.8   | 3.5   | 7     | 12.4  | 4.6   | 6.26       | 12.76         | 12.94       |
| 2      | NB        | 3     | 6.2   | 3.4   | 0     | 0     | 0     | 6.41       | 0              | 6.41        |
|        | B90       | 3.2   | 5.7   | 3     | 2.4   | 10.1  | 4.5   | 5.94       | 10.21         | 10.49       |
|        | B110      | 3     | 5.5   | 3.6   | 8.7   | 12.7  | 5.2   | 5.84       | 13.42         | 13.54       |
|        | B130      | 3.7   | 5.2   | 4     | 9.3   | 11.3  | 5.8   | 5.85       | 12.56         | 12.71       |
| 3      | NB        | 5.5   | 8.5   | 4     | 0     | 0     | 0     | 8.94       | 0              | 8.94        |
|        | B90       | 6.8   | 8.6   | 6.1   | 4.5   | 15.2  | 7.7   | 9.74       | 15.47         | 16.05       |
|        | B110      | 6.8   | 9.9   | 6.7   | 14.7  | 19.7  | 11.8  | 10.83      | 21.58         | 21.91       |
|        | B130      | 5.7   | 8.1   | 5.7   | 12.1  | 19.7  | 7.8   | 8.95       | 20.48         | 20.66       |
| 4      | NB        | 4     | 7.8   | 4.7   | 0     | 0     | 0     | 8.17       | 0.00          | 8.17        |
|        | B90       | 3.9   | 6.8   | 4.5   | 2.8   | 13.4  | 5.4   | 7.26       | 13.49         | 13.77       |
|        | B110      | 4.3   | 7.7   | 4.5   | 5     | 15.8  | 6.4   | 8.08       | 15.94         | 16.20       |
Table 2. Average values of the VDV’s on the seat and backrest.

|   | Seat       | Backrest   | Total         | Grand Total |
|---|------------|------------|---------------|-------------|
|   | X  | Y  | Z   | X  | Y  | Z   | Seat | Backrest | Seat+backrest |
| NB | 3.95 | 6.88 | 4.22 | 0.00 | 0.00 | 0.00 | 7.33 | 0.00     | 7.33          |
| B90 | 4.03 | 6.43 | 4.30 | 3.12 | 12.70 | 5.53 | 6.98 | 12.83    | 13.12         |
| B110 | 4.38 | 7.18 | 4.67 | 9.17 | 15.32 | 7.12 | 7.72 | 16.12    | 16.33         |
| B130 | 4.33 | 6.70 | 4.53 | 9.97 | 15.03 | 6.00 | 7.28 | 15.88    | 16.05         |

3.1.1 Effect of Driver mass, stature and BMI on VDV.

The results of VDV and anthropometric data (mass, stature and body mass index (BMI)) were subjected to Karl Pearson’s correlation analysis. Karl Pearson’s correlation of the anthropometric data showed that there existed a relation between Mass and BMI and total VDV. However, there was negative correlation found between the total VDV and stature. Table 3 shows the seat total VDV w.r.t mass, stature and BMI of the driver. Table 4 gives the correlation of anthropometric data and total VDV.

Table 3. Total VDV w.r.t mass, stature and BMI.

| S.No | Mass(kg) | Stature (m) | BMI | No Backrest | Backrest 90deg. | Backrest 110deg., | Backrest 130deg., |
|------|----------|-------------|-----|-------------|------------------|-------------------|-------------------|
| 1    | 60       | 1.76        | 19.37 | 6.67 | 5.42 | 6.06 | 6.26 |
| 2    | 64       | 1.64        | 23.80 | 6.41 | 5.94 | 5.84 | 5.85 |
| 3    | 72       | 1.58        | 28.84 | 8.94 | 9.74 | 10.83 | 8.95 |
| 4    | 67       | 1.69        | 23.46 | 8.17 | 7.26 | 8.08 | 7.87 |
| 5    | 70       | 1.61        | 27.01 | 6.71 | 6.75 | 8.29 | 7.52 |
| 6    | 65       | 1.7         | 22.49 | 7.08 | 6.76 | 7.22 | 7.25 |
Table 4. Pearson Correlation coefficient of Mass, Stature and BMI for Total VDV.

