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A STUDY ON IMPROVING MINIBUS TRAVEL COMFORT BY USING VIBRATIONS ATTENUATOR MATERIAL

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Abstract: The purpose of this work was to study how the vibrations transmitted to passengers by the minibuses can be reduced. This paper has three parts:

i. Transmissibility determination for some damping materials in terms of elasticity

ii. Determination of vibration acceleration at the floor, handle, seat back, lumbar spine and wrist during minibuses rides

iii. Passengers questionnaire to study the influence of vibration on reading and writing

In the first part, in order to obtain lower vibrations transmitted to passengers, the transmissibility for 34 damping materials was studied in terms of elasticity. The best attenuation was obtained for rigid polyurethane foam. In the second part the weighted acceleration was measured for the 6 men with and without attenuators at floor level, on the hand, at the back rest, near the lumbar spine and at the wrist to ascertain how the whole body vibrations are transmitted (whole body vibrations) and how these vibrations are attenuated by the rigid polyurethane foam. In the third part, 48 passengers were questioned about the vibrations influence on reading and writing and were asked to describe the buss ride in terms of comfort. The results obtained from this study show without doubt that placing a damper on the contact surface between the passenger and seat significantly reduce the minibus-transmitted vibrations, thus increasing the comfort of travelling.

Keywords: whole body vibrations, damping materials, vibrations transmissibility, passengers’ comfort.

1. INTRODUCTION

Sustainable development is a result of the interference among environment, economy, culture and social (Ianos et al. 2009), (Mrkajici et al. 2010). Therefore, any factor that acts negatively on one of these 4 elements is a disturbance in a constant development.

Due to current socio-economic conditions, more people were forced to leave their home towns to go to other cities for jobs (or study), leading to an increasingly use of minibuses.

Also due to the lack of housing in cities, many people moved to suburbs or to satellite towns. Minibuses are a common mean of transport in and between cities. Passengers’ comfort is assured by the quality of roads and also of the cars, which implies quality seats, back and elbow rests, controlled temperature and also noise and vibration reduction.

These conditions affect the different activities during a minibus ride (as reading and writing) (Blood et al., 2010).

There are a lot of studies which have examined the effect of cars vibration on drivers (Atmaca et al., 2005), but fewer on passengers’ comfort (Mansfield 2005), (Narayanamoorthy et al., 2008).

The most used standards (ISO 2631-2:2003, BS 6841:1987) refer to comfort (whole body vibration) to whole-body vibration of passengers inside the busses (Verichev et al., 2010).

The vibrations are transmitted through the car floor but also through the seats, including through the back and elbow rests (Corrie et al., 2006), (Morioka & Griffin 2008).

In order to study the influence of vibrations on passengers, in this paper is investigating how certain damper substances reduced vibration transmissibility, thereby helping to improve passengers’ comfort (Barkanov, et al., 2009).

This paper contains 3 parts:

1. Determination of vibro-elastic characteristic of damping materials in terms of elasticity.

2. Determination of vibrations accelerations at the floor, armrest, backrest, lumbar spine, wrist during minibus ride.

3. The passengers' questionnaire which studies the influence of vibration on reading and writing during minibus ride.

2. EQUIPMENTS AND RESULTS

2.1. Transmissibility determination for certain insulating materials in terms of elasticity

For this purpose was used the equipment shown in figure 1.

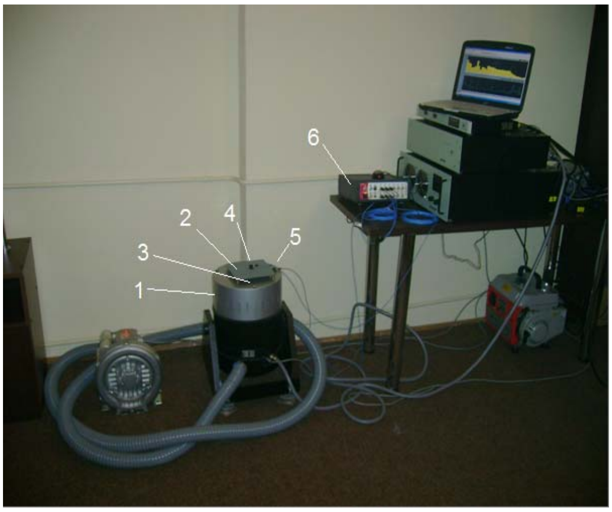


Figure 1. Experimental assembly to determine the vibration damping through different mediums (1) exciter, (2) contact sheets, (3) damper medium, (4) accelerometer for the initial excitation, (5) accelerometer for the final vibrations, (6) acquisition system NetdB.

