The Transmission of Vibration at Various Locations on Vehicle Seat to Seated Occupant Body

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ABSTRACT

Previous research showed that vehicle seat has generally three fundamental vibration mode shapes (lateral, fore-aft, and twisting) in the frequency range below 80 Hz which is well within human perception to vibration. However, the effects of seat structural dynamics on the vibration comfort may not be captured properly by current ISO 2631-1 (1997) suggested measurement locations. Therefore, this study evaluated the current center measurement locations on seat surfaces (seat cushion and seatback foams) in assessing transmission of vibration of the occupied vehicle seat. Vibration transmissibility from vibration platform to occupant body was measured at ten different locations between human body and seat surfaces, and nine different locations on seat frame. The vehicle seat was excited in multi-direction (fore-aft, lateral, and vertical) with random vibration of 1.0 m/s^2 r.m.s. for each axis over the frequency range 1 - 100 Hz. The results showed that the transmission of vibration from vehicle seat structure to human body varies with vibration mode shapes. The transmissibility was greatest at the top measurement location on the seatback surface in y-axis when seat structure undergoes lateral and twisting vibration mode shape. The transmissibility was greatest at the top measurement location on the seatback in x-axis when seat structure undergoes fore-aft vibration mode shape. The variations in transmissibility with modes of vibration and with location of measurements suggest that more than one measurement location is required to evaluate the transmissibility of vehicle seat.

Keywords: Seat, Vibration, Structural Dynamics I-INCE Classification of Subjects Number(s): 72.2

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1. INTRODUCTION

Seat vibration is one of the known causes of dynamic discomfort in vehicle. By increasing the comfort expectations of the vehicle, an improvement in dynamic comfort is necessary to satisfy passenger expectations. To reduce the discomfort caused by structural vibration, the resonant frequencies of the seat must be designed to be away from automotive fundamental modes. The optimization of the seat designs to reduce the transmission of vibration requires an understanding of how seat structure transmits the vibration to human body.

The transmission of vibration from seat to occupant body depends on the seat structural dynamic and dynamic response of human body [1]. It can be amplified or attenuated which is depended on structural resonance of the combined human body and seat. Therefore, it is important to consider vehicle seat and human as a coupled system. The challenge in predicting the transmission of vibration from vehicle seat to human body is mainly due to the complex dynamic interaction between vehicle seat and human body. In this research, the transmission of vibration from vehicle seat system to occupant body is studied.

Vehicle seat is consisted of metal frame, polyurethane foam cushion, and spring which result in a complex vibration characteristic [2]. Moreover, the dynamic response of seated human body is depended on the subject build, height, weight, and sitting posture [3]. Seated human body sensitivity to vibration is in frequency between 0.1 -80 Hz [4]. The direction of vibration and level of vibration are also important factors to be considered. Fundamental modes of the coupling system between seated human body and seat foam cushion are in frequency between 0.1-10 Hz [5-7].

The measurement of the seat transmissibility is usually measured by using accelerometer pad located at the center of seat surface (ISO 2631-1 (1997)). However, the transmissibility measured at center location may not be able to capture the correct vibration transmission to occupant body. It has been reported by [8-10] that the transmissibility of foam cushion-seated human body varies with vertical position. The measurement at the center of seat surface showed fundamental resonance in frequency 1-10 Hz which is the coupling of human body and foam cushion. In the frequency range between 10-50 Hz, the coupling of human body and seat frame structure occurred [7, 11]. Three resonant frequencies and three corresponding vibration modes of vehicle seats were found below 80 Hz [11]. Therefore, this research aimed to study the transmission of vibration from vehicle seat to seated occupant by taking the resonant frequency and mode shape as key vibration attributes. Different measurement locations on seat frame and seat surface were measured and compared.

2. Method

The experiments were conducted on multi-axis shaker table (figure 1) using 8 electro-dynamics shakers to reproduce uncorrelated Gaussian random vibration in fore-aft, lateral, and vertical direction. Vibration magnitude of 1.0 ms-2 r.m.s. was used in the experiment and the vibration platform was excited for 60 seconds over frequency range 1-100 Hz.

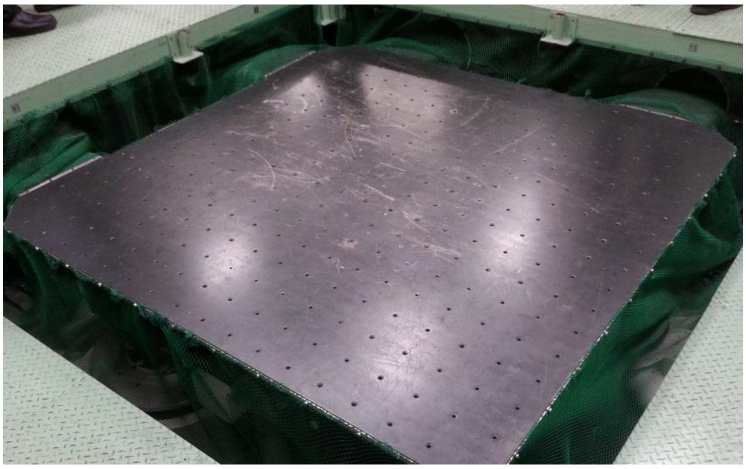

Figure 1 Multi-axial vibration platform.

