A biomechanical modeling of an automotive passenger body to investigate the vertical vibration in various road profiles using transmissibility analysis

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Abstract

In the current paper, a biomechanical model of human body with unique structure is developed for evaluating the biodynamic responses, the vibration transmissibility and the transmitted accelerations to vertical vibration for the seated position with ignoring backrest support. In this regard, the 6-DoF Lumped-parameter model with six concentrated masses which are connected with linear springs and dampers is presented. Further, the full vehicle model is developed in ADAMS/CAR software in order to utilize the accelerations of seat under various roads excitation for different amount of vehicle speeds. Also, the vibration transmissibility and transmitted accelerations in vertical direction are measured for the different segments of human body including: Pelvis, Abdomen and Diaphragm, Chest, Torso, Back, Head and Neck. Finally, vibration transmissibility and transmitted accelerations due to the roughness of the roads surfaces are investigated for the different segments of human body in frequency domain from 0 to 50 Hz. As it is illustrated the maximum values for transmissibility for different body segments occurred for frequencies equivalent 20 to 30 Hz, it can be concluded that the human body is more sensitive to vibration with frequencies under 30 Hz.

Keywords: *Biomechanical, Vibration, Transmissibility, Automotive passenger body, Vehicle model.*

1. Introduction

Due to satisfy the passenger comfort, the crucial parameters using biomechanical modeling of human body should be investigated. The biomechanical models include lamped parameter, multi body and finite element models, which among all the accuracy of lumped parameter models are proved to be capable for assessment vibration in one direction.

Many lumped parameter models have been proposed for various applications. For example, Allen et al. [1] presented a 2-DoF biomechanical model which this linear model utilized in other works in order to assess automotive comfort quality. Suggs et al. [2] created a 3-DoF biomechanical model, the model which they presented has been used for years to assess automotive comfort. And also, Wan and Schimmels [3] proposed a 4-DoF biomechanical models for the seated posture, mentioned model in 2000, utilized to study human-automotive system responses and evaluation quality comfort by Wagner and Liu [4]. Muksian and Nash [5] created a nonlinear 6-DoF biomechanical model while the addition of this model is completed with spring and damper by Patil et al. [6]. Moreover, this model utilized in a tractor model to evaluate driver-tractor system vibrating responses [7], [8]. Afkar et al. [9] suggested a 7-DoF biomechanical model to obtain dynamic responses. In addition, their proposed model is used to evaluate health risks associated with various speeds passing control humps. The study of both vertical and horizontal cross axis apparent mass for human body is done by Naser Nawayseh [10]. While his aim of this study is to investigate seat different conditions effects on received vibration. Salam Rahmatalla and Jonathan DeShaw [11] obtained seat-to-head transmissibility matrices for an input and multi output in both horizontal and vertical directions, and also they have calculated seat-to-head transmissibility matrices for multi input and multi output. Rakheja and Boileau [12] investigated contact pressure distribution and applied force between seated posture and viscoelastic seat on an experimental basis under vertical vibration. Furthermore, various values of dynamic pressure is evaluated on elastic seat under sinusoidal vertical vibration frequency ranges from 1-10 Hz, by using a flexible network of pressure sensors. Neil Mansfield et al. [13] conducted an experiment in order to investigate discomfort range for starting and stopping frequency in vibration. Blood et al. [14] designed a test to evaluate and compare three seats of urban bus drivers. In this test, the seats with standard and Silicon foams and individual factors such as seat pressure and human body weight settings are investigated. Marzbanrad and Afkar have created a 7-DoF model with the aid of unique variations in the structure of the Patil's model which shows better biomechanical responses of human body [15].

Lots of literature works studied the road profiles excitation and seat various conditions such as damping and stiffness coefficients and foam influences on vibration analysis and automotive passenger comfort, separately. Whereas investigating road profiles excitation conditions with biomechanical modeling on vibration transmitted to automotive passenger with investigating the vibration transmissibility of all human body segments using MATLAB/Genetic Algorithm and ADAMS/CAR software's is rather limited. This motivated the current work which is concerned with using a 6-DoF biomechanical human model and a full vehicle model, the vibration transmissibility in vertical direction for the human body segments is measured according to simulated human body model. In this study, three tests by a SANDERO vehicle model weighing 1146 Kg which is developed in ADAMS/CAR software, are done to measure the applied vertical acceleration to the passenger seat on three different road profiles include: C, D and G profiles. The C, D and G road profiles are the stochastic-uneven which are known as ISO-ROAD [16]. The mentioned vehicle is moved on the road profiles consisted of C with the speed of 70 Km/h, D for the speed of 50 Km/h and G profiles with speed of 20 Km/h. The accelerations which are obtained from these three tests are applied to the6-DoF biomechanical model that is developed in MATLAB software using Genetic algorithms, and the vibration transmissibility in vertical direction are investigated. Moreover, the effects of roads roughness on vibration transmissibility values to the human body are shown.

2. Method

In this section, the automotive passenger biomechanical model and full vehicle model are presented for evaluating vibration transmissibility in vertical direction.

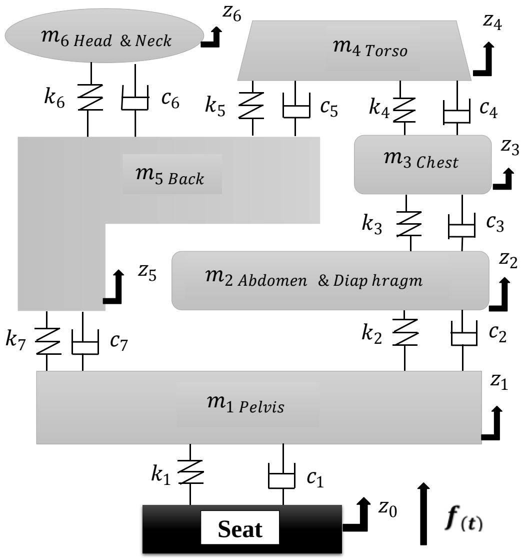

Fig1.. The automotive passenger model

Table 1 The obtained experimental data by Boileau [12]

STHT	DPMI (Kg/s)	APM (Kg)	Frequency (Hz)
1.010	254	61.200	0.500
1.010	304	61.400	0.630
1.010	359	60.600	0.800
1.020	424	59.600	1.000
1.030	493	59.200	1.250
1.060	627	60.000	1.600
1.080	768	60.800	2.000
1.100	947	62.600	2.500
1.160	1429	70.700	3.150
1.290	2002	79.300	4.000
1.450	2346	74.500	5.000
1.230	2065	53.200	6.300
1.010	1939	38.500	8.000
0.960	1981	31.500	10.000
0.860	2023	25.900	12.500
0.710	1750	17.400	16.000
0.630	1755	14.100	20.000

3. Automotive passenger modeling

The model of passenger body is shown to investigate vibration transmissibility for different segments of human body due to road various profiles excitation and speeds. For this purpose, a lumped parameter 6-DoF biomechanical model is suggested with six concentrated masses by using the springs and dampers for connecting to each other. The presented model is similar to the Muksian model [5] while has more accurately with linear dampers and springs and unique structure; But in the Muksian model the dampers and springs were considered to be nonlinear. The offered model is considered to calculate biodynamic responses consisted of Apparent Mass (APM), Driving Point Mechanical Impedance (DPMI) and Seat-To-Head Transmissibility (STHT) for the sitting position of human body without backrest support in vertical direction. The 6-DoF model is illustrated in Fig. 1.