The vibro-isolating materials are those, which, in slabs or individual elements, are placed under a device or under a person and which, under the current dynamic forces have a linear elastic behaviour.

The proposed solution can make quick measurements in real time. Measurements are made in open field, just near the area of interest, which is very important in practical terms.

In this case it is necessary that the frequency bandwidth to be limited (does not work with infinite bandwidth), depending on sample size and on its location. This is done to work with plane wave, avoiding the border effects (Flaga et al., 2008).

Using the resonant method the natural frequency will be determined for an oscillating system with one degree of freedom (where the spring is made up from the material to be studied), also it will be determined the bandwidth of the frequency that corresponds to certain level decreases near the resonance area and amplitude oscillatory motion speed decrease.

The samples were taken from the studied materials in the form of square plates and variable thicknesses are placed on the exciter (1).

In practice it is necessary to characterize materials in terms of waves absorption for an octave or 1/3 octave (Reis & Nicoletti, 2008).

In practical terms, the most interesting frequency bandwidth is 16-5000Hz (Toward & Griffin 2009a), (Toward & Griffin 2009b). The acceleration values for 1/3 octave are used to calculate the root mean square acceleration:

$$a_{hw} = \left[\sum_{j=1}^{n} \left[W_{hj} \cdot a_{hj} \right]^2 \right]^{1/2} \qquad (1)$$

where W_{hj} is the weighting factor for 1/3 octave and a_{hj} is the acceleration measured in that 1/3 octave.

The transmissibility was calculated with:

$$T = \frac{a_{hw\,max_{out}}}{a_{hw\,max_{in}}} \qquad (2)$$

where $a_{hw\,max_{in}}$ is maximum input acceleration and $a_{hw\,max_{out}}$ is maximum output acceleration.

The results of experiments are presented in figures 2÷16 and tables 1÷8.

From the figures can be seen that the lowest transmissibility values are obtained for rigid polyurethane foam namely:

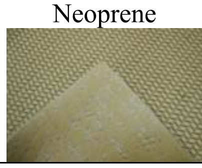
- for the first rigid polyurethane foam was obtained T_{max}=4 at the frequency of 20Hz and T_{min}=0.002 at the frequency of 25Hz;
- for the second rigid polyurethane foam was obtained T_{max}=6 at the frequency of 20Hz and T_{min}=0.004 at the frequency of 25Hz;
- for the third rigid polyurethane foam was obtained T_{max}=9 at the frequency of 40Hz and T_{min}=0.009 at the frequency of 50Hz.

In future experiments will be use the first type of rigid polyurethane foam, as it exhibits the lowest values of transmissibility.

Table 1. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous kind of rigid polyurethane foams

No	Rigid polyurethane foam	$a_{hw\,max_{out}}$ (m/s^2)	Tmax Tmin
1		1,3	4 (20Hz) 0,002 (25Hz)
2		1,5	6 (20Hz) 0,004 (25Hz)
3		1,6	9 (40Hz) 0,009 (50Hz)

Table 2. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous kind of rubber and neoprene

No	Rubber	$a_{hw\,max_{out}}$ (m/s^2)	Tmax Tmin
4		3,2	9,9 (500Hz) 0,01 (630Hz)
5		3,3	9,5 (800Hz) 0,012 (1000Hz)
6		3,3	9,1 (1000Hz) 0,011 (1250Hz)
7	Neoprene 	3,1	10 (500Hz) 0,009 (630Hz)