The vehicle seat was attached onto the vibration platform via rigid mounting (figure 2). The vehicle seat was equipped with seat height adjuster device which was set at the middle position throughout the experiments. The tested vehicle seat is also equipped with common devices which are rail adjuster, seatback adjuster, seat cushion adjuster, and headrest. The seatback angle of the tested seat was set at 25° from vertical direction and the seat cushion was set at 15° from horizontal. The rail position was set at the rear-most.

Fore-aft, lateral, and vertical acceleration of the vibration platform was measured using one (PCB 356A09) tri-axial accelerometer located on the vibration platform and at the center of attached test seat. Nine (PCB 356A09) tri-axial accelerometers were placed on different points of the seat frame (figure 2) to find transmissibility to seat frame and the dynamic properties (resonant frequency and corresponding vibration mode shape) of the vehicle seat. The seat accelerometer pad (B&K 4515-B) was taped to the seat cushion at the center. The similar accelerometer pad was taped on the seatback at the center. Four (PCB 356A09) accelerometers were mounted on the thin plastic base and taped to seat cushion and seatback (figure 3). LMS SCADAS Mobile front end are used for data acquisition, and data analyzing. The measurement resolution was set to 0.5 Hz with 60 averaging. Hanning window was applied to both input and output signal.

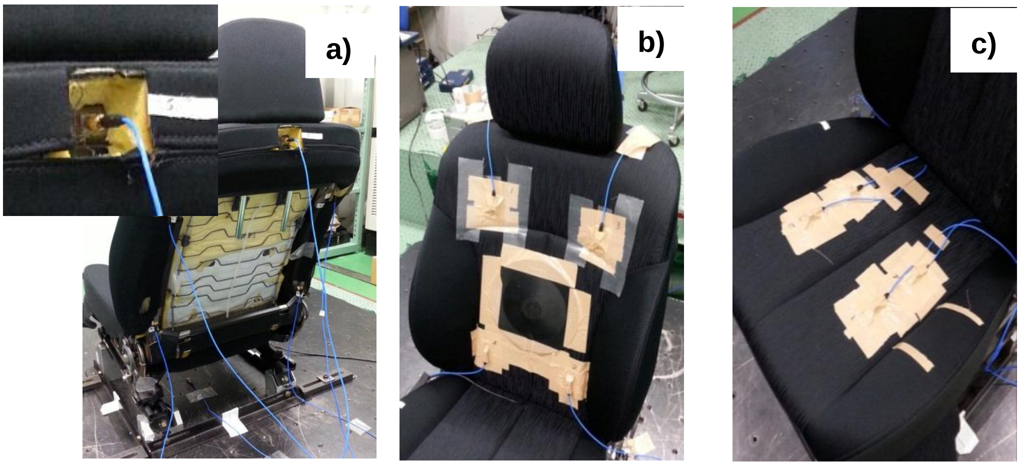

Figure 2 Measurement locations a) tri-axial accelerometers on seat frame. b) Measurement locations on seatback surface with accelerometer pad and tri-axial accelerometers. c) Measurement locations on seat cushion surface with accelerometer pad and tri-axial accelerometers.

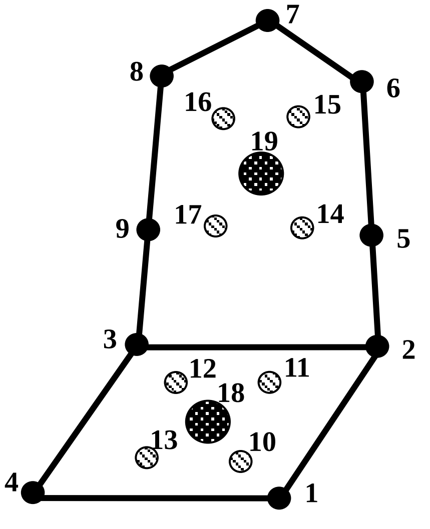

Figure 3 Measurement locations - nine accelerometers were attached to seat frame and 10 accelerometers were attached to the seatback and seat cushion surfaces.

Transfer function of the systems was derived using H1 estimation. $H(f)H(f)$ can be derived from experimental data by using the cross-spectral density function method,

$$H(f) = \frac{G_{io}(f)}{G_{ii}(f)} \tag{1}$$

Where $G_{io}(f)$ is cross spectrum of input (reference tri-axial accelerometer) and the output (tri-axial accelerometers of various measurement points), and $G_{ii}(f)$ is the power spectrum of the input.