For adaptation the presented model the experimental data by Boileau et al. [12] have been used. The mentioned experimental data include: Seat-To-Head-Transmissibility (STHT), Driving Point Mechanical Impedance (DPMI) and Apparent Mass (APM) responses which, is illustrated in Table 1.

The dynamic equations for the suggested model in the time domain are as follows:

$$\begin{cases} m_1\ddot{z}_1 + c_2(\dot{z}_1 - \dot{z}_2) + k_2(z_1 - z_2) + c_7(\dot{z}_1 - \dot{z}_5) + k_7(z_1 - z_5) \\ + c_1\dot{z}_1 + k_1 z_1 = c_1\dot{z}_0 + k_1 z_0 \end{cases} \quad (1)$$

$$m_2\ddot{z}_2 + c_2(\dot{z}_2 - \dot{z}_1) + k_2(z_2 - z_1) + c_3(\dot{z}_2 - \dot{z}_3) + k_3(z_2 - z_3) = 0 \quad (2)$$

$$m_3\ddot{z}_3 + c_3(\dot{z}_3 - \dot{z}_2) + k_3(z_3 - z_2) + c_4(\dot{z}_3 - \dot{z}_4) + k_4(z_3 - z_4) = 0 \quad (3)$$

$$m_4\ddot{z}_4 + c_4(\dot{z}_4 - \dot{z}_3) + k_4(z_4 - z_3) + c_5(\dot{z}_4 - \dot{z}_5) + k_5(z_4 - z_5) = 0 \quad (4)$$

$$\begin{cases} m_5\ddot{z}_5 + c_5(\dot{z}_5 - \dot{z}_4) + k_5(z_5 - z_4) + c_6(\dot{z}_5 - \dot{z}_6) + k_6(z_5 - z_6) \\ + c_7(\dot{z}_5 - \dot{z}_1) + k_7(z_5 - z_1) = 0 \end{cases} \quad (5)$$

$$m_6\ddot{z}_6 + c_6(\dot{z}_6 - \dot{z}_5) + k_6(z_6 - z_5) = 0 \quad (6)$$

Where in the above equations m_i denotes the mass and z_i , $\dot{z}_i$, $\ddot{z}_i$ is displacement, velocity and acceleration, respectively. Also, c_i and k_i represented damping and stiffness coefficients for i = 1, 2, 3…, 6 respectively. z_0 , $\dot{z}_0$ represented seat displacement and velocity, respectively, which are

considered as system inputs. If the initial conditions are assumed to be zero then equations (1) to (6) in the frequency domain is as follows:

$$\left[Z(j\omega)\right]=\left[\left[K\right]-\omega^2\left[M\right]+j\omega\left[C\right]\right]^{-1}F(j\omega)$$

(7)

Where in the above equation $F(j\omega)$ represents applied force to passenger body system. The equations of motion for this vibrational human body system are written in the frequency domain in the matrix as:

$$\begin{bmatrix} m_1s^2+(c_1+c_2+c_7)s+k_1+k_2+k_7 & -c_2s-k_2 & 0 & 0 & -c_7s-k_7 & 0 \\ -c_2s-k_2 & m_2s^2+(c_2+c_3)s+k_2+k_3 & -c_3s-k_3 & 0 & 0 & 0 \\ 0 & -c_3s-k_3 & m_3s^2+(c_3+c_4)s+k_3+k_4 & -c_4s-k_4 & 0 & 0 \\ 0 & 0 & -c_4s-k_4 & m_4s^2+(c_4+c_5)s+k_4+k_5 & -c_5s-k_5 & 0 \\ -c_7s-k_7 & 0 & -c_5s-k_5 & -c_5s-k_5 & m_5s^2+(c_7+c_6+c_5)s+k_7+k_6+k_5 & -c_6s-k_6 \\ 0 & 0 & 0 & 0 & -c_6s-k_6 & m_6s^2+(c_6)s+k_6 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \\ z_6 \end{bmatrix} = \begin{bmatrix} c_1s+k_1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}\left[z_0\right]$$

(8)

Replacing s by $j\boldsymbol{\omega}$ in above matrix, Vibration transmissibility seat to head in frequency domain is:

$$STHT=\left|STHT(j\omega)\right|=\left|\frac{\ddot{z}_6(j\omega)}{\ddot{z}_0(j\omega)}\right|=\left|\frac{(j\omega)^2Z_6(j\omega)}{(j\omega)^2Z_0(j\omega)}\right|=\left|\frac{Z_6(j\omega)}{Z_0(j\omega)}\right|$$

(9)

And driving point mechanical impedance is obtained as:

$$DPMI=\left|DPMI(j\omega)\right|=\left|\frac{F(j\omega)}{\dot{z}_0(j\omega)}\right|=\left|\frac{(k_1+j\omega c_1)(Z_0(j\omega)-Z_1(j\omega))}{(j\omega)Z_0(j\omega)}\right|$$

(10)

Also, human body apparent mass responses is illustrated as eq. (11):

$$APM=\left|APM(j\omega)\right|=\left|\frac{F(j\omega)}{\ddot{z}_0(j\omega)}\right|=\left|\frac{(k_1+j\omega c_1)(Z_0(j\omega)-Z_1(j\omega))}{(j\omega)^2Z_0(j\omega)}\right|$$

(11)

Errors' rate in biomechanical responses consist of STHT, DPMI and APM in a sitting position are defined as:

$$J_1=STHT_{error}=\sum_{i=1}^{N}\left(STHT_{Experimental}(f(i))-STHT_{Model}(f(i))\right)^2$$

(12)

$$J_2=DPMI_{error}=\sum_{i=1}^{N}\left(DPMI_{Experimental}(f(i))-DPMI_{Model}(f(i))\right)^2$$

(13)

$$J_3=AP_{error}=\sum_{i=1}^{N}\left(APM_{Experimental}(f(i))-APM_{Model}(f(i))\right)^2$$

(14)

where in the above equations N is the number of points in the frequency range. Although by increasing the number of points the precision become higher but in too large values the accuracy doesn't show much increase. The stimulation frequency of f (1) = 0.5 to f (N) = 20 Hz is defined. In order to optimize the objective functions, the following equation will be used simultaneously:

$$J_{6DOF\ Model}=\sum_{i=1}^{3}\left[\frac{J_i^*-J_i}{J_i^*}\right]^2$$

(15)

Using Genetic Algorithms (GA) in MATLAB parameters of the masses, stiffness and damping of the 6-DoF model so that the minimum $J_{6DOF\ Model}$ function is obtained. The only condition in this issue is that the total mass of the human body is equal to 60.98 Kg.