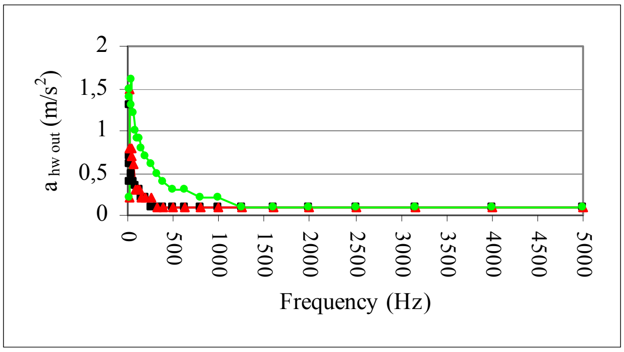


Figure 2. Variation of output vibration amplitude *versus* frequency for miscellaneous rigid polyurethane foams
(■) Rigid polyurethane foam 1,
(▲)Rigid polyurethane foam 2,
(●)Rigid polyurethane foam 3

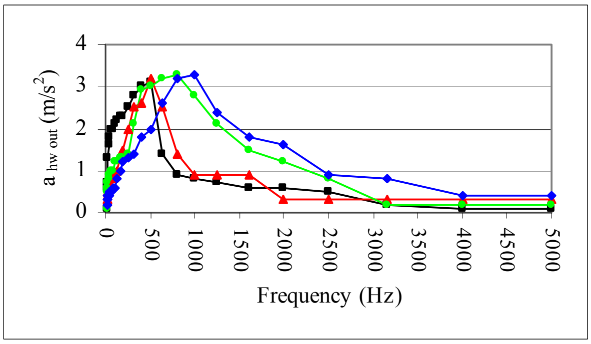


Figure 4. Variation of output vibration amplitude *versus* frequency for miscellaneous rubber and neoprene
(▲)Rubber 4, (●) Rubber 5, (♦) Rubber 6,
(■) Neoprene

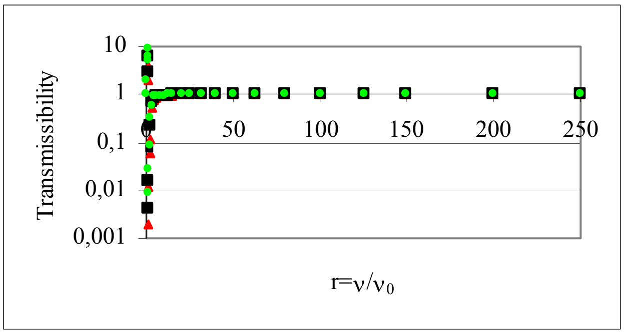


Figure 3. Variation of transmissibility with ratio r for miscellaneous rigid polyurethane foams
(■) Rigid polyurethane foam 1,
(▲)Rigid polyurethane foam 2,
(●)Rigid polyurethane foam 3

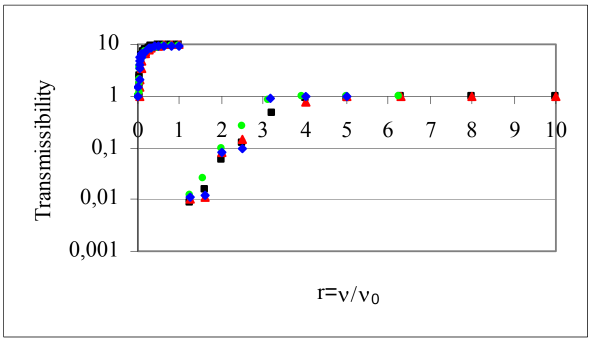
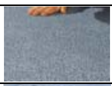
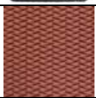
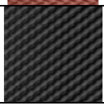


Figure 5. Variation of transmissibility with ratio r for miscellaneous rubber and neoprene
(▲)Rubber 4, (●) Rubber 5, (♦) Rubber 6,
(■) Neoprene

Table 3. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous rubbed material and carpet rubber