The results obtained by the use of cross-spectral density method was examined with the coherency function or ordinary coherency (magnitude squared coherence function $C_{io}^2(f)$ that was defined, Eq. (2),

$$C_{io}^2(f) = \frac{|G_{io}(f^2)|}{G_{ii}(f)G_{oo}(f)} \tag{2}$$

Coherence is a frequency dependant function that its value is always between 0 and unity. A value of coherence close to unity usually gives promise of a good correlation between the excitation and output signals. The obtained values coherences at all measured frequencies of the experiments were found to be higher than 0.7 close to unity.

3. Results

The tested vehicle seat showed three fundamental vibration mode shapes in frequency range from 1 to 40 Hz which are lateral mode shape, fore-aft mode shape and twisting mode shape. The first peak below 10 Hz in the frequency response function belongs to the resonance of foam cushion. However, the vibration mode shapes of the tested seat in this study were the deformations of seat frame structure at resonant frequencies which were above 10 Hz. The lateral mode shape was at 17 Hz. The fore-aft mode shape was visible at 23 Hz. The twisting mode shape was at 30 Hz. Figure 4-6 showed vibration mode shapes of the tested seat. These figures were extracted from experimental data using the LMS TEST.Lab software package. Visual observation of structural deformation of the tested vehicle seat shows that in lateral mode shape, whole seatback generally vibrates in lateral (Y) direction. In fore-aft mode shape, the major deformation is from seatback in fore-aft (X) direction. In twisting mode shape, the whole seat (seatback and seat cushion) vibrates in both fore-aft and lateral direction. The obtained mode shapes were mainly the deformation of the seat supporting structure not the foam cushion.