4. 2.2. Vehicle modeling and Analysis various vehicle speeds and road profiles effects

In this part, vehicle condition and road tests on three different profiles are explained at various speeds. Three tests with real conditions are done by the SANDERO developed vehicle model with weighs 1146 Kg on three different road profiles consisted of C, D and G profiles which are stochastic-uneven road. The present simulated vehicle is moved on three road profiles for various speeds with 70 Km/h on the C road, 50 Km/h on the D road and 20 Km/h on the G road. At each stage the accelerations which are induced by road excitations are applied to the automotive passenger seat in a vertical direction are calculated. Further, the vibration transmissibility are evaluated for all human body segments in vertical direction and in frequency range 0 to 50 Hz. However, the ideal range for vibration analysis of the human body is from 0 to 20 Hz, but for greater precision in the obtained results the frequency range is considered from 0 to 50 Hz. The applied accelerations to the under passenger's seat due to the road profiles including C, D and G profiles can be observed in Figs. 2-4 respectively. In addition, comparing the accelerations of the C road, D road and G road are also shown in Fig. 5.

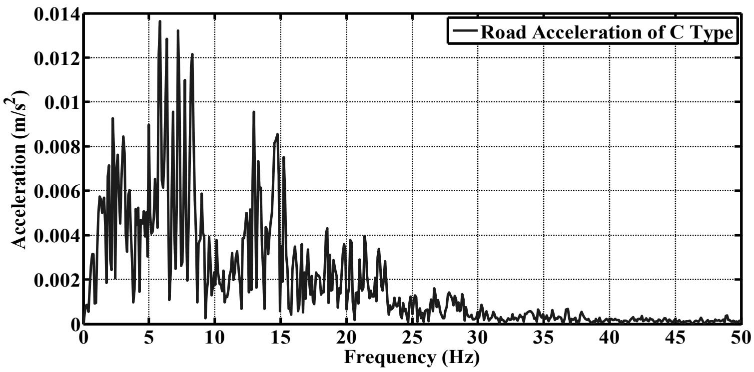

Fig2. C road acceleration

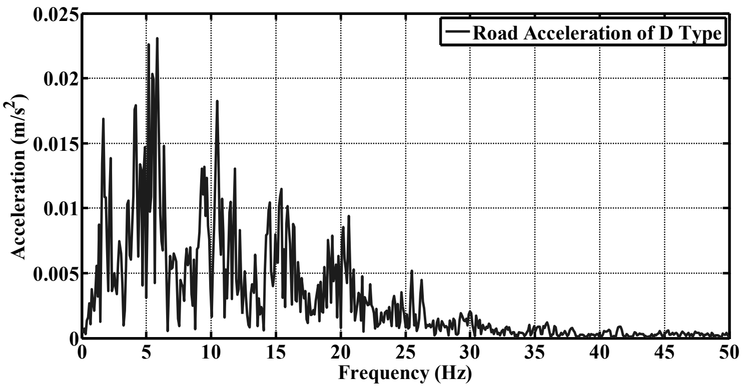

Fig3. D road acceleration

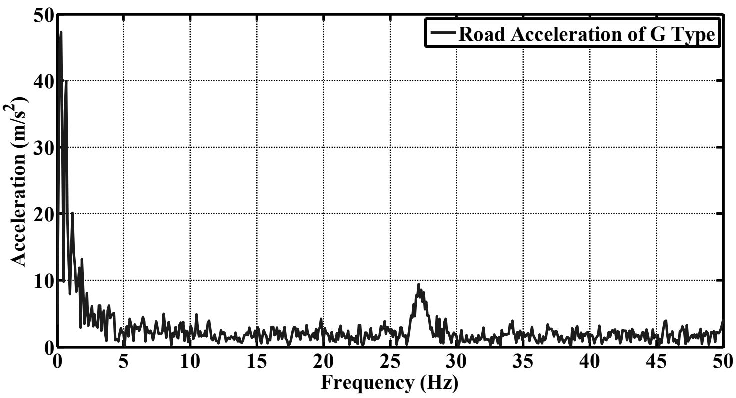

Fig4. G road acceleration

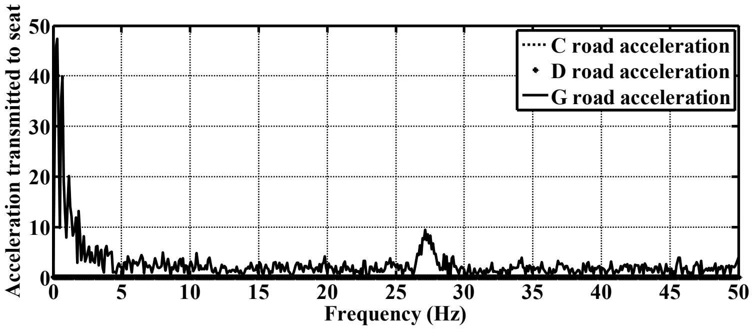

Fig5. The comparison between C, D and G roads accelerations

Table 2 The optimal parameters for a 6-DoF model

Parameters	Values	Parameters	Values
$c_1\ (Ns/m)$	2475	$k_1\ (N/m)$	49340
$c_2\ (Ns/m)$	330	$k_2\ (N/m)$	20000
$c_3\ (Ns/m)$	200	$k_3\ (N/m)$	10000
$c_4\ (Ns/m)$	250	$k_4\ (N/m)$	134400
$c_5\ (Ns/m)$	316	$k_5\ (N/m)$	2916
$c_6\ (Ns/m)$	3252.9	$k_6\ (N/m)$	146640
$c_7\ (Ns/m)$	2166.5	$k_7\ (N/m)$	66958
$m_1\ (kg)$	5.5	$m_5\ (kg)$	15.856
$m_2\ (kg)$	20	$m_6\ (kg)$	5.807
$m_3\ (kg)$	4.17	$m_{total}\ (kg)$	60.67
$m_4\ (kg)$	9.337		

5. 3. Results and discussion

In this part, the results of the models that were presented in the previous sections, will be discussed. The 6-DoF biomechanical model is created based on the obtained results by Boileau et al. [12]. While the experimental data include: Seat-To-Head Transmissibility, Driving Point Mechanical Impedance and Apparent Mass responses. To achieve the parameters of 6-DoF biomechanical model, the Boileau results can be used. The only linear requirement that must be met during the multi-objective optimization is the summation of the masses should be equal to 60.98 Kg in accordance with the following equation:

$$m_{Total} = \sum_{i=1}^{6} m_i = 60.98Kg \tag{16}$$

In Table (2), the optimal parameters of the proposed model is displayed using genetic algorithm.

Liang and Chiang [17], have done a comparison between twelve biomechanical models of 1 to 11 degrees of freedom and concluded that the Wan model [3], had the best fit with the Boileau experimental data. In order to a better compare for the presented model results with the experimental results the Wan model results are added in Figs. 6-8. In Fig.

