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Investigation of Vehicle Vertical Vibrations and Ground Effects While Passing Over a Speed Breaker

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Abstract— **Road surface roughness is an important parameter in the field of research in recent days. Road surface unevenness directly affects vehicle dynamics and ground–borne vibrations in the nearby buildings, historical monuments, and other structures. In this study, we use accelerometers to measure surface unevenness and a geophone to measure resulting ground vibration as the initial and running costs of the conventional profiler are very high. The sensor's information is simultaneously recorded with DEWESoft DEWE-43 data acquisition hardware. We compare the surface unevenness effect on ground vibration with a fixed speed of two vehicles, the car TAVERA NEO 3 comes with ground velocity 0.49 mm/s, and the bus has almost 8 times the car generation ground vibration (4.3 mm/s). Further, the acquired data has been analyzed in MATLAB environment. An analysis also has been done on produced vertical vibrations in suspension and the body of the vehicle.**

Keywords— **Vehicle dynamics; Surface unevenness/roughness; Quarter car model; Seismic vibration**

I. Introduction

This document is template. We ask that authors follow ibrations induced by road traffic are one of the major concerns in cities where traffic density on the road remains always high even excessively high in peak hours. People living in the buildings near these roads may complain about annoyance and building damage due to the vibration produced by the highly dense traffic. There may be long-term adverse effects on the historical monuments especially, those that are in weak condition. Even these vibrations can interfere with the sensitive equipment of nearby hospitals at operation theatres. According to report of NHTSA (2004), an unevenness index value less than 1500 mm/km is considered good, a value less than 2500 mm/km is satisfactory up to a speed 100 kmph, and values greater than 3200 mm/km are considered uncomfortable even at 55 kmph. Ground vibration also depends on the vehicle. To study the difference, we consider two different vehicles.

Further, vibration in the vehicle is also an important aspect as it largely affects ride comfort, vehicle safety, and mechanical failure of the vehicle parts (Mitschke and Wallentowitz,1972) Hence, vibration in the suspension and the body should be under the permissible range.

In the early days road surface unevenness was measured using conventional profilometers. However, as the cost of using these types of profilometers is very high, people trying to measure by using various non-contact-based sensors which are not only cheap but also have better accuracy. The

sensors include ultrasonic, LASER, camera, and accelerometer are even convenient to use and acquire data . In this study, we use accelerometers to measure the roughness of the road as it is the only sensor that gives the roughness where the tire is in contact with the road. On the other hand, vibration in the vehicle also plays a crucial role in the ride comfort and safety of the vehicle. In the present competitive market, to survive in the competition the industries have to be focused on passengers' ride comfort along with cost-effectiveness. Therefore, to achieve the aforementioned goals, a passenger vehicle has to be passed through several trials to become competitive in the market.

Surface unevenness is the major cause of vibrating the adjacent buildings and historical monuments as well as the vehicle itself. Consequently, for the safety of vehicles and adjacent constructions, surface unevenness must be surveyed periodically. Further, as stated earlier, the initial and running costs of conventional profilometers are very high thus it is significant to find some alternatives which is inexpensive without compromising much accuracy. Contrary, unevenness of the surface influences vehicle operating cost, riding comfort, safety, and wear and tear of the tires of the vehicles. Hence, for passenger comfort and safety the vibrations in the car in the suspension as well as in the seat should be under control even in harsh road surface conditions. However, this vibration in the car can be controlled by improving the suspension system of the vehicle.

Hence, this study aims to find both the vibrations ground borne and vehicle vertical vibration which not only determine the vibration in the nearby structures or historical monuments of importance but also the vibration in the vehicle itself which is the indication of ride comfort.

Rest of the paper has been organized as follows: section 2 presented review of related literature; section 3 presented problem statement and details of hypothesis of this study; section 4 provides outcomes of this study; finally, section 5 presented the conclusion of this research along with future scope.

II. Related Literature

In this section related literature has been presented on the following two topics: Ground vibration due to heavy traffic on road and vehicle vertical vibration.

Ground vibration generated due to heavy traffic on the road is serious concern as it has significant negative impact on the buildings, infrastructure, and the environment. Vehicle vibrations, particularly those from large trucks, have the potential to destroy structures, compromise pavement integrity, and contaminate the surrounding noise. The study on the causes, consequences, and mitigation techniques of traffic-induced ground vibration is summarized in this article (in sub section 2.1).

A. Ground Borne Vibration

Hence, from the above backdrop, it can be found that, Heavy traffic-related ground vibrations are a complicated problem including interconnections between moving cars, surface imperfections, and building components. To decrease the effects of these vibrations, recent study emphasizes the significance of vibration isolation techniques, vehicle technology, and road maintenance.

Measurement of ground borne vibrations due to rail can be frequently found in the literature. For example, Sanayei et al. (2013) measured ground-borne vibration at six sites in the Boston city among them three sites were chosen for measuring train-induced vibration and another three were selected for subway-induced vibration. Stolarik et al, (2019) presented a theoretical analysis and novel findings about the seismic load on old and decaying structures in brownfield sites because of ground- borne vibration from automated construction. On the other hand, Ainalis et al., (2018) presented comparison between different approaches to the analysis of a set of tri-axial ground vibration measurements produced by road, rail, and explosive blasts. However, ground borne vibration due to rail transportation has been discussed by various authors (Shao et al., 2023; Augusztinovicz et al., 2021; Sheng, 2019; Villot et al., 2018).

Jean and Carter (2021), suggested and measured ways to lower the structures' internal vibration and ground-borne noise levels due to railways. Further, the objective of Dashti (2023) is to create a ground-borne noise prediction model for subterranean tunnels that will be utilized in a project by the Swedish Transport Administration. In the other study of Dashti et al., (2024), ground borne prediction model has been developed considering various new factors such as train type, track type, track treatment, train speed, distance attenuation, foundation coupling, and floor-to-floor attenuation. Therefore, it can be seen from the literature that, most of the articles discussed on ground borne vibration due to railway transportation. Further, previous researchers suggested that to solve the problems caused by ground vibrations caused by road traffic, more study and development in these fields are necessary (Khan and Burdzik, 2023).