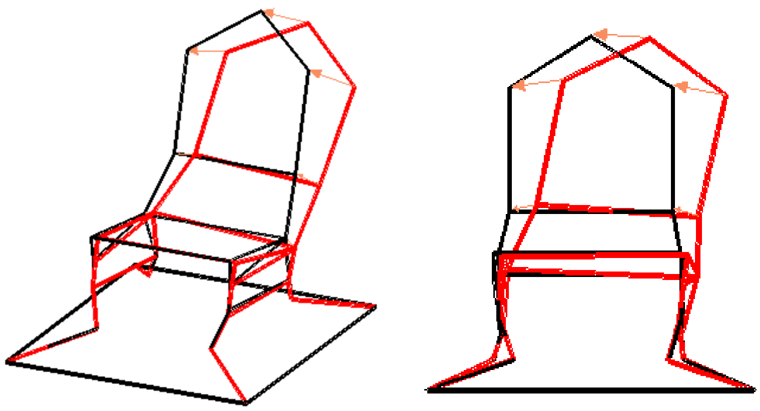

Figure 4 Lateral vibration mode shapes

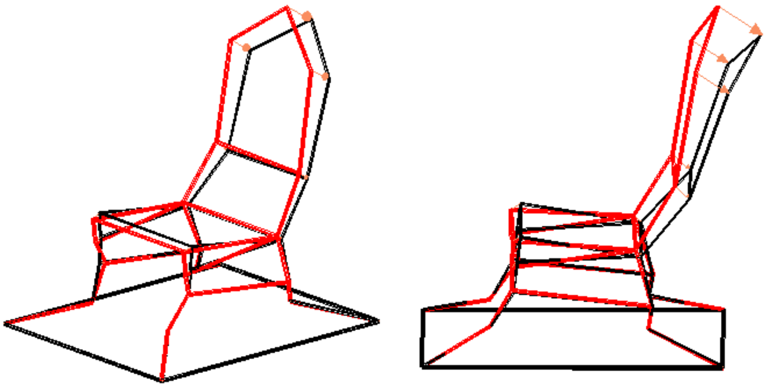

Figure 5 Fore-aft vibration mode shapes

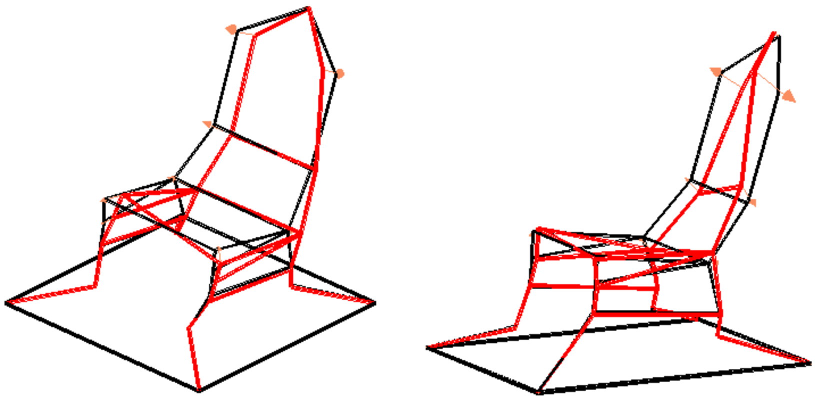

Figure 6 Twisting vibration mode shapes

The transmission of vibration from each obtained vibration modes of the tested seat was measured by accelerometers attached along the frame. It was found that seat vibration modes caused complex transmission of vibration to various axis and locations (figure 7-9). In lateral resonant frequency (17 Hz), the major vibration transmission from seat frame was at the top of seatback in y-axis (location 7). In fore-aft resonant frequency (23 Hz), the dominant vibration transmission from seat frame was at the top of seatback in x-axis (location 7). In twisting resonant frequency (30 Hz), the dominant vibration transmitted from seat frame was at the bottom of seatback frame in y-axis (location 2, 3)