No	Rubbed material	$a_{hw\,max_{out}}$ (m/s^2)	Tmax Tmin
8		3,3	12 (160Hz) 0.11 (200Hz)
9		3,5	14 (160Hz) 0.15 (200Hz)
10		3,5	11 (100Hz) 0.32 (125Hz)
11		3,6	11 (400Hz) 0.12 (500Hz)
12	Carpet rubber 	4,1	15 (500Hz) 0.56 (630Hz)
13		3,8	18 (500Hz) 0.64 (630Hz)
14		3,6	21 (500Hz) 0.46 (630Hz)

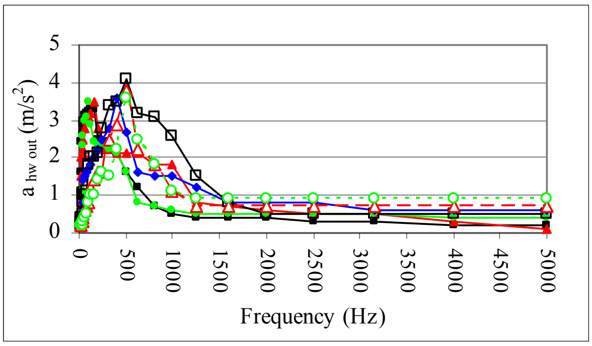


Figure 6. Variation of output vibration amplitude *versus* frequency for miscellaneous rubbed material and carpet rubber: (■)Rubbed material 8, (▲)Rubbed material 9, (●)Rubbed material 10, (♦)Rubbed material 11, (□)Carpet rubber 12, (Δ), Carpet rubber 13, (o) Carpet rubber 14

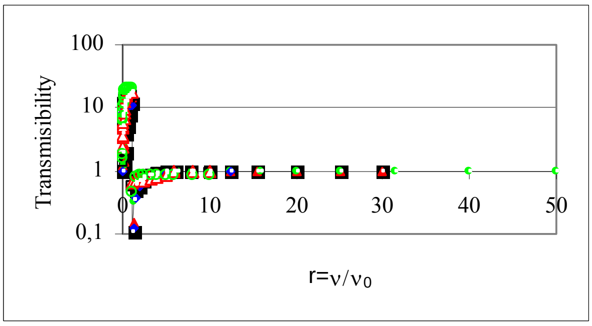
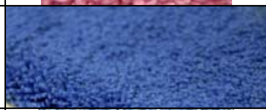
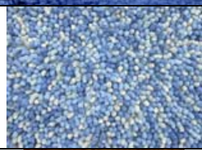
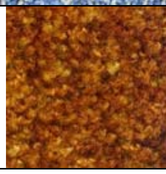


Figure 7. Variation of transmissibility with ratio r for miscellaneous rubbed material and carpet rubber: (■)Rubbed material 8, (▲)Rubbed material 9, (●)Rubbed material 10, (♦)Rubbed material 11, (□)Carpet rubber 12, (Δ), Carpet rubber 13, (o) Carpet rubber 14

Table 4. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous kind of microfiber

No	Microfibre	$a_{hw\,max_{out}}$ (m/s^2)	Tmax Tmin
15		5,8	9 (31,5Hz) 0.12 (40Hz)
16		4,4	8.5 (40Hz) 0.15 (50Hz)
17		4,2	8.7 (40Hz) 0.25 (50Hz)
18		4,3	8.8 (40Hz) 0.4 (50Hz)

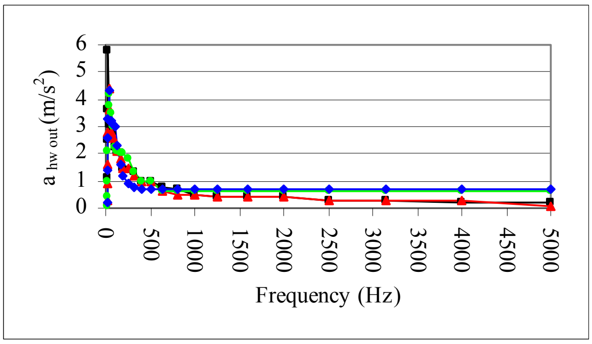


Figure 8. Variation of output vibration amplitude *versus* frequency for miscellaneous microfibre: Microfibre 15, (▲) Microfibre 16, (●) Microfibre 17, (♦) Microfibre 18