B. Vehicle Vertical Vibration

In this section, literature review on the topic of vehicle vertical vibration has been discussed. A crucial component of vehicle dynamics that impacts handling and ride comfort is vertical vibration. The interaction between the vehicle's suspension system and tires, as well as irregularities in the road surface, are the primary causes of these vibrations. It is essential to comprehend and manage these vibrations to enhance vehicle efficiency and passenger comfort. A crucial component of vehicle dynamics that impacts handling and ride comfort is vertical vibration. The interaction between the vehicle's suspension system and tires, as well as irregularities in the road surface, are the primary causes of these vibrations. It is essential to comprehend and manage these vibrations to enhance vehicle efficiency and passenger comfort. Different studies related to vehicle vertical vibration can be found in the literature. For example, Xu et al. (2017) performed nnaturalistic driving tests using real vehicles on six roads to examine the level of driving comfort and identified the key influencing factors. Another article found of the authors about the level of ride comfort of passenger cars on two-lane mountain highways (Xu et al., 2017). Later, Kasprzyk et al. (2017) presented that Linear Variable Differential Transformer (LVDT) measure the suspension deflection and determine its relative velocity. The article presented that use of LVDT improve ride comfort by controlled vibration attenuation of the car body. Du et al. (2021) proposed a new method by applying deep learning to measure passenger car vibration comfort based on the vibration signals.

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C. Contribution to the Study

In this study ground vibration generated while a vehicle passes through a speed braker is determined for the small car and a bus. This is important to investigate the vibration propagation to the nearby structures or to the historical monuments so that the damage can be prevented due to vibration either by reducing or repairing road or by renovating structures. Also, the accelerometer sensors are deployed on the vehicles to study the vibration in the vehicle itself. Which actually indication of road roughness and vehicle condition which effects the passenger ride comfort. This road roughness is also a major factor of ground vibration generated.

III. Problem Formulation And Hypothesis Development

The previous work has presented various approaches in road Surface unevenness measurement. The approaches and their application based on the types of sensors used have been analyzed and the problem faced in their application has been discussed in this section. It has been followed by the approach being followed in this study, and the hypothesis developed to minimize the problem.

A. Problem Statement

Road surface unevenness measurement and compare to corresponding ground borne vibration is a very challenging field of research. The main challenge is to detect the vibration in real time. It will be very challenging to spot out the corresponding vibration of the road section. The synchronization of geophone and accelerometer is essential. Majority of the work have been done only to find surface unevenness. There are lots of problems in using mechanical arrangements because of low accuracy and cost. Use of Laser is costly and not convenient. Laser gets affected by sunlight. Ultrasonic sensors are also found a number of disadvantages including loss of energy in receiver and affection to pressure, temperature and other environmental conditions. Moreover, as in this study, it is required to compare the roughness to corresponding vibration, also the surface area is required where the dynamic load is exerted by the vehicle. This point cannot be seen by any of the above. Hence only option is to use accelerometer on the unsprang and on the sprung masses of the vehicle. After that an operator has to convert the acceleration data to displacement and has to feed in the quarter car model suspension system. Another problem can be found in the tire-road interaction due to variation of height with respect to tire (Zhang et al., 2021).

B. Hypothesis Development

H1 - Road unevenness can be determined by using two accelerometers effectively if we know the vehicle parameters. Although, the unevenness we will find is not the actual one but how the tire experiences the road.

H2 - Road unevenness directly affects the ground-borne vibration and can be found as a function of road unevenness for a particular vehicle.

H3 - Vehicle vertical vibration can be analyzed using two accelerometers

The hypothesis formed in this section has been tested on the road with two vehicles and results are obtained. Ground vibration is captured with the single vehicle on the bump at a distance of 1 meter from the road end. However, in the practical cases the number of vehicles and type of vehicles differ and those are yet to be done. The methodology of testing the hypothesis and obtaining results are described in the subsequent section.

IV. Design Of Experiment

The basic idea is to study the vertical vibration and ground borne vibration and simulate the quarter car model for predicting virtual road profile. It is noted that the profile we get from simulation are solely with assumed data. However, even for golden vehicle (i.e. all the parameters of the vehicle) the road profile generated is not the actual one, rather the profile of how the tire is experiencing the road. On the other hand, ground vibration i.e. seismic signal is captured where bump is present to study the effect of vehicle operation on the bump of the road. It is further noted that the vibration will be more near bump because of more dynamic thrust on the road on the bump. Hence, in this study, a Simulink model of quarter car model is developed to simulate the predicted road profile with the acquired acceleration information and assumed vehicle parameters.

In case of, vibration, the main parameters are frequency and the acceleration. The acceleration of the sprung (body) and unsprang masses are obtained by the Accelerometers directly. The further processing (i.e. extracting frequency components, Power spectral density etc.) of the acceleration data has been done on the MATLAB platform. The schematic diagram of the above processes has been shown below in Figure 1.

Step 1: Data is obtained by using two different accelerometers acquired with DEWETRON (Data acquisition system (DAQ))	→	Step 2: The obtained data is processed using MATLAB and corresponding velocity, displacement and frequency components are determined

Figure 1: Flowchart of processing Acceleration data

At the same time a *geophone* is used to capture vibration of the seismic signal. The seismic data is also acquired using DEWETRON data acquisition system. The schematic diagram of the same is shown below in Figure 2.

Data is acquired using single axis Geophone using DEWETRON data acquisition system

↓

Data is processed in MATLAB and Fast Fourier Transform (FFT) is generated to study frequency

Figure 2: flowchart of processing geophone data and Geophone

A. Experimental Setup

The experimental setup can be divided into three distinct divisions: First, application of Sensors i.e. Accelerometers and Geophone, Second, Data acquisition system (DAQ) i.e. DEWETRON (with DeweSoft software) and third, application of MATLAB to take care of the processing part of the data. The experimental set up for the bus unsprung mass accelerometer is shown in the below in Figure 3.

Figure 3: Unsprung mass Accelerometer position

The position of sprung mass accelerometer on the bus is shown in the Figure 4.

Figure 4: Sprung mass Accelerometer position

The geophone position in the case of bus is shown in the below in Figure 5. The geophone is placed in 1 meter distance in the same line of the bump on the near ground.

Figure 5: Geophone position in the experimental setup

B. Sensor Characteristics

In this study, we use accelerometer to measure acceleration of vehicle and geophone to measure ground vibration. There are different types of accelerometers available based on their working principle i.e. piezoelectric, piezoresistive and capacitive. However, all these accelerometers convert mechanical motion into electrical signal. The type of accelerometer we use is piezoelectric.

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The accelerometers are of Bruel & kjaer type 4533-B-002 with IEPE excitation current of 4 mA. Sensing element of piezoelectric accelerometer is piezoelectric Type PZ 23, which is a piezoceramics. We use Piezoelectric accelerometer for the following reasons: (i) extremely wide dynamic range with low output noise (ii) suitable for measuring shock as well as very imperceptible vibration (iii) good linearity over the wide dynamic range (iv) wide range of frequencies and highly sensitive (v) No moving parts hence no wear (vi) acceleration signal can be integrated to determine velocity and displacement signal easily. Furthermore, the Piezoelectric accelerometer we used are of measurement range of ±14g peak, sensitivity of 49.04 mV/m/s2 and 50.59 mV/m/s2, bandwidths of 2 Hz to 1.5 kHz and resonance frequency of above 38 kHz.