6, the STHT responses are shown in the frequency domain 0 to 20 Hz. As indicated in Fig. 6, laboratory results has the highest value for transmissibility in 5 Hz, while in the current model this maximum value for transmissibility is occurred in the same frequency with a little difference in the value of transmissibility while for Wan model this difference is not appeared. As the adaptation is observed from Fig. 6, it can be said that the presented model is in a great improvement with Seat-To-Head transmissibility over previous models. In Fig. 7, the Driving Point Mechanical Impedance responses with the unit Kg/s in the frequency domain 0 to 20 Hz, are illustrated.

As shown in Fig.7, laboratory results for the DPMI responses had a peak in 5 Hz, while for the presented model the peak occurred in 5.5 Hz, but for the Wan model this peak happened in 7 Hz. Also, in all the frequency domain, a good match between the proposed model and experimental results have been established. While, this adjustment is occurred for the Wan model only at frequencies below 5 Hz.

The Apparent Mass responses are illustrated in Fig. 8, with the unit of Kg in the frequency range of 0 to 20 Hz. Last diagrams are shown a good agreement between experimental results and presented model with higher quality in compare with the Wan model.

Simulated vehicle is moved on the C road profile with a speed of 70 Km/h and the vertical accelerations are calculated. These accelerations are applied to the vehicle passenger model with 6-DoF in order to evaluate vibration transmissibility in vertical direction. The acceleration which are applied to human model in order to calculate transmissibility for individual segments for m1 to m6 are shown in Figs. 9 -14, respectively.

The maximum values for transmissibility and the corresponding frequency for each body segments which are shown in Figs.9 -14, are presented Table 3.

The simulated vehicle is moved on the D road profile with the speed equal 50 Km/h. The vibration transmissibility results for all body segments consisted of m_1 to m_6 are shown in Figs. 15 - 20 respectively.

The maximum values for transmissibility and the corresponding frequency for each body segments which are shown in Figs.15-20, are presented in Table 4.

The simulated vehicle is moved on the G road profile with the speed equal 20 Km/h. The vibration transmissibility results for all body segments consisted of m1 to m6 are shown in Figs. 21 - 26 respectively