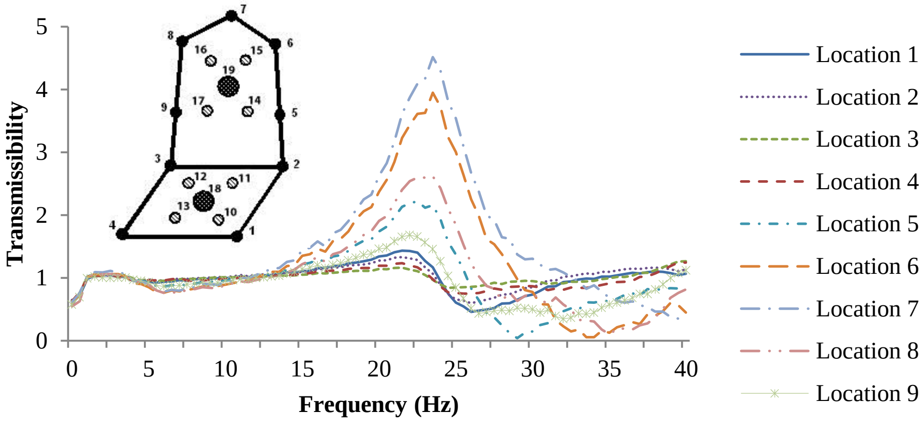

Figure 7 Fore-aft transmissibilities at measurement locations on seat frame

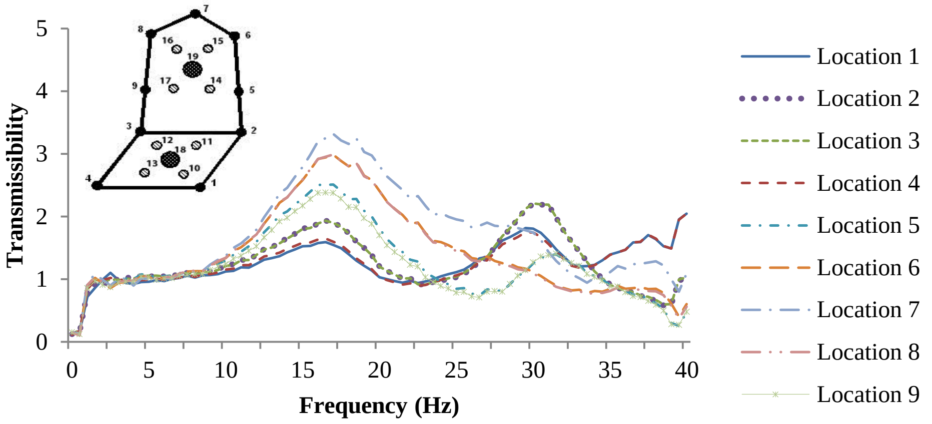

Figure 8 Lateral transmissibilities at measurement locations on seat frame

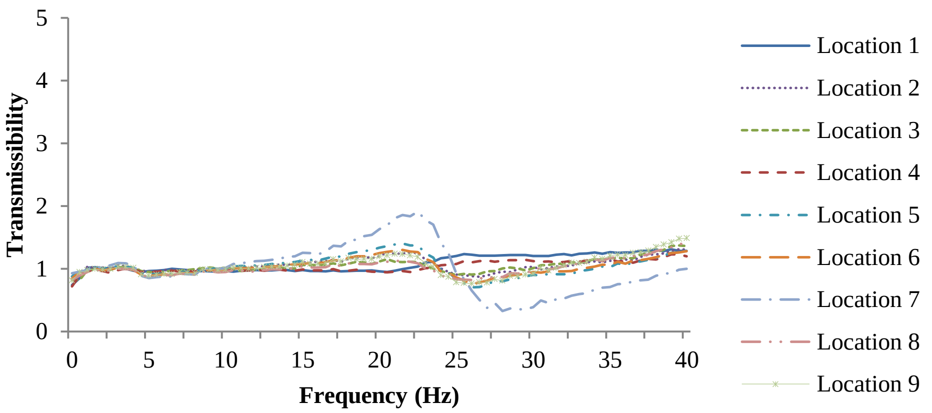

Figure 9 Vertical transmissibilities at measurement locations on seat frame

The transmissions of vibration from seat surface (foam cushion) when occupied seat undergoing structural resonant frequencies (>10 Hz) were measured using accelerometer pads and tri-axial accelerometers taped to foam cushion (both seat cushion and seatback). The results indicated that the seatback fore-aft transmissibilities showed two resonances in between 3-6 Hz, and 20-25 Hz. The high transmissibility at low frequency (<10 Hz) was the resonance from the coupling effect of human body and foam cushion. The fore-aft transmissibility on seat surface (figure 10) between 20-25 Hz was caused by the seat frame vibration in fore-aft direction (24 Hz – fore-aft mode). The fore-aft transmissibilities on seat surface showed variation with vertical measurement location with the greatest value at the top measurement points (location 15, 16).

The seatback lateral transmissibilities on seat surface (figure 11) showed two resonances in between 15-20 Hz, and 27-31 Hz. The lateral transmissibilities on seat surface were correlated to the seat frame vibration modes (17 Hz – lateral mode, 30 Hz – twisting mode). Lateral transmissibilities were greatest at the top measurement location (location 15, 16) in both lateral and twisting resonances.

The seatback vertical transmissibility on seat surface (figure 12) showed resonance in between 3-6 Hz. The vertical transmissibility was almost unity for all measurement locations in frequency above 10 Hz.

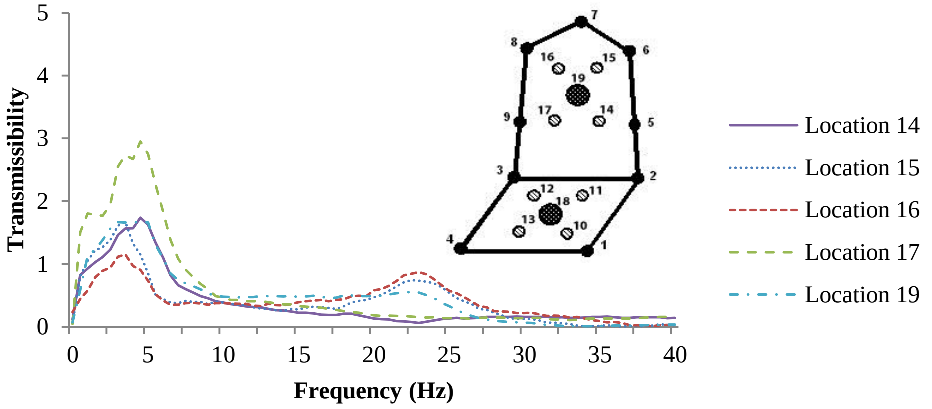

Figure 10 Fore-aft transmissibilities at measurement locations on seatback surface.

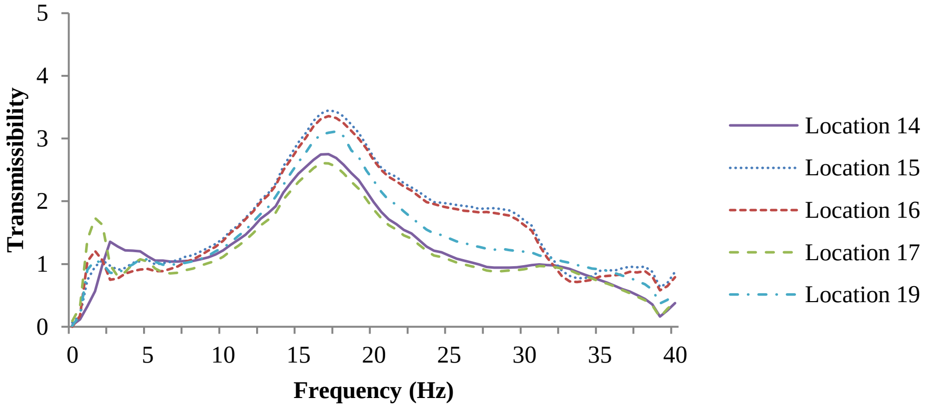

Figure 11 Lateral transmissibilities at measurement locations on seatback surface.