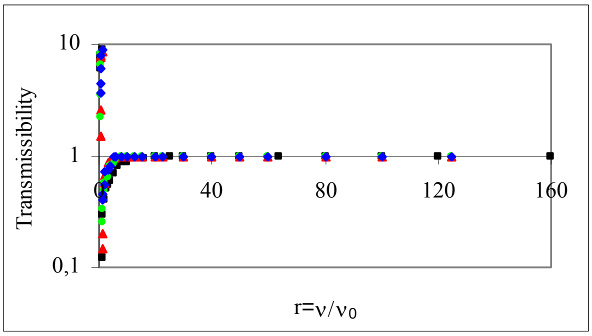


Figure 9. Variation of transmissibility with ratio r for miscellaneous microfibre: (■) Microfibre 15, (▲) Microfibre 16, (●) Microfibre 17, (♦) Microfibre 18

Table 5. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous kind of sponge

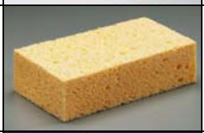
No	Sponge	$a_{hw\,max_{out}}$ (m/s^2)	Tmax not exist Tmin
19		5,6	36 (16Hz)
20		4,5	29 (31.5Hz)
21		4,6	23.7 (16Hz)
22		5,3	18.4 (16Hz)

Table 6. Values of $a_{hw\,max_{out}}$ and transmissibility for miscellaneous kind of wool

No	Wool	$a_{hw\,max_{out}}$ (m/s^2)	Tmax Tmin
23		6,5	43 (25Hz) not exist Tmin
24		5,8	23 (16Hz) 0.5 (100Hz)
25		6,4	56 (20Hz) 0.05 (50Hz)
26		6,8	35 (25Hz) not exist Tmin

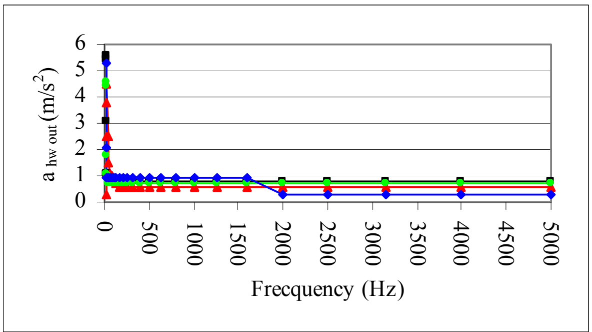


Figure 10. Variation of output vibration amplitude *versus* frequency for miscellaneous sponge: (■) Sponge 19, (▲) Sponge 20, (●) Sponge 21, (♦) Sponge 22

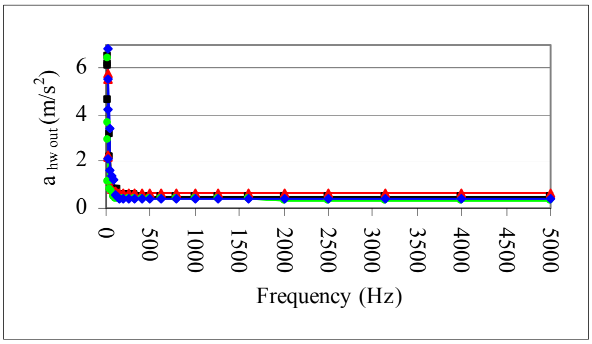


Figure 12. Variation of output vibration amplitude *versus* frequency for miscellaneous wool: (■) Wool 23, (▲) Wool 24, (●) Wool 25, (♦) Wool 26

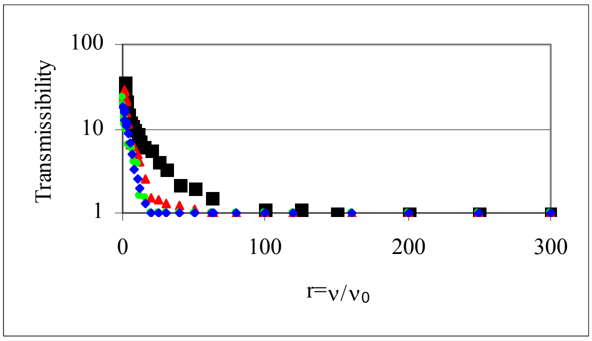


Figure 11. Variation of transmissibility with ratio r for miscellaneous sponge: (■) Sponge 19, (▲) Sponge 20, (●) Sponge 21, (♦) Sponge 22