| Variable             | Pearson correlation | Significance                  | p value |
|----------------------|---------------------|-------------------------------|---------|
| Mass Vs Total VDV (NB) | 0.65                | Strong Positive correlation   | 0.163   |
| Mass Vs Total VDV (B90) | 0.85                | Strong Positive correlation   | 0.03    |
| Mass Vs Total VDV (B110) | 0.90                | Strong Positive correlation   | 0.01    |
| Mass Vs Total VDV (B130) | 0.85                | Strong Positive correlation   | 0.032   |
| Stature Vs Total VDV (NB) | -0.39               | Weak Negative Correlation     | 0.44    |
| Stature Vs Total VDV (B90) | -0.7                | Strong Negative correlation   | 0.125   |
| Stature Vs Total VDV (B110) | -0.69               | Strong Negative correlation   | 0.13    |
| Stature Vs Total VDV (B130) | -0.55               | Moderate Negative Correlation | 0.26    |
| BMI Vs Total VDV (NB) | 0.54                | Moderate Negative Correlation | 0.268   |
| BMI Vs Total VDV (B90) | 0.5                 | Moderate Positive correlation | 0.054   |
| BMI Vs Total VDV (B110) | 0.83                | Strong Positive correlation   | 0.041   |
| BMI Vs Total VDV (B130) | 0.72                | Strong Positive correlation   | 0.107   |

3.2 Wilcoxon Signed Rank Test
The Wilcoxon signed-rank test is a non-parametric statistical hypothesis test used when comparing two related samples, matched samples, or repeated measurements on a single sample to assess whether their population mean ranks differ (i.e. It is a paired difference test). The statistical significance of the test variables such as backrest contact and backrest angle effect with the transmission of vibration through the seat and backrest has been studied using the Wilcoxon signed rank test. The significance level of p=0.05 was taken for this statistical analysis. Wilcoxon signed-rank test was performed using the Minitab software.

3.2.1 Effect of Backrest Contact.
The VDV on the seat in (x, z) directions and, on the backrest in (x, y, z) directions were found to increase from NB to B110 and then decreased at B130. But in the y direction the VDV on the seat decreased from NB to B90 and again increased at B110. In all the cases, the VDV were significantly higher at B110 and drastically decreased at B130. However the statistical analysis "Wilcoxon signed rank test" showed that there is no statistical significance at NB, B90 and B110 in all three directions x,y, and z (p>0.05). At B130, a statistical significant observed with that of no backrest condition in the x direction (i.e. Fore-aft direction of seat). The total VDV on the seat did not have any statistical significance between the no backrest and other seating conditions. But, the Grand total VDV (seat + backrest) had a statistical significance in all directions (p<0.05).
3.2.2 Effect of Backrest angle.

Figure 3 shows the effect of VDV on the seat and backrest at different backrest angles. It can be observed that average values of VDV in all three directions had a minimal change between B90, B110 and B130 on seat, whereas the average values of VDV on backrest showed a drastic increase between B90 and (B110, B130). Table 5 shows the percentage increase of VDV from B90 to (B110 and B130) on backrest and seat. The percentage response of the backrest in the x direction between B90 and B110 as well as B90 and B130 increased to 194% and 220% respectively. This change was also found statistically significant at p<0.05. It can also be observed that the percentage response of the backrest in the y and z direction between B90 and B110 were minimized (21% and 29%, respectively). In this case, the VDV response in the y direction was statistically significant, when compared to the z direction (p=0.05).

4. Discussion

4.1 Effect of Driver Mass, Stature and BMI on Backrest

A positive correlation is observed between anthropometric data (Mass and BMI) and total VDV for different backrest angles. Fig. 4. Shows the variations of total VDV for different backrest angles. The figure 4 reveals that the increase in mass increased the total VDV and B130 showed a higher VDV when compared to B90. However, the values of total VDV of B90 and B130 are proportional, with
similar trends. In the case of B130, shifting of Centre of Gravity towards the backrest, as well as increase in the area of contact of the body mass cause more frictional force towards backrest. Therefore, the stiffness of the body in case of B130 will be more compared to B90, where the mass is mostly supported over the seat only, and having CG towards the steering wheel. Hence B130 will provide an additional fore-aft directional force of the mass inducing more VDV. It can be observed that there is no statistical significant between B90 and B110.