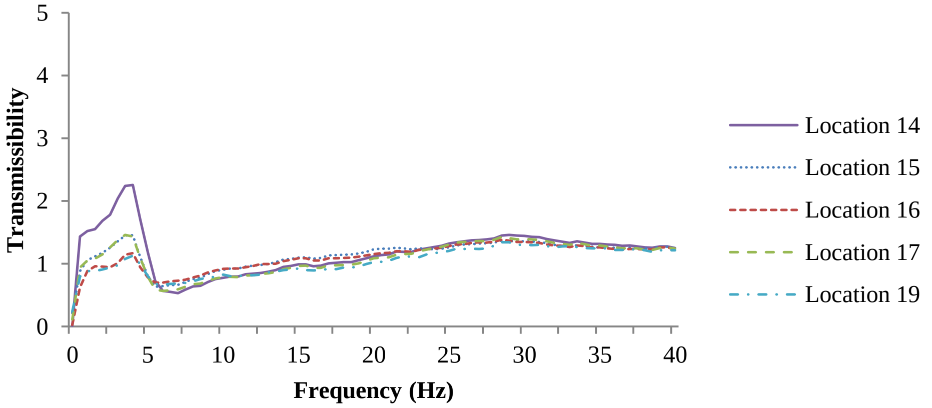

Figure 12 Vertical transmissibilities at measurement locations on seatback surface.

The fore-aft transmissibilities on seat cushion surface (figure 13) showed two resonances in between 3-5 Hz, and 20-25 Hz. The resonance between 3-5 Hz was the resonance from the coupling effect of human body and foam cushion. The transmissibility between 20-25 Hz was caused by the seat frame vibration in fore-aft direction (24 Hz – fore-aft mode). The seat cushion fore-aft transmissibility does show variation with measurement location.

The lateral transmissibilities on seat cushion surface (figure 14) showed three resonances in between 2-4 Hz, 15-20 Hz, and 27-31 Hz. The resonance between 2-4 Hz was either from seat cushion or human body. In the higher frequency (>10 Hz) where lateral transmissibilities showed resonance were coincided with seat frame modes (17 Hz – lateral mode, 30 Hz – twisting mode). Seat cushion lateral transmissibilities were greatest at the rear-most measurement location (location 11, 12) in frequency between 15-20 Hz and 27-31 Hz.

The vertical transmissibilities on seat cushion surface (figure 15) show resonances in between 3-10 Hz, 15-20 Hz and 27-31 Hz. The vertical transmissibilities of the seat cushion showed variation with measurement locations along x-axis. In low frequency (<10 Hz) the greatest transmissibility was at the rear-most measurement location (location 11, 12). The vertical transmissibility was greatest at front-most measurement location (location 13, 10) in high frequency (>15 Hz).

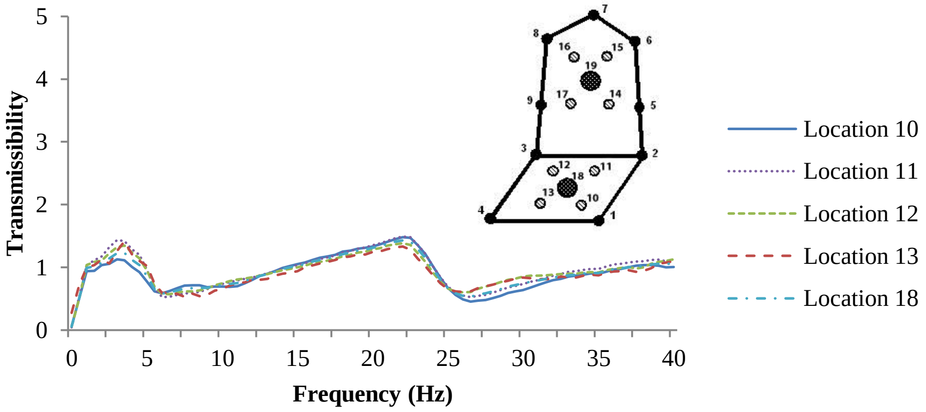

Figure 13 Fore-aft transmissibilities at measurement locations on seat cushion surface.

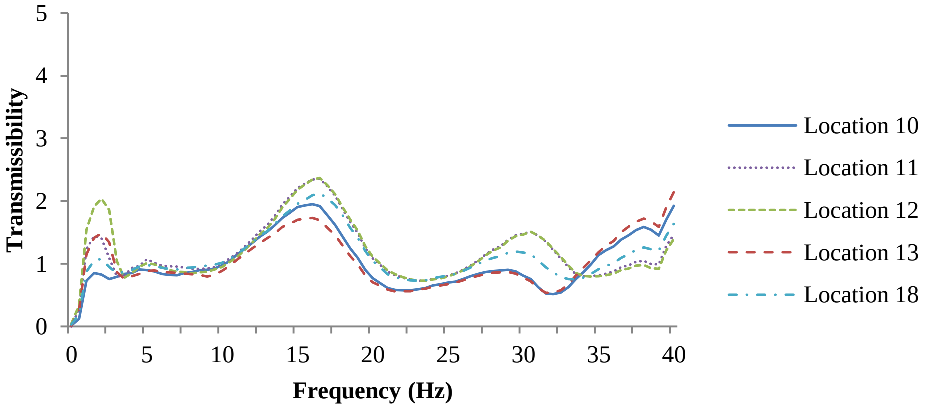

Figure 14 Lateral transmissibilities at measurement locations on seat cushion surface**.**