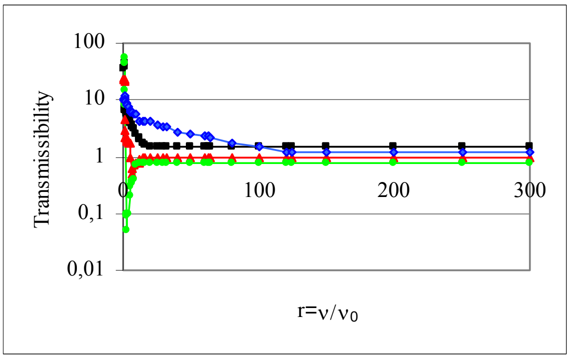


Figure 13. Variation of transmissibility with ratio r for miscellaneous wool: (■) Wool 23, (▲) Wool 24, (●) Wool 25, (♦) Wool 26 (■) Felt 29, (▲) Felt 30

Table 7. Values of $a_{hw\,max\,out}$ for miscellaneous kind of glass wool and felt

Nr crt	Glass wool	$a_{hw\,max\,out}$ (m/s^2)
27		No maximum for this range of frequencies
28		No maximum for this range of frequencies
29	Felt 	No maximum for this range of frequencies
30		No maximum for this range of frequencies

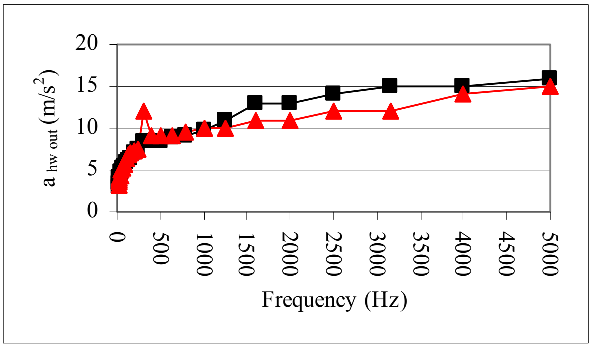


Figure 14. Variation of output vibration amplitude *versus* frequency for miscellaneous glass wool: (■) Glass wool 27, (▲) Glass wool 28

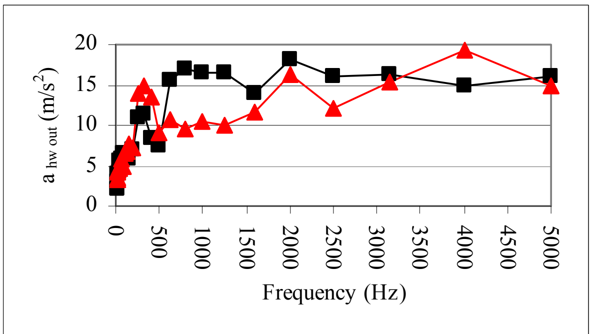


Figure 15. Variation of output vibration amplitude versus frequency for miscellaneous felt:

Table 8. Values of $a_{hw\,max\,out}$ for miscellaneous kind of processed shoddy

No	Processed shoddy	$a_{hw\,max\,out}$ (m/s^2)
31		No maximum for this range of frequencies
32		No maximum for this range of frequencies
33		No maximum for this range of frequencies
34		No maximum for this range of frequencies