Geophone is the most popular sensor for measuring seismic vibration. In this study, GS- 20DM with sensitivity 19.7 V/m/s has been used for acquiring the ground velocity.

C. Data Acquisition

A data acquisition system acquires data from the sensor and presents the acquired data on computer with the help of software. The sensor is connected to the DAQ hardware and the hardware is connected to PC with software. The hardware is DEWE- 43A and DEWE- 43V and the software is Dewesoft. For Accelerometer sampling rate, we fix 2000 Hz for bus and 200 Hz for car (four- wheeler). Geophone sampling rate are 20000Hz and 1000 Hz respectively. The schematic diagram of the connections and setup has been shown in the block diagram below in Figure 6.

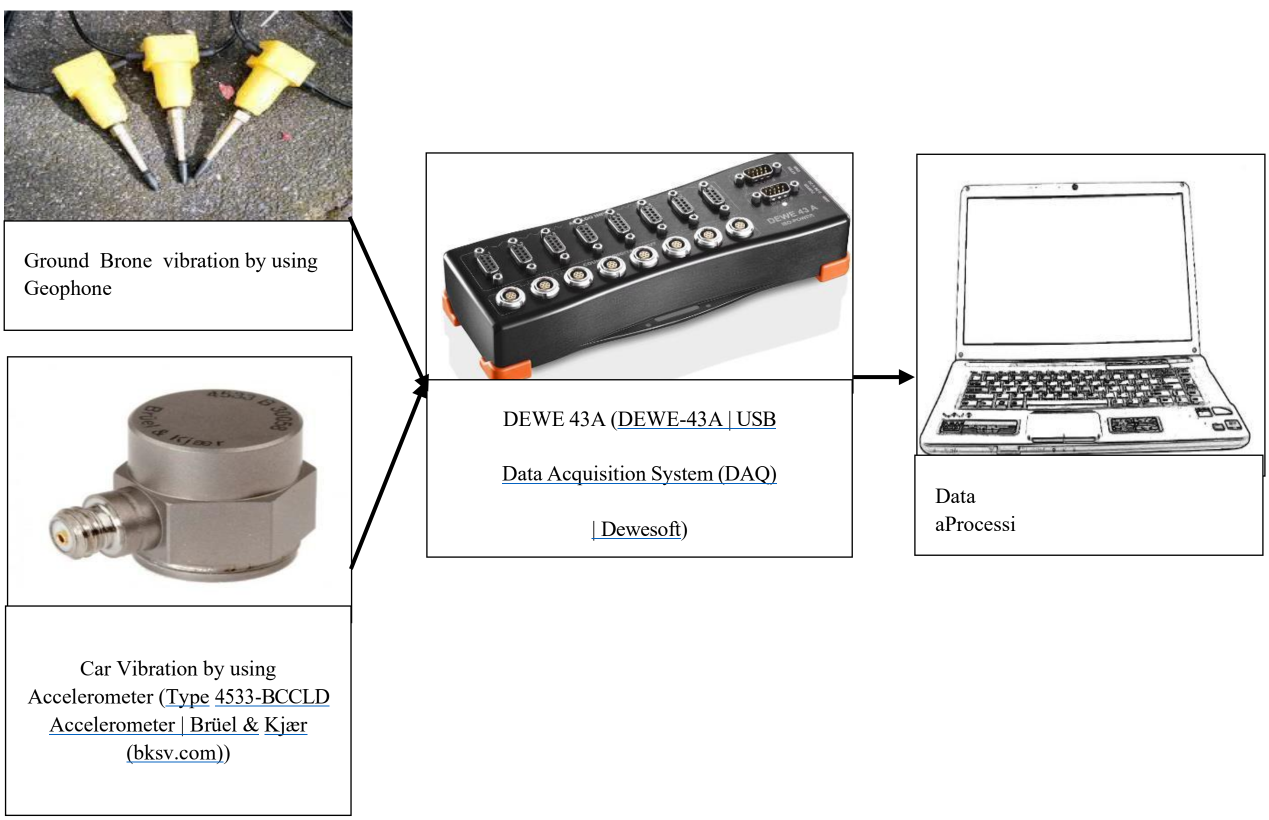

Figure 6: sensor placements and all connections

In Figure 6, two accelerometers are used on the vehicle to determine vehicle vibration- One on the sprung mass and one on the unsprung mass of the vehicle. Both the accelerometers are connected with one of the DEWE 43A. This accelerometer information is recorded in a PC with Dewesoft.

After that the file is exported in MATLAB file (.mat) and analysed in MATLAB. One geophone has been mounted at a distance of 1 meter from the road to record ground vibration. This sensor was also connected to another DEWE 43A hardware system to record data.

D. Processing of Acceleration Data

The acceleration information is exported from Dewesoft to .mat file for further processing. On exporting the file in .mat file the data is analysed in MATLAB to find FFT and subsequent double integration in MATLAB using Simpson's 3/8th rule (Qureshi, 2023).

Simpson's 3/8th rule is numerical integration method which gives better result than existing Trapezoidal and Simpson's 1/3rd rule. The sequence of processing acceleration data is given below in the block diagram in Figure 7.

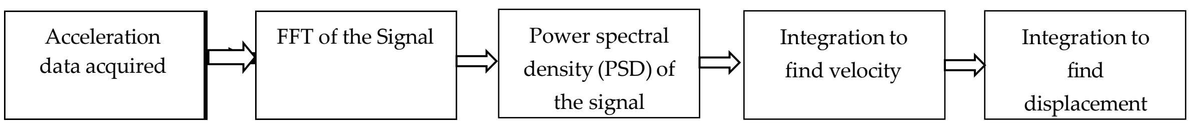

Figure 7: Sequence of processing accelerometer information

E. Processimg of Geophone Data

Further, we export it in .mat file for further processing and we obtain the velocity of the ground due to the vehicle operation on passing the bump. FFT has been determined to analyze frequency. Power spectral density (PSD) is also obtained to check signal strength. The sequence of processing the signal has been presented in block diagram in the Figure 8.

After finding ground velocity, it can be easily estimated that at that position for the operation of the vehicle how much vibration is producing and if that vibration exceeds the human perception level, it will be felt by human. Moreover, if the vibration is too large that it can damage the structure the road is potentially to be repaired.