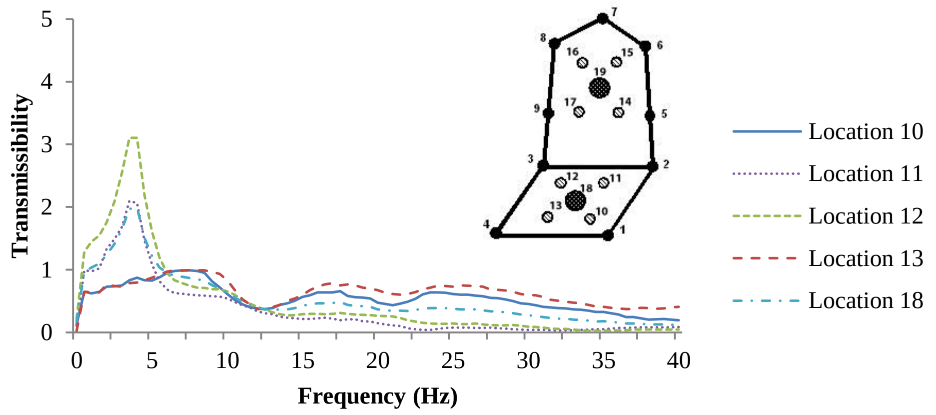

Figure 15 Vertical transmissibilities at measurement locations on seat cushion surface.

4. Discussion

The vibration modes found in the study were similar to results reported by [11, 12] who investigated the effect of human body on seat structural dynamics however, the resonant frequencies were different. The first occupied seat vibration mode found in this study was lateral mode 17 Hz. The second occupied seat vibration mode was fore-aft mode at 24 Hz. The third occupied seat vibration mode was twisting at 30 Hz.

The transmissibility at measurement locations along seat frame (location 1-9) in all direction are unity in frequency below 10 Hz. However, the transmissibilities at measurement locations on seat surface (location 10-19) showed resonances below 10 Hz. This suggested that the transmissibility below 10 Hz was caused by the dynamic response of the seat foam cushion and human body. In higher frequency (>10 Hz), the transmissibilities at seat frame measurement locations (location 1-9) showed three resonances between 15-20 Hz, 20-25 Hz, 27-31 Hz. At 17 Hz the tested seat exhibited lateral vibration mode which transmitted vibration in y-direction. At 24 Hz the tested seat exhibited fore-aft vibration mode which transmitted vibration in x-direction. The transmissibilities at 17 Hz, and 24 Hz showed an increasing trend with the vertical location along seatback frame. The transmissibility was greatest at the top of the vehicle seat. At 30 Hz the tested seat exhibited twisting vibration mode shape which transmitted vibration in y-direction. The greatest transmissibility was at the joint location between seatback and seat cushion frame (location 2, 3) and at the top of seatback (location 7). The transmissibility decreased with horizontal distance away from the measurement location 2 and 3.

The transmissibility at measurement locations on seat surface (location 10-19) also showed resonances in frequency above 10 Hz. In accordance with the seat frame transmissibilities, it was shown that the modes of vibration cause complex transmission of vibration to occupant body. It is expected that the foam cushion would damp the vibration from seat frame. In lateral resonant frequency (17 Hz), the measured transmissibility at location (10-19) showed that the transmissibilities were similar to the measurement locations on seat frame (location 1-9). The greatest lateral transmissibility was at the top of seatback surface (location 15, 16). This suggested that the foam cushion does not contribute to the transmission of vibration from seat to human body. The transmission of vibration at lateral vibration mode is mainly from the seat frame. In fore-aft resonant frequency (24 Hz), the measured transmissibility at location 10-19 showed that the greatest transmissibility is at the top of the seatback surface (location 15, 16). However, transmissibilities at seatback surface (location 14-19) showed significant difference between vibrations measured on the seat frame (figure 16). The dynamic properties of the foam cushion and the interaction with human body are likely to have effect on the fore-aft transmissibility at fore-aft resonant frequency. In twisting resonant frequency (30 Hz), the measured transmissibilities at location (10-19) showed similar trend to the measurement location on seat frame (location 1-9). The high transmissibility was observed at top measurement locations on seatback surface (location 15, 16) and at the rear-most measurement locations on seat cushion surface (location 11, 12). Moreover, the levels of the lateral transmissibilities due to twisting vibration mode measured on seat surface were similar to that measured on seat frame (figure 17). This also suggested that the foam cushion does not contribute to the transmission of vibration from seat to human body in lateral direction.