![Total VDV vs Mass at B90 and B130](image)

**Figure 4.** Mass Vs Total VDV at B90 and B130.

![Spectrums of driver Seat without and with backrest](image)

**Figure 5.** Spectrums of driver Seat without and with backrest.

### 4.2 Effect of back rests contact

The VDV in the fore-aft (x) and vertical direction (z) on the seat pad increased when a vertical backrest was used compared with no backrest condition. The finding corroborated by the previously reported results with a sedan car (Nawayseh, [5]) The presence of the upright backrest exposed the subjects to an additional source of excitation along the z-axis of the back. This has the tendency to increase the perception of vibration in the body parts like upper back, shoulder, neck and head at the backrest conditions. The excitation along the z axis on the back is due to the presence of resonance effect.

The measured VDV on the seat in the x-direction with B130 were statistically significant from those measured in the same direction on the seat with NB. The figure 5 shows the spectrum of driver’s response to vibration at different resonance frequencies without backrest and with backrest (B130). From the figures, it can be observed that the resonance frequencies have shifted from 0.92 Hz to 2.00 Hz when the drivers are subjected to NB and B130 respectively. The resonance frequency increased due to the increase in body stiffness. This is due to the fact that the change in the dynamic response of the body arising from the difference in the vibration transmission paths in the body through the backrest.
4.3 Effect of Backrest Angle

The results show that the effect of VDV from B90 to (B110 and B130) on backrest increased in the x direction. This is due to the fact that in case of vertical backrest, only a friction force would have been prevailed to oppose the motion in the vertical direction, whereas in an inclined backrest, the vertical forces in the backrest would have arisen from the mass of the parts of the upper body supported in the backrest as well as from the pitching movements of the upper body. In order to react to the pitch movement during vibration, the upper body has to be pushed against the backrest, which may have increased the dynamic force on the backrest in the fore-and-aft (x) direction (Nawayseh, [3])

The study on the VDV at the backrest through virtual dummy simulation and the results indicated a decrease in the VDV in the x-direction. This decrease in VDV observed may be attributed due to the less stiffness of the backrest in the x-direction. Whereas in a real situation, as the x-axis is perpendicular to the backrest, the gradual increase in the backrest angle in turn increases more mass to be supported on the backrest and subsequently increasing the stiffness resulting in the increase of the VDV (Pennestri et al. [6])

Generally, in order to determine the effect of backrest vibration, the measurement is made in the z direction. However, in this study, it is evidence that in a real road conditions the drivers are being subjected to the vibration effect in all x, y and z directions. Here it is important that while measuring the grand total VDVs, one must consider the x and y direction also. The total VDV (x, y and z axes) on the backrest is higher than the seat in all the inclination angles. This proves the significance of the x, y and z direction for calculating the VDVs. Increasing the speed of the bus will increase the input vibrations which in turn change the VDV (Nahvi et. Al., [1]). However the present study was focused with only one speed (40kmph) because of the non-linearity of the human body, of which the bio-dynamics response will also change, which in turn will affect the vibrations transmitted through the seat.

5. Conclusion

Current study investigated the effect of different backrest angles on the VDV in a midibus with respect of six male drivers. The anthropometric data with the VDV was correlated. From the present study, the following conclusions are drawn:

- The correlation analysis of the driver’s anthropometric data showed a positive relation between Mass and BMI and Total VDV and negative relation between stature and total VDV.
- The analysis on the vibration effect between no backrest and different backrest contact evidence that the increase in VDV was observed to increase in backrest angle from B90, B110 to B130. The spectral analysis of resonance frequencies between no backrest and backrest angle (B130) showed that there was a shifting in resonance frequencies from 0.92Hz TO 2Hz. This indicates that at a higher backrest angle the body stiffness increases, causing change in the dynamic response of the body to vibration.
- At a higher backrest angle the vdv is more on backrest x-direction as compared to seat vdv. The percentage response of VDV with x direction resulted in increased up to 194% and 220% between B90 and B110 as well as B90 and B130 respectively. At a higher backrest angle the mass of the upper body creates a higher vertical frictional force as well as a higher pitching movement during vibration. In order to react to the pitch movement during vibration, the upper body has to push against the backrest that would have caused more dynamic force in the x direction (fore and aft).

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