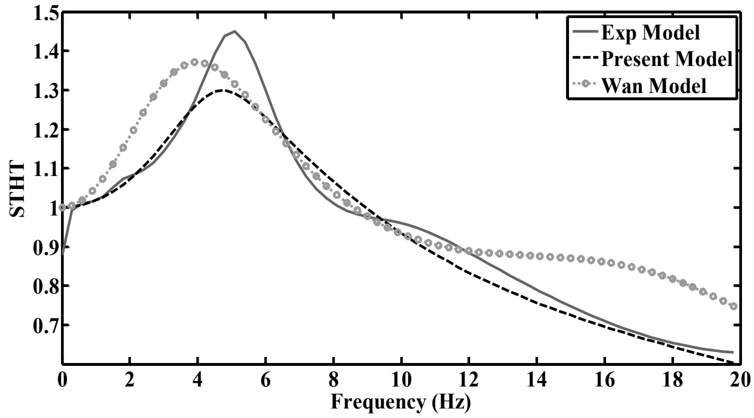

Fig6. Seat-To-Head Transmissibility responses

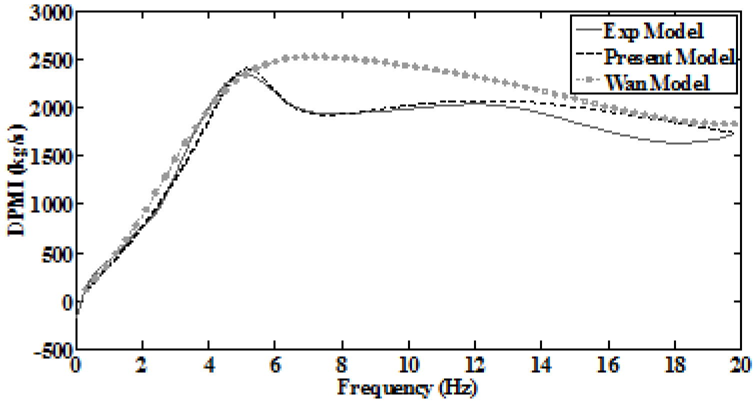

Fig7. Driving Point Mechanical Impedance responses

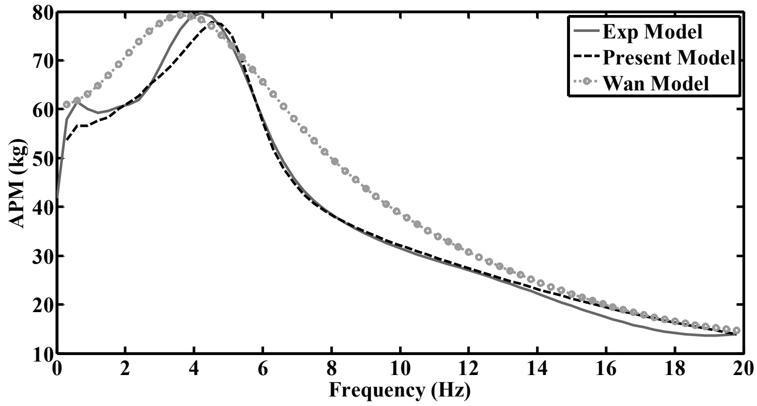

Fig8.. Apparent Mass responses

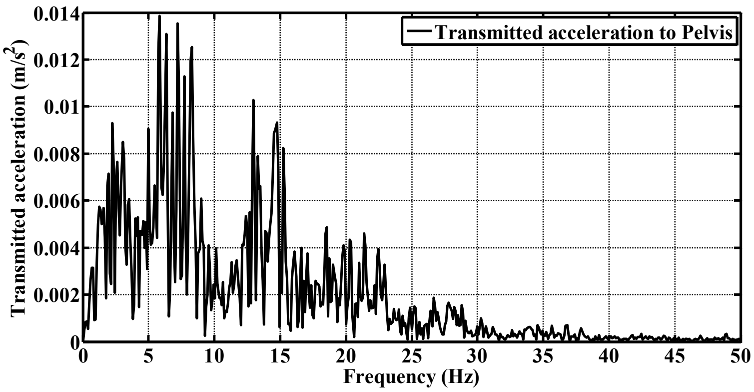

Fig9. Transmitted accelerations to pelvis due to C road profile

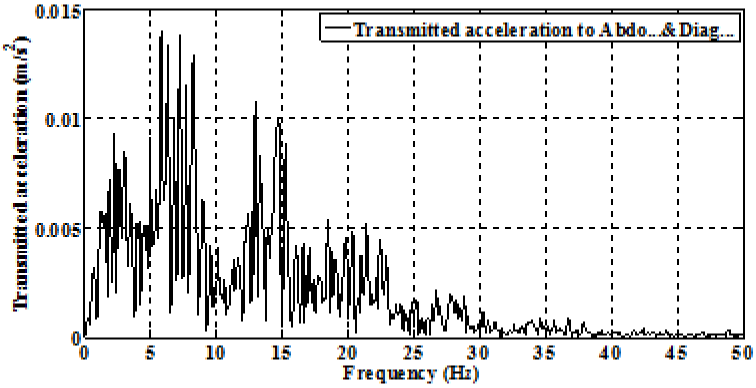

Fig10. Transmitted accelerations to abdomen & diaphragm due to C road profile

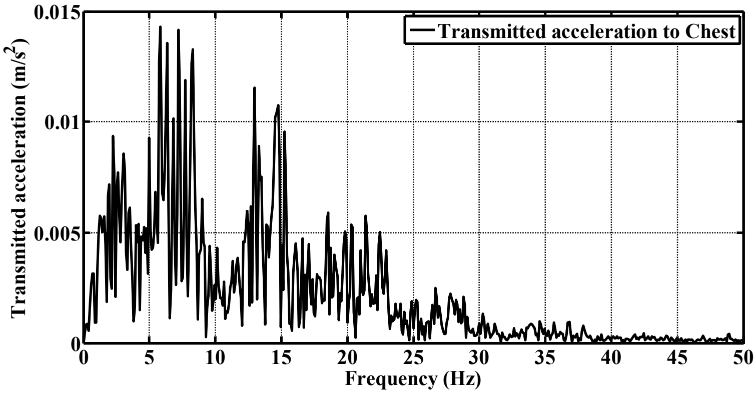

Fig11. Transmitted accelerations to chest due to C road profile

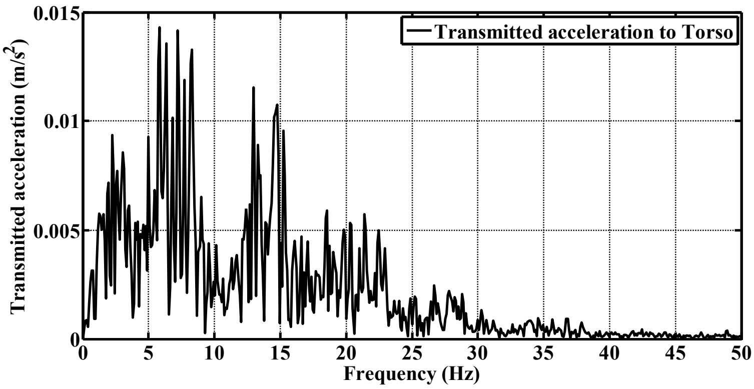

Fig12. Transmitted accelerations to torso due to C road profile

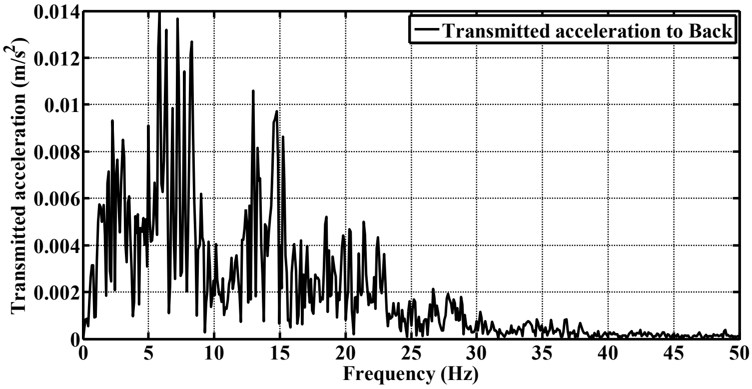

Fig13. Transmitted accelerations to torso due to C road profile

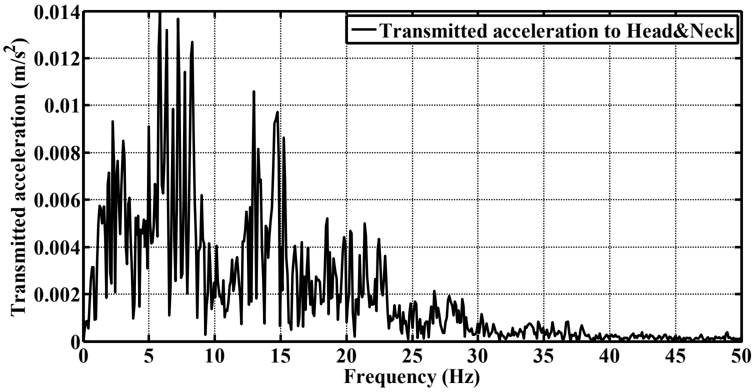

Fig14. Transmitted accelerations to head & neck due to C road profile

Table 3 The transmitted accelerations results for all body segments due to C road profile excitation

human body segments	maximum values of Transmitted accelerations (m/s^2)	Frequency range (Hz)
Pelvis	~ 0.0140	5-10
Abdomen & Diaphragm	~ 0.0135	5-10
Chest	~ 0.0139	5-10
Torso	~ 0.0130	5-10
Back	~ 0.0140	5-10
Head & Neck	~ 0.0140	5-10