It is also observed that the transmissibility measured at the center location as stated in the ISO 2631-1 (1997) could not capture all the vibration transmitted to human body. This is because vehicle seat exhibits structural resonance with correspond mode shape. These can cause complex transmission of vibration to human body. From the result, it showed that the fore-aft and lateral transmissibility measured at the center locations underestimated the total vibration transmitted to human body. The results of the transmissibility measured at center measurement locations were consistent with the finding in [3, 9, 10, 13] who studied the effect of vertical measurement locations on transmissibility in low frequency (<10 Hz).

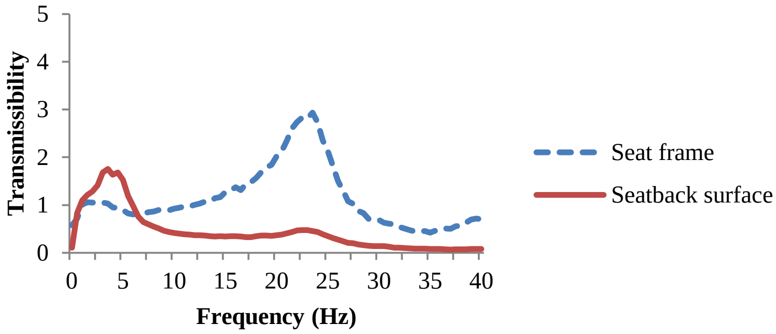

Figure 16 Average fore-aft transmissibilities on seatback frame and seatback surface**.**

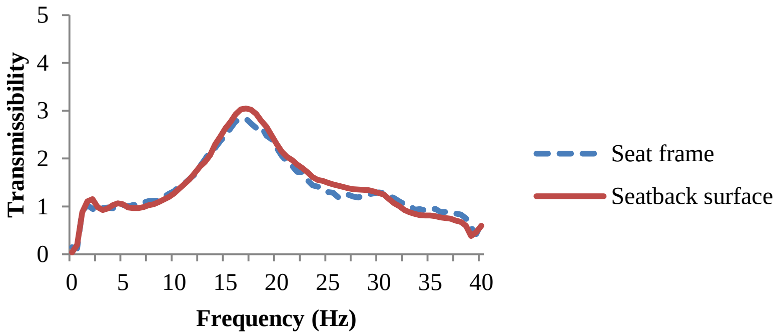

Figure 17 Average lateral transmissibilities on seatback frame and seatback surface.

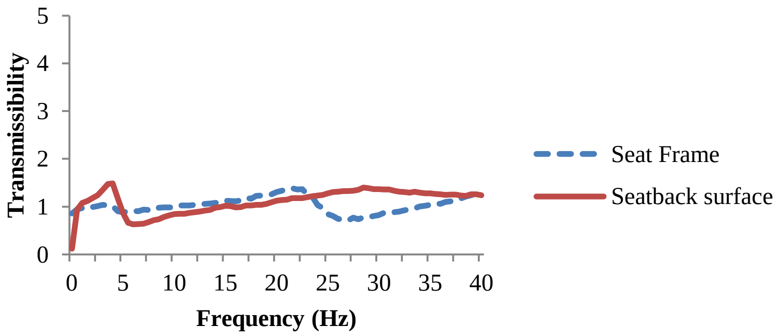

Figure 18 Average vertical transmissibilities on seatback frame and seatback surface.

5. Conclusion

Experimental results of occupied seat transmissibility showed that in low frequency (<10 Hz), the major transmission of vibration correlated mainly with the seat foam cushion whereas in high frequency (>10 Hz) the major transmission of vibration correlated mainly with seat frame. For the tested seat there were three major seat frame vibration modes above 10 Hz which are lateral mode shape, fore-aft mode shape and twisting mode shape. Comparison of the seat frame vibration with the seat surface vibration showed that the frame lateral vibration significantly transmitted vibration to the occupant body in higher frequencies (>10 Hz).

The center measurement location stated in the ISO 2631-1 (1997) cannot capture the accurate vibration transmitted to human body. In the fore-aft and lateral transmissibility measured with the center locations underestimated the total vibration transmitted to human body. There was a small variation in the lateral transmissibility at lateral resonant frequency measured at seat frame and at seat foam cushion. The lateral transmissibilities were similar at both measurement locations on the seat frame and on the seat foam cushion. However, there were large variations in lateral and fore-aft transmissibilities at different vertical measurement locations on seatback and at different horizontal measurement locations on seat cushion.

The variations in transmissibility with modes of vibration and with locations of measurement suggested that more than one measurement location is needed to evaluate the transmissibility of vehicle seat. Furthermore the small difference in lateral transmissibility measured on seat frame and on seat surface may lessen the need for the complex dynamic model of occupied vehicle seat to predict lateral transmissibility.

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