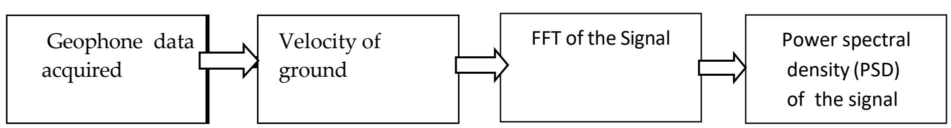

Figure 8: Sequence of processing ground vibration signal

V. RESULTS AND DISCUSSIONS

The experiment has been done in real condition with a single vehicle for experiment purpose. In case of real condition, a number of different kinds of vehicles can operate.

A. Ground Vibration for Car and Bus

The Figure 9 presents the ground velocity of the Four-wheeler car (For e.g. Chevrolet Tavera Neo 3) and a bus (For e.g. Swaraj Mazda) in below. The average ground velocity at 1 m distance for bus is around 4.3 mm/s and for the car it is 0.499 mm/s. In the Figure 10 the peak frequency of the ground vibration is plotted. The average peak frequency in the case of bus is 17 Hz whereas in the case of car it is 11.67 Hz. The ground velocity graph for experiment 1 is shown in the Figure 11.

While the bus is crossing the bump eventually the velocity increases to 4.3 mm/s. Although this is very less than human perception level, it is for only one vehicle. In actual case number of vehicles will be there and vibration will increase exponentially. At around 8 seconds the event occurs. In the below Figure 12 presents the FFT of the signal. The graph clearly shows that the peak frequency is 17.19 Hz. And this frequency is somewhat constant in every experiment with the same vehicle and other conditions. As the frequency is somewhat more the attenuation of the signal with the distance is also has a higher value which tells the vibration wave will not travel a lot distance unlike the wave generated in Earth quake. In Earth quake the peak frequency is very small and hence it travels a longer distance.

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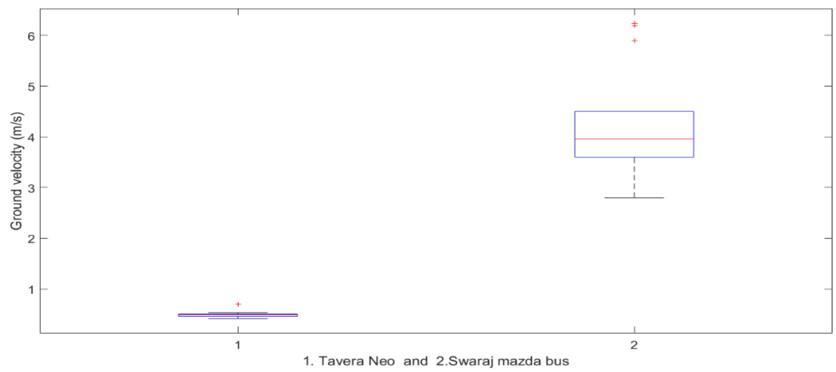

Figure 9: Ground velocity for both the vehicles

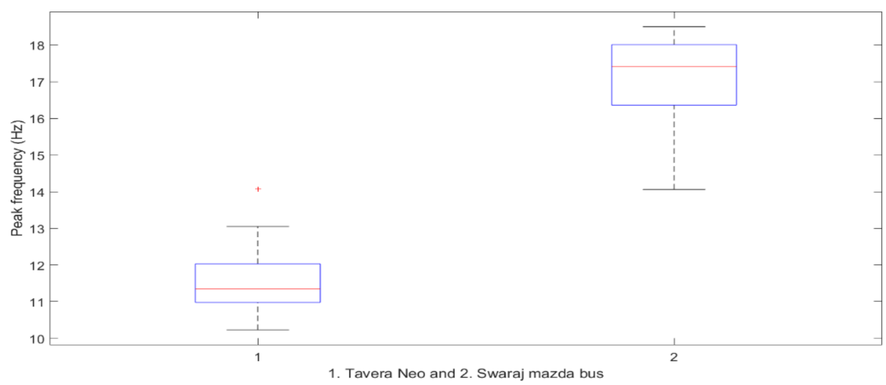

Figure 10: Peak frequency of the ground vibration

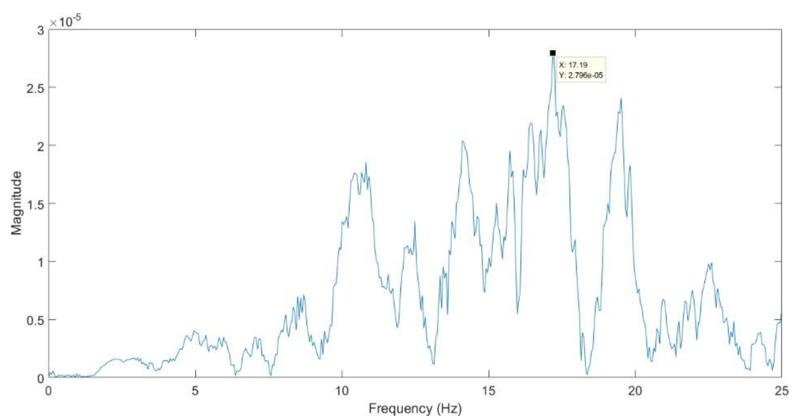

Figure 11: Ground velocity plot for bus

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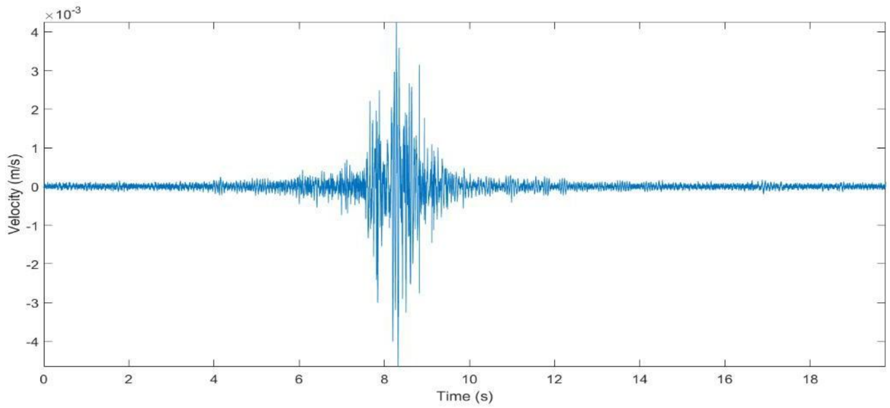