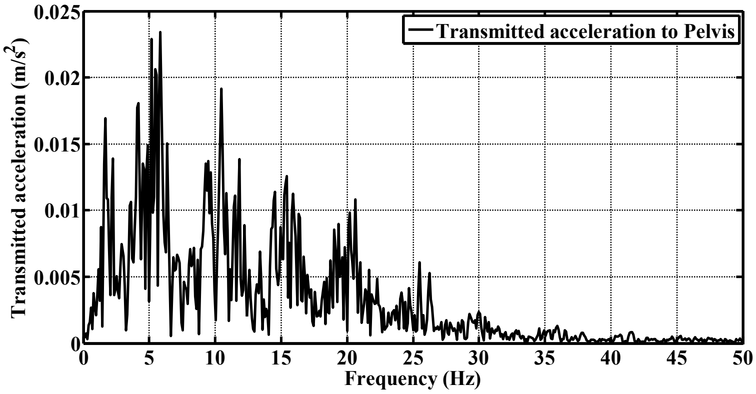

Fig15. Transmitted accelerations to pelvis due to D road profile

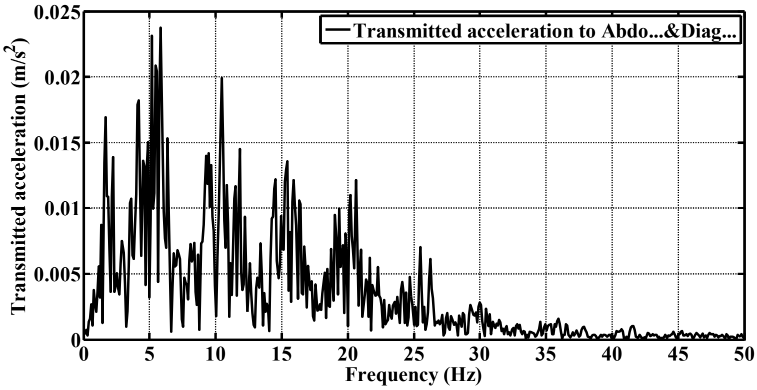

Fig16. Transmitted accelerations to abdomen & diaphragm due to D road profile

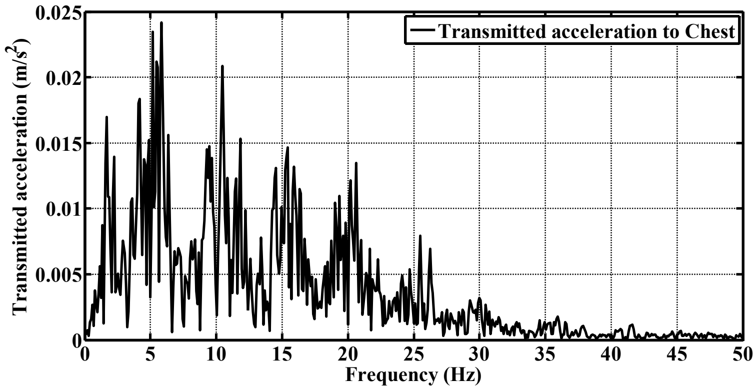

Fig17. Transmitted accelerations to chest due to D road profile

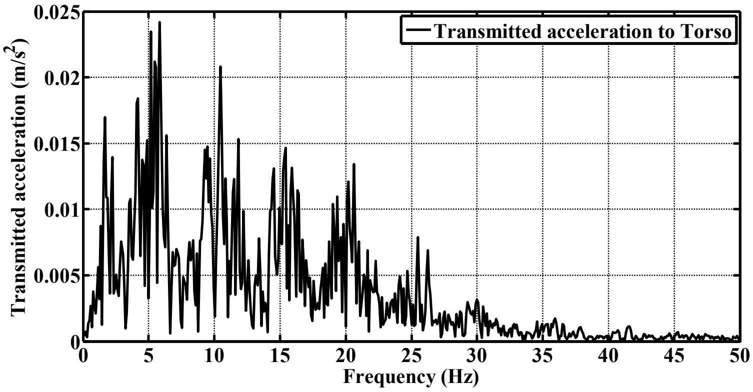

Fig18. Transmitted accelerations to torso due to D road profile

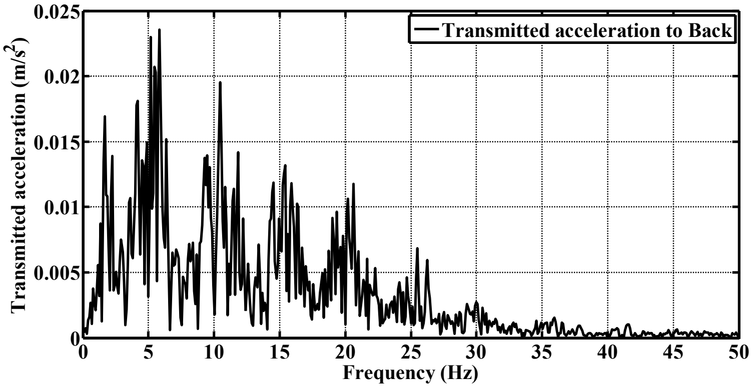

Fig19. Transmitted accelerations to back due to D road profile

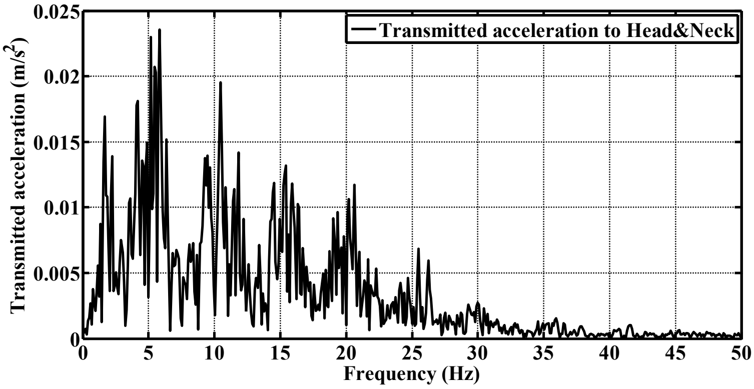

Fig20. Transmitted accelerations to head & neck due to D road profile

Table 4 The transmitted accelerations results for all body segments due to D road profile excitation

human body segments	maximum values of Transmitted	Frequency range (Hz)

	acceleration (m/s^2)	
Pelvis	~ 0.0235	5-10
Abdomen & Diaphragm	~ 0.0240	5-10
Chest	~ 0.0245	5-10
Torso	~ 0.0248	5-10
Back	~ 0.0230	5-10
Head & Neck	~ 0.0232	5-10