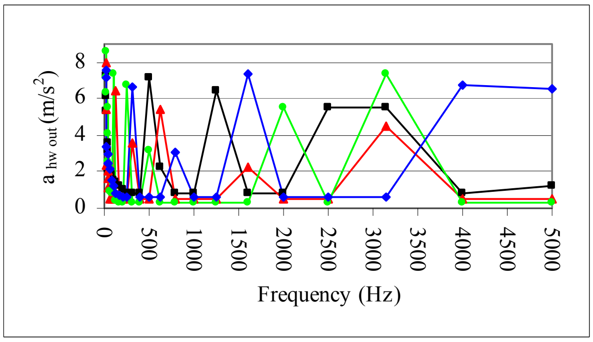


Figure 16. Variation of output vibration amplitude *versus* frequency for miscellaneous processed shoddy: (■) Processed shoddy 31, (▲) Processed shoddy 32, (●) Processed shoddy 33, (♦) Processed shoddy 34

2.2. Determination of vibration acceleration at the floor, handle, seat back, lumbar spine and wrist during minibuses rides

Measurements were made during three consecutive days in September and October 2009.

Minibuses were used on the Braila - Buzau route and back; the distance between these two towns is 105 km and average time of journey is 1h15min on DN2B.

Six men aged 25-35 years were chosen and they were fitted triaxial accelerometers (PCB Piezotronics 356A16 Triaxial accelerometer) on the elbow and wrist. These triaxial accelerometers were connected to NetdB – Complex system for analysis and measurement of vibration to human body.

Seat pad 01dB triaxial accelerometers were mounted on the floor of the car, the back rest and seat, so that the accelerometers show the acceleration values for the foot, lumbar and thoracic spine (Fig. 17). Data were processed with vibration meter MAESTRO 01dB.

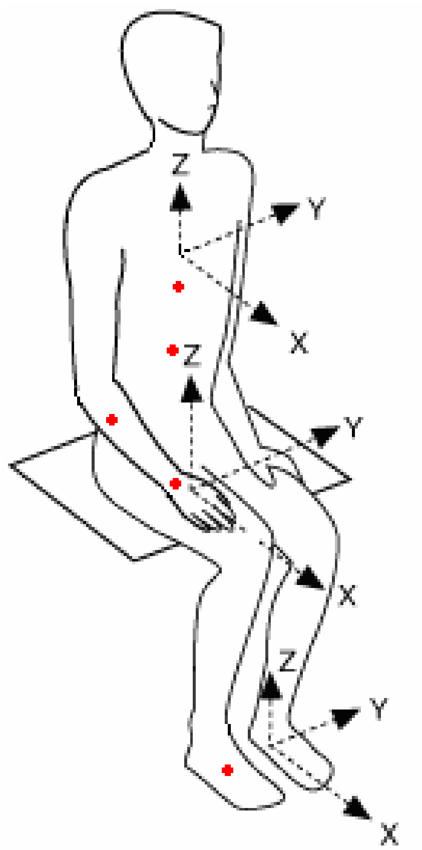


Figure 17. Point of measure

The 6 people travelled in normal conditions (sitting directly on the seats, no attenuators) and also with passive attenuators (rigid polyurethane foam) placed on the seat, the back rest and on the seat handle.

Measurement results are shown in figure 18 and 19.

From these figures it can be seen that due to the attenuator's location:

- at the back rest, a_w decreased by 14.83%
- on the handle, a_w decreased by 14.08%
- near the lumbar spine, a_w decreased by 13.81%
- at the wrist, a_w decreased by 15.38%

At floor level, a_w did not change, because attenuators were not placed under the feet.

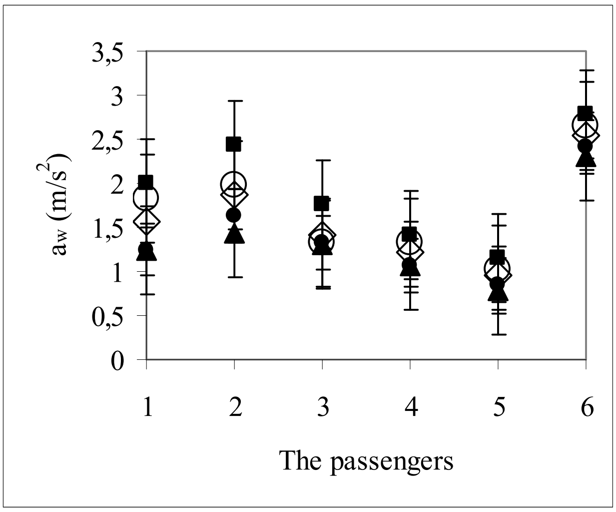


Figure 18. Weighted acceleration for the 6 men without attenuators (■) - a_w at floor level, (▲) - a_w on the handle, (●) - a_w at the back rest, (a) - a_w near the lumbar spine, (◊) - a_w at the wrist