Figure 12: FFT of ground vibration for bus

The spectrogram of the signal is plotted and shown below in the Figure 13. Spectrogram tells us the energy content at each frequency. The y-axis is the frequency axis whereas x-axis is the time axis. At around 8 seconds at the peak frequency the energy is maximum, denoted by the color red. The energy is in the unit dB/Hz. Along with ground vibration we capture the vehicle vibration using two accelerometers. The average value of the acceleration is about 16.32 m/s2 or the sprung mass of the bus and corresponding velocity found by integrating the acceleration data by Simpson's 3/8th rule is about 0.1838 m/s. On further subsequent integration of the velocity data the average displacement comes to be around 2.6033 mm. The peak frequency in the FFT plot is near somewhat 2.788 Hz. The ground velocity graph for the car is shown in the below Figure 14. While the car is crossing the bump eventually the velocity increases to 0.5 mm/s. Although this is very less than human perception level, it is for only one vehicle. In actual case number of vehicles will be there and vibration will increase exponentially. At around 8 seconds the event occurs. The below graph in Figure 15 is the FFT of the signal. The FFT is generated in the MATLAB. The graph clearly shows that the peak frequency is 17.19 Hz. And this frequency is somewhat constant in every experiment with the same vehicle and other conditions.

As the frequency is somewhat more the attenuation of the signal with the distance is also has a higher value which tells the vibration wave will not travel a lot distance unlike the wave generated in Earth quake. In Earth quake the peak frequency is very small and hence it travels a longer distance. The spectrogram of the signal is plotted and shown below in the Figure 16. Spectrogram tells us the energy content at each frequency.

The y-axis is the frequency axis whereas x-axis is the time axis. At around 8 seconds at the peak frequency the energy is maximum, denoted by the color red. The energy is in the unit dB/Hz.

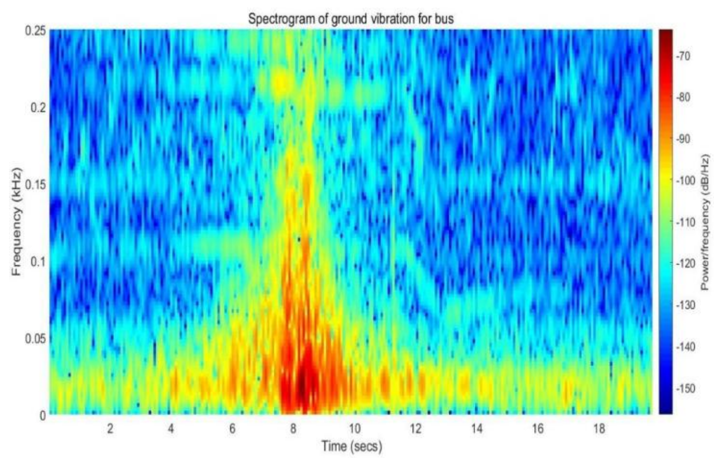

Figure 13: Spectrogram for ground vibration for bus

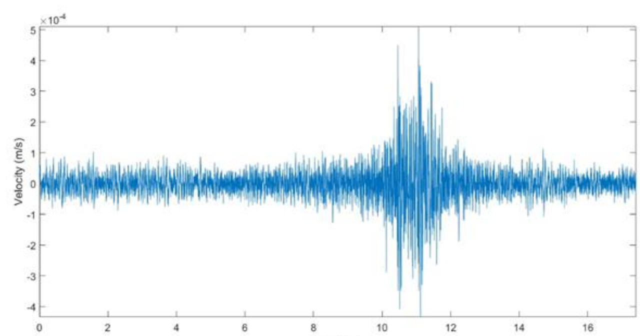

Figure 14: Ground velocity plot for car

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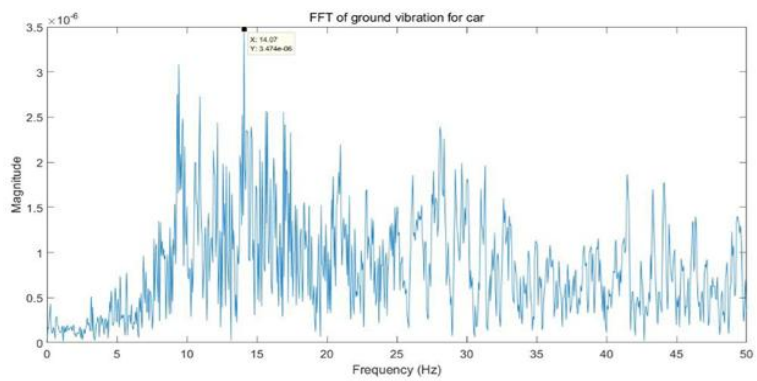

Figure 15: FFT plot for ground vibration for car

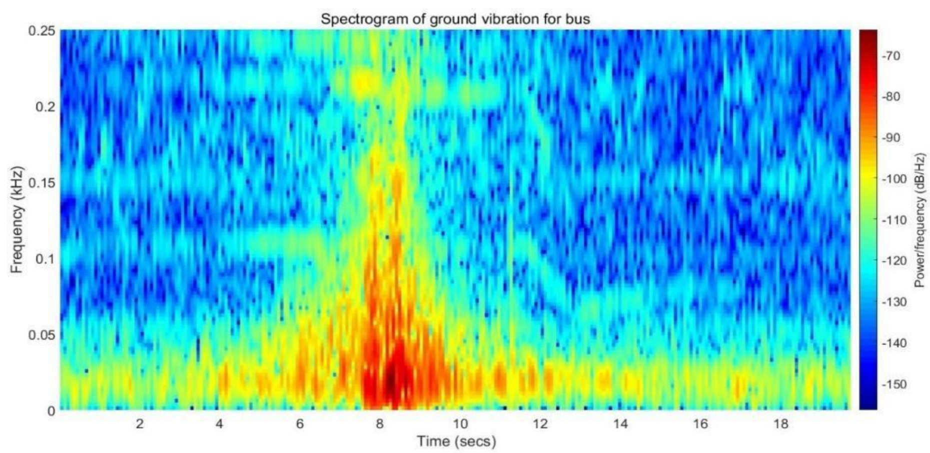

Figure 16: Spectrogram of ground vibration for bus

B. Vehicle vibration for both the vehicles

Peak frequency of the sprung mass of a vehicle is actually the deciding factor of the passenger comfort. In the below figure it is clearly shown that the peak frequency of the car is very low in the case of car. Hence car has more degree of comfort as comparison to bus. The average peak frequency for the car is 0.16 Hz whereas for bus it is 2.8 Hz. In the below Figure 17 the data we collected with accelerometer mounted on sprung mass of the vehicles is shown. The peak acceleration of the sprung mass of both the vehicles is shown below in the Figure 18. The average acceleration for the car is 0.0066 m/s2 and for the bus it is 16.32 m/s2. Velocity of sprung mass of both the vehicles is shown below in the Figure 19. The velocity for the bus is 0.1838 m/s and for the car 0.0044 m/s. The less value depicts the degree of comfort of the vehicle. The sprung displacement of the bus is 2.603 mm and for the car it is 1.515 mm. It can be easily visualized that less displacement is good for passenger. The Figure 20 shows the sensor data of sprung mass displacement.