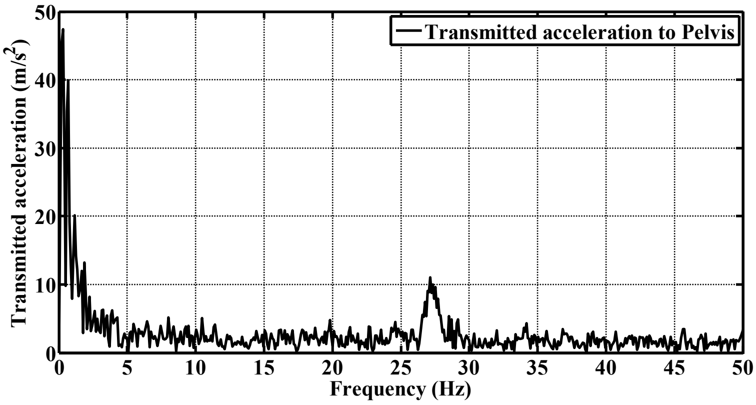

Fig21. Transmitted accelerations to pelvis due to G road profile

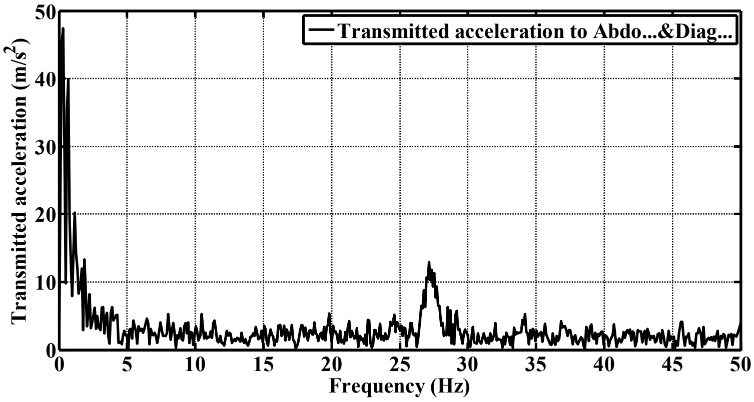

Fig22. Transmitted accelerations to abdomen & diaphragm due to G road profile

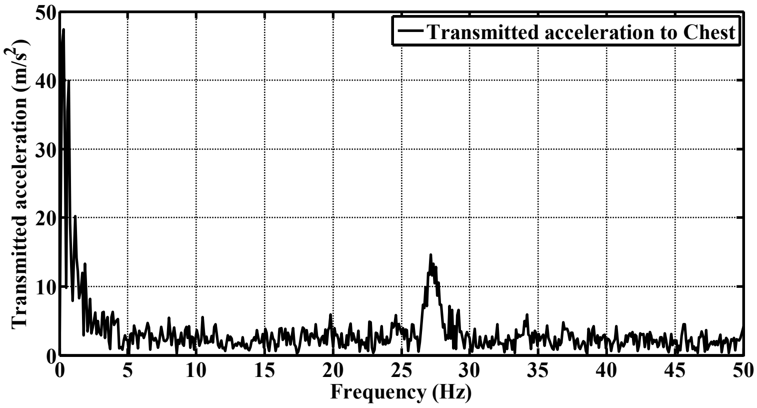

Fig23. Transmitted accelerations to chest due to G road profile

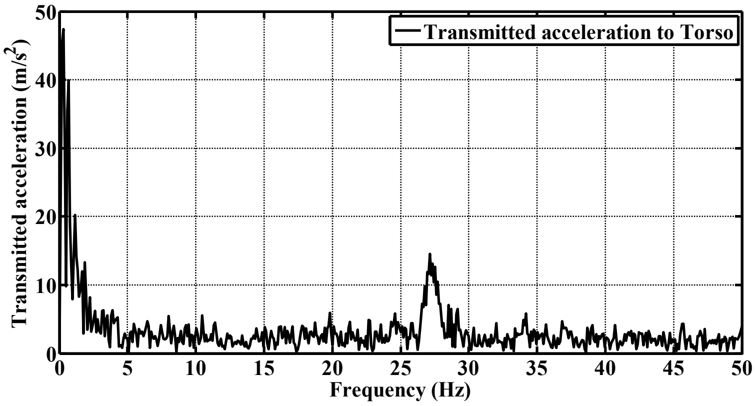

Fig24. Transmitted accelerations to torso due to G road profile

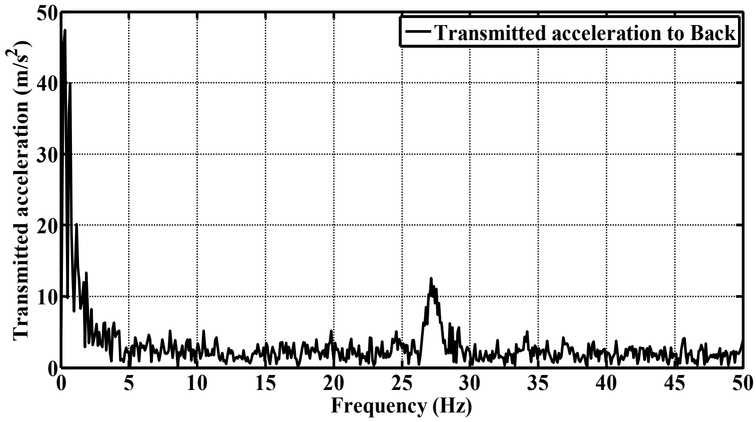

Fig25. . Transmitted accelerations to back due to G road profile

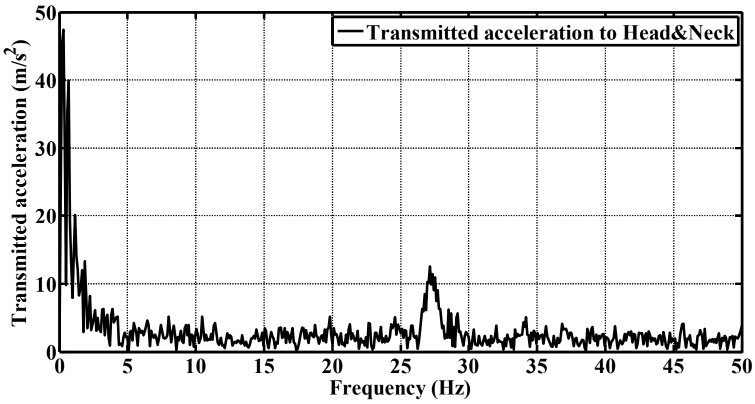

Fig26. Transmitted accelerations to head & neck due to G road profile

Table 5. The transmitted accelerations results for all body segments due to G road profile excitation

human body segments	maximum values of Transmitted accelerations (m/s2)	Frequency range (Hz)
Pelvis	~ 47.0	0-5
Abdomen & Diaphragm	~ 48.5	0-5
Chest	~ 47.8	0-5
Torso	~ 48.0	0-5
Back	~ 47.0	0-5
Head & Neck	~ 47.0	0-5