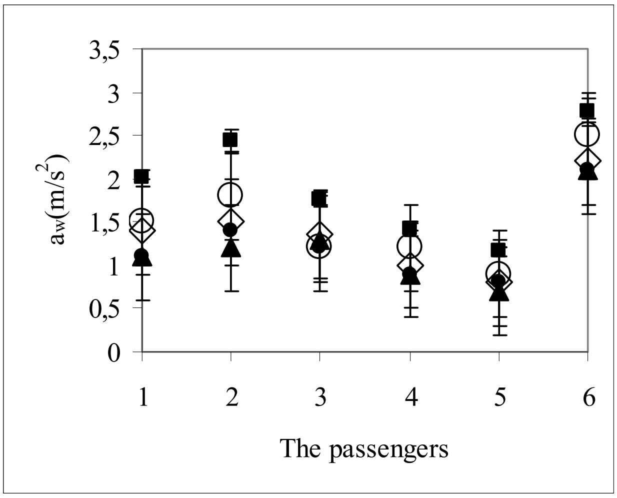


Figure 19. Weighted acceleration for the 6 men with attenuators (■) - a_w at floor level, (▲) - a_w on the handle, (●) - a_w at the back rest, (a) - a_w near the lumbar spine, (◊) - a_w at the wrist

2.3. Passengers questionnaire to study the influence of vibration on reading and writing

In order to study the influence of vibration on reading and writing of the minibuses passengers, the participants in the first part of the experiment were interviewed along with other 42 persons, of which 12 women and 30 men aged 19-54 years.

Of these, 32% are college graduates and the rest are high school graduates. Regarding the type of work they conducted, 54% have a sedentary life and the rest, a dynamic one.

Respondents were asked to read and write a text in order to fit the type of journey in one of the situations specified in ISO-2631-1 (Table 9).

Table 9. Assessing the discomfort of whole-body vibration according to ISO-2631-1:1997

r.m.s vibration level (m/s^2)	**Perception**
< 0.315	Not uncomfortable
0.315 - 0.63	A little uncomfortable
0.5 - 1	Fairly uncomfortable
0.8 - 1.6	Uncomfortable
1.25 - 2.	Very uncomfortable
> 2	Extremely uncomfortable

In figure 20 is shown that vibrations do not disturb too much the reading activity, 70% of the respondents could read between the limits: Not uncomfortable-Fairly uncomfortable, the others at a rate of 30% having difficulties and referring to this task as: Uncomfortable-Extremely uncomfortable.

In figure 21 is shown that vibrations do disturb the writing activity of, 60% of respondents could write between the following limits: Not uncomfortable-Fairly uncomfortable, the other at a rate of 40% having difficulties and referring to this task as: Uncomfortable-Extremely uncomfortable.

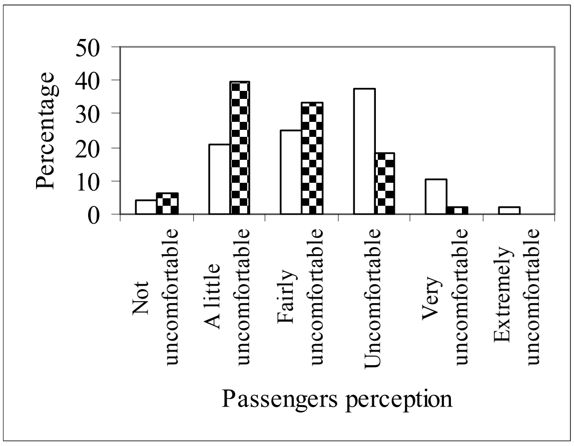


Figure 20. Perception of