Peak frequency of the unsprung mass of the both vehicles are somewhat same varying from 14 to 16 Hz. The plot of the acceleration of the unsprung mass for both the vehicles is shown below in the Figure 21. The below graph is of the acceleration of the unsprung mass of the bus. As in the Figure 22 shows at around 18 seconds the acceleration becomes around 14 m/s2. The higher value of the acceleration tells higher vibration and degree of discomfort. The velocity of the above acceleration signal is shown in Figure 23. When the event occur the velocity reaches at its maximum is around 0.25 m/s which are greater than the value which we got in the case of sprung mass. The displacement graph is shown in the Figure 24 below of the above signal. The displacement value is around 3.5 mm. The displacement value is not the key factor of comfort. Still low displacement is better. The main factor which plays key role for passenger comfort is peak frequency. One can even imagine that if even the amplitude of the signal is higher, for the low frequency the passenger can feel comfortable.

International Journal of Recent Development in Engineering and Technology
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The FFT of unsprung mass vibration is shown in the Figure 25. The peak frequency in the FFT plot is 16.82 Hz. The power spectral density plot for the bus unsprung mass is shown below in the Figure 26. At the peak frequency the energy is maximum. The acceleration value is far more than in the case of sprung mass which is expected. Not only the acceleration, velocity and displacement are also higher with higher frequencies. The lower frequency of the sprung mass dictates the comfort of the passenger seating over sprung mass. It is concluded if the passenger would seat on the unsprung mass, the passenger would feel more uncomfortable. The design is done in such a way so that the frequency ultimately passenger feel should be as low as possible which further depend upon the suspension system quality as well as the superiority of the design. Graphs for the first experiment for the sprung mass are given below in Figure 27. The first graph is of the acceleration of the sprung mass of the car. As the figure shows at around 4000 samples the acceleration becomes around 0.006 m/s2. The higher value of the acceleration tells higher vibration and degree of discomfort. The velocity of the above acceleration signal is shown in Figure 28. When the event occur the velocity reaches at its maximum is around 0.0096 m/s which are lesser than the value which we found in the case of unsprung mass. The displacement graph is shown the figure below in Figure 29 of the above signal. The displacement value is around 1.438 mm. The displacement value is not the key factor of comfort. Still low displacement is better. The main factor which plays key role for passenger comfort is peak frequency. One can even imagine that if even the amplitude of the signal is higher, for the low frequency the passenger can feel comfortable. The FFT of unsprung mass vibration is shown in the below figure in Figure 30. The peak frequency in the FFT plot is 0.1693 Hz.

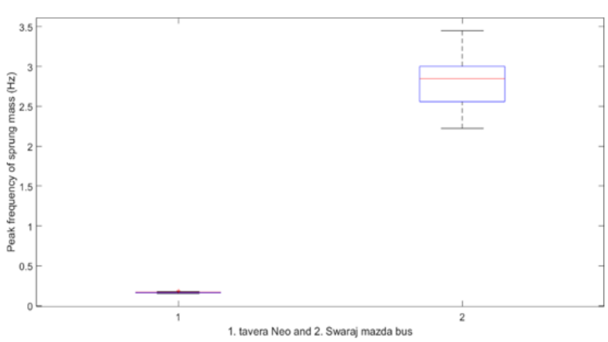

Figure 17: Peak frequencies of sprung mass

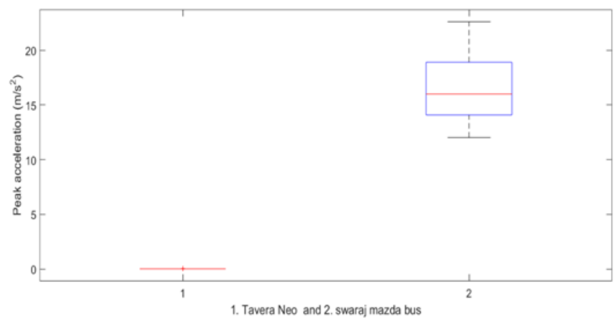

Figure 18: Accelerations of sprung mass

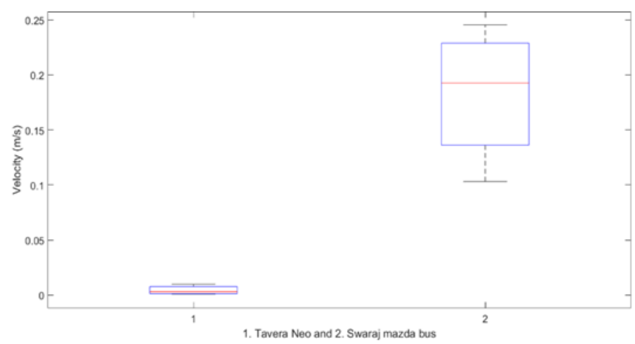

FIGURE 19: VELOCITIES OF SPRUNG MASS

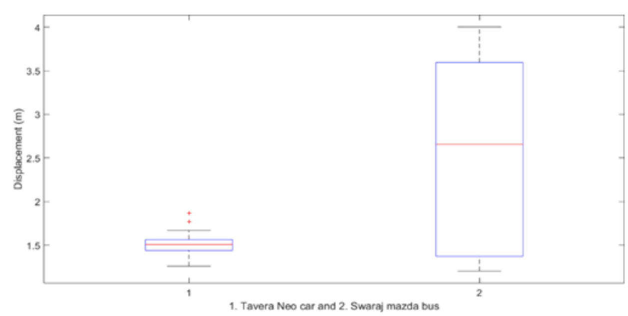

Figure 20: Displacement of sprung mass for the vehicles

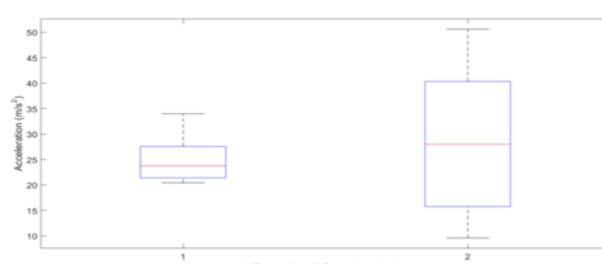

Figure 21: Peak acceleration of unsprung mass for the vehicles

International Journal of Recent Development in Engineering and Technology
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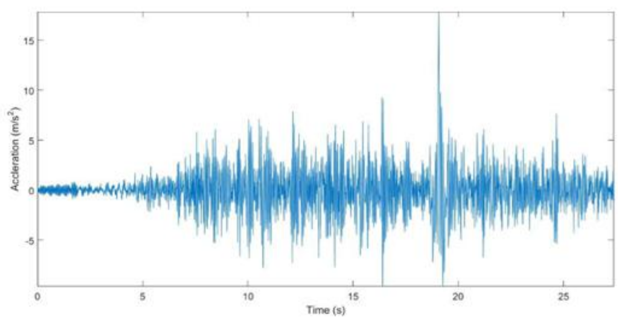