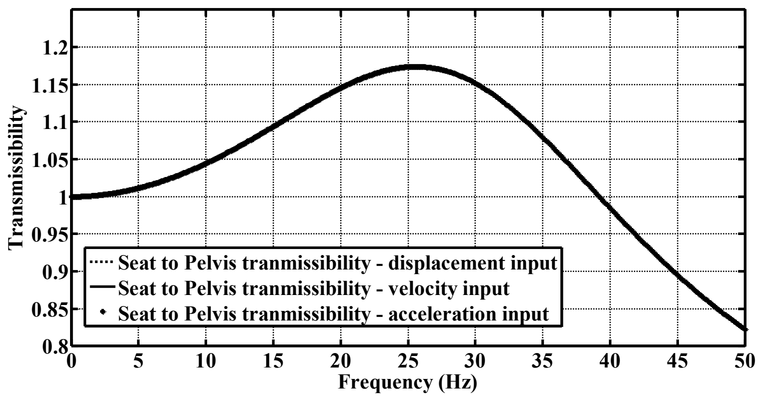

Fig27. . Seat to pelvis transmissibility

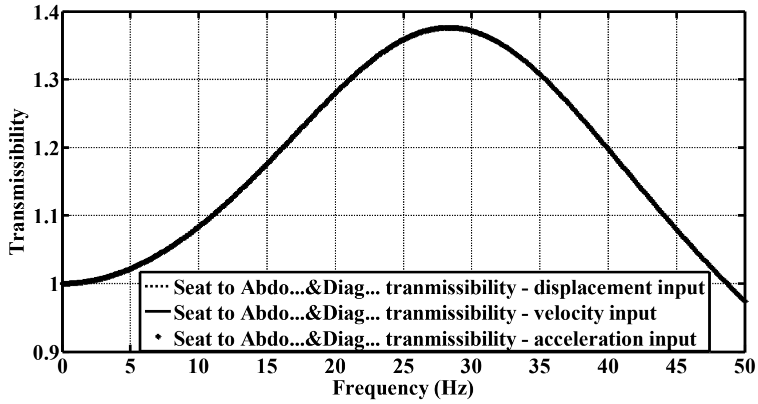

Fig28. Seat to abdomen & diaphragm transmissibility

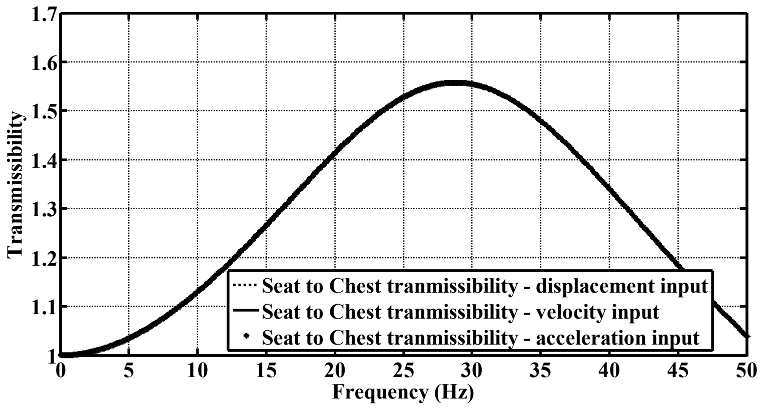

Fig29. Seat to chest transmissibility

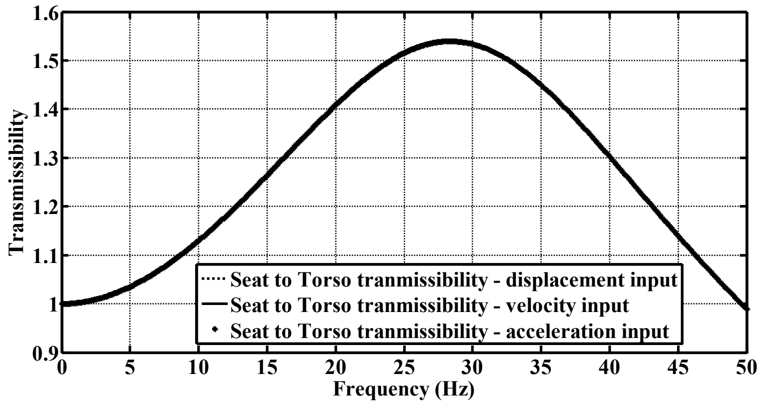

Fig30. Seat to torso transmissibility

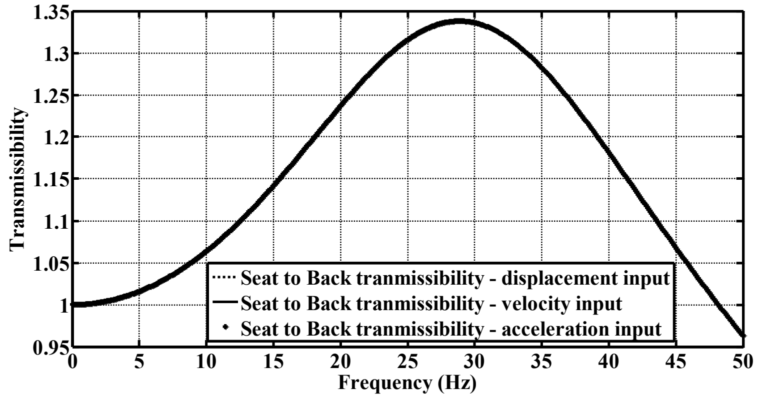

Fig31. Seat to back transmissibility

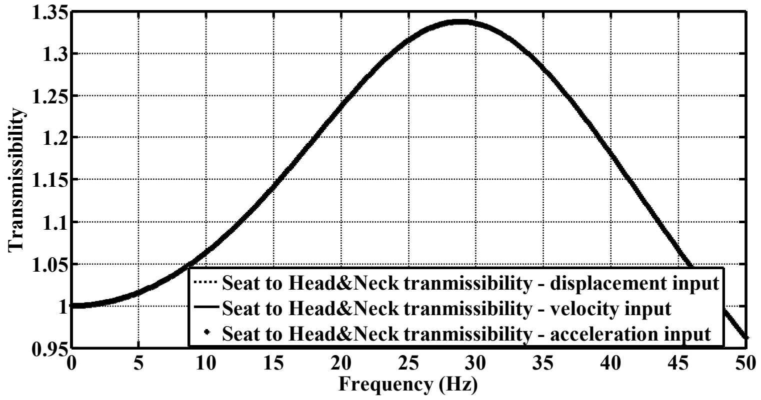

Fig32. Seat to head & neck transmissibility

Table 6. The transmissibility results for all body segments due to C, D and G roads profiles excitation with three inputs (applied displacement, velocity and acceleration to the occupant's seat)

human body segments	maximum values of Transmissibility	Frequency range (Hz)
Pelvis	1.17	20-30
Abdomen & Diaphragm	1.38	25-30
Chest	1.55	25-30
Torso	1.45	25-30
Back	1.33	25-30
Head & Neck	1.34	25-30

The maximum values for transmissibility and the corresponding frequency for each body segments which are shown in Figs.21-26, are presented in Table 5.

The proposed human body model is a linear system. For this reason, the transmissibility values are equaled for all body segments with three inputs (displacement, velocity and acceleration) applied to the occupant's seat under roads profiles excitation (C, D and G roads). The transmissibility values are shown in Figures 27-32, for m1 to m6 respectively.

The maximum values for transmissibility and the corresponding frequency range for each body segments which are shown in Figures 27-32, are presented in Table 6.

According to the obtained results, it can be said that the higher value of transmissibility for human body segments is occurred in the range of frequencies below 30 Hz. Moreover, the higher value of transmitted accelerations for human body segments are happened in the range of frequencies below 5 Hz.

Generally, the roads surfaces roughness is one of the most important parameter on the vibration transmissibility and transmitted accelerations values to the automotive passenger body. For this purpose, the governments should pay attention to roads construction in order to improve the transmitted accelerations and ride comfort.

6. . Conclusion

In this research, the automotive passenger body by a 6-DoF lumped parameter model is modeled without backrest and model parameters using Genetic Algorithms with the least error compare to laboratory results. Furthermore, the SANDERO vehicle model is developed with ADAMS/CAR software and by using the simulated vehicle three tests are investigated on three roads include: C, D and G roads. The mentioned vehicle is moved on roads with 20, 50 and 70 Km/h speeds and the transmitted accelerations to under the passenger's seat due to excitation roads are calculated. By using calculated acceleration, the vibration transmissibility and the transmitted accelerations for all human body segments are investigated. As a result, it can be said that with increasing roads surfaces roughness, the transmitted accelerations for human body segments significantly are increased. Also, the transmissibility values are equaled for all body segments under various inputs, because the human body model is a linear system. Further, the maximum values for transmitted accelerations happened for frequencies equivalent 5 to 10 Hz for C and D roads; but, for G road in frequencies domain under 5 Hz is occurred. In order to increase automotive passenger comfort the transmitted acceleration to the vehicle cabin must be reduced as much as possible. For this purpose, the vibration and energy absorbing foams in seat design or a shock absorber system can be used under passenger's seat. Finally, the effects of roads' roughness on transmitted accelerations to the automotive passenger body are shown. According to the obtained results, the C and D kinds are useful for the private vehicles while, the G road is useful for the off-road vehicles.

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