Figure 22: Unsprung mass Acceleration plot of the vehicles

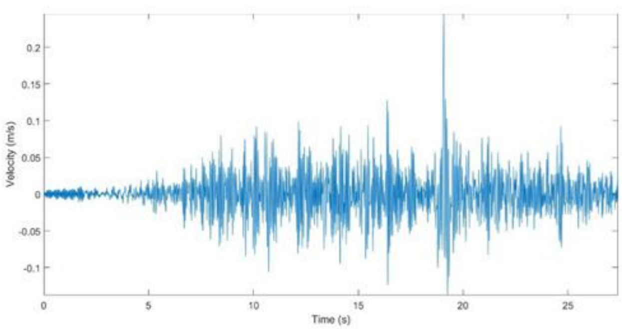

Figure 23: Unsprung mass velocity plot of the vehicles

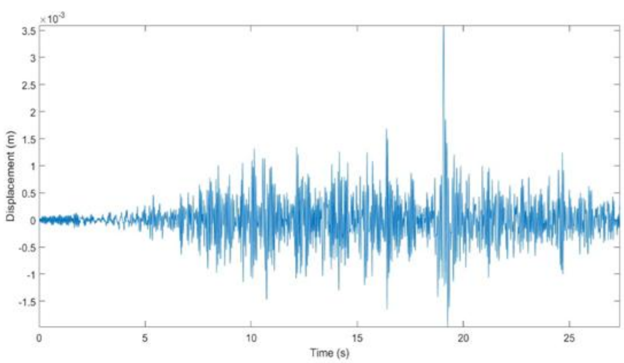

Figure 24: Unsprung mass displacement plot of the bus

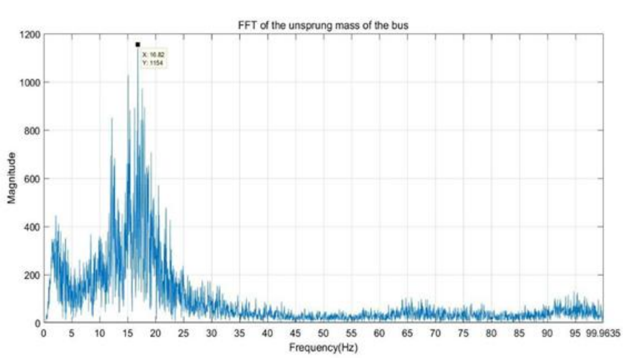

Figure 25: Unsprung mass FFT of the Bus

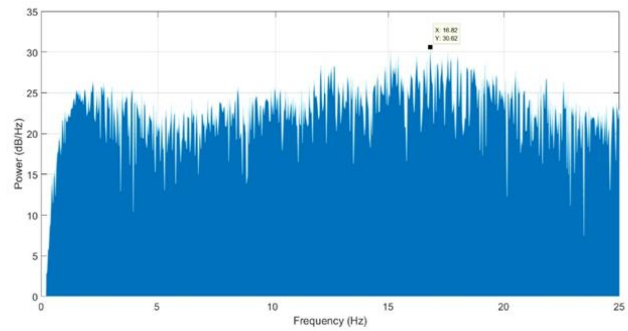

Figure 26: PSD of the sprung mass of the bus

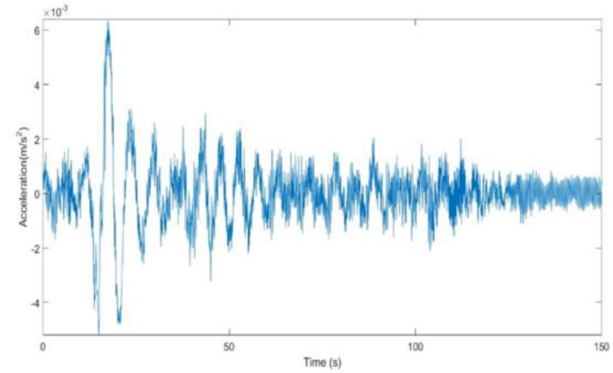

Figure 27: Displacement of the sprung mass of the car

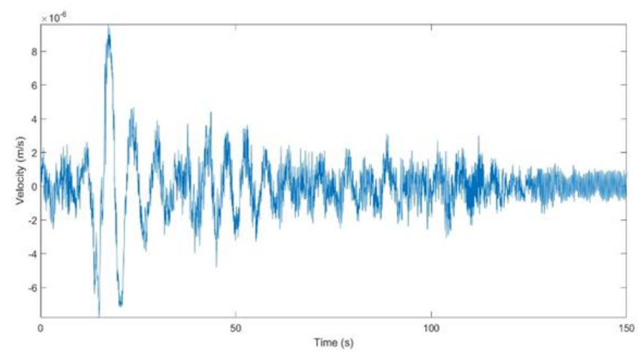

Figure 28: Velocity of the sprung mass of the car

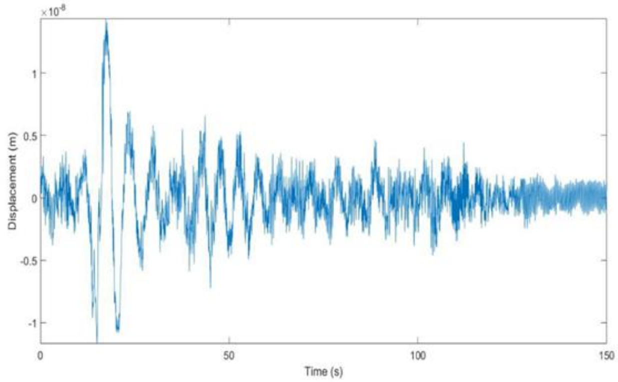

Figure 29: Displacement of the sprung mass of the car

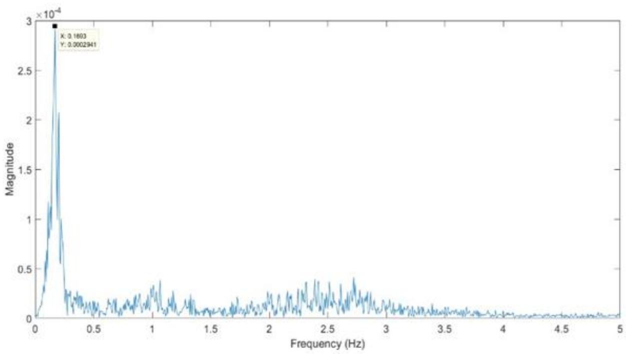

Figure 30: FFT of the sprung mass of the car

C. Comparison of both the vehicles

All the features like acceleration, displacement, peak frequency and ground vibration are less in the case of car. These properties depicted that the car has better passenger and driver comfort and less vibration. Further, on operation on the road car generates less vibration. A column chart for the ground vibration produced in the ground for both the vehicles has been presented in Figure 32. The repeatability of the car seems to be very good and all the time precise values are outputted. The ground velocity is also very less in the case of car. In Figure 31 the comparison of peak frequencies of both the vehicles is presented. The peak frequency for the car is negligible as compared to bus. It clearly presents that the riding by car is more comfortable than the bus. Outcome of the comparison of both vehicles can easily be concluded that passenger in the car will feel highly comfort comparing with the bus. The Peak frequency of the sprung mass for the car is 0.16 Hz which actually the deciding factor of comfort. The displacement is also negligible which indicated that the car is very good in terms of comfort. The entire three hypotheses have been verified. The bus while not crossing the bump is shown in the below Figure 33. The value is around 0.6 mm/s which is very lesser than the case where bump is present.

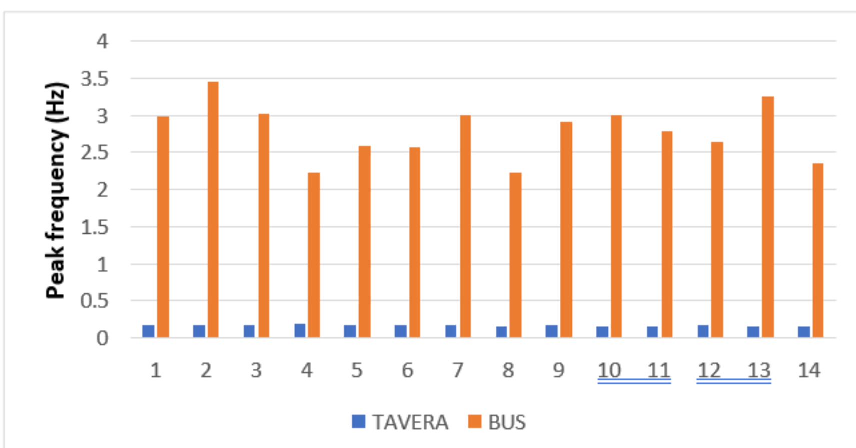

Figure 31: Peak frequency of the sprung masses of the vehicles

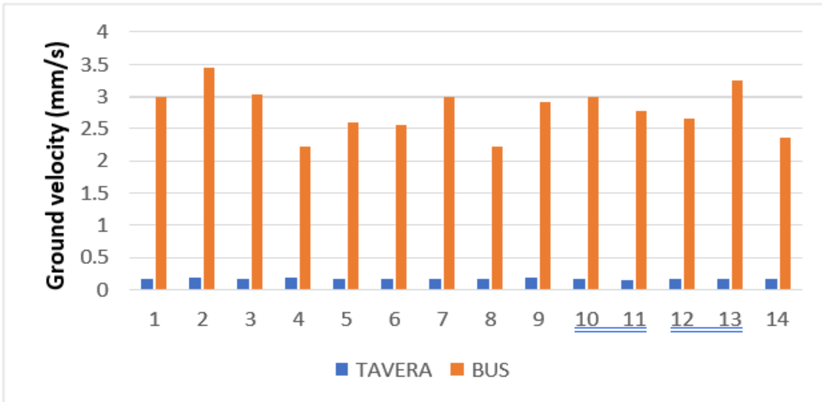

Figure 32: Bar graph for ground vibration for both the vehicles

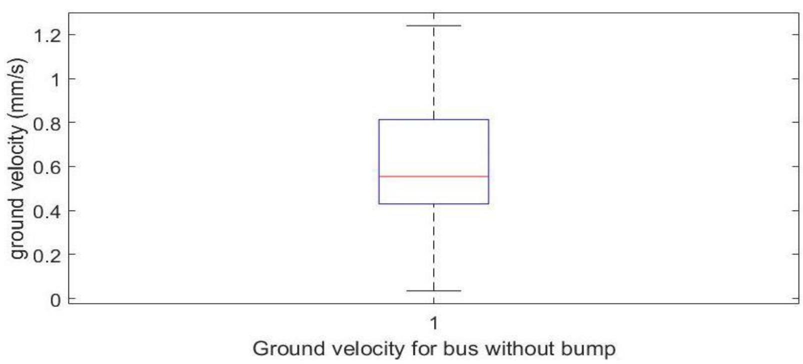

Figure 33: Ground velocity for bus without bump

VI. Conclusion And Future Scopes

The vertical vibration and the ground vibration for the both bus and car are determined effectively using two accelerometers. Along with the above also seismic vibration is captured by a Geophone in both the cases. In real condition in the same method ground borne vibration can be measured at any distance before planning any constructive work. As stated earlier the structural damages because of the seismic vibration born from the road traffic are more severe in recent days. Even as it is concluded that more roughness leads to more vibration, the existing structures can also be recovered from the ground vibration by repairing the road periodically. Moreover, in case of the places where historical monuments exist in bad condition the roughness of road should be repaired periodically and in the worst-case light vehicles which generate less vibration in the ground only should be allowed. It is because as the results shows bus generates about six times ground vibration than car we used in the same other conditions. Further, vehicle vertical vibration differs a lot in heavy vehicle and light vehicle with superior suspension system.

Hence, where comfort for passengers is prime concern, vehicle should be selected such a way that the frequency of the unsprung mass is lesser. For the future research, this problem can be studied further by developing a physical and black box model of the system. Further, issues such as, uncertainty related to road surface roughness classification and suspension system can be considered while extending this study. However, optimization of the suspension system for better comfort of passengers also can be incorporated in this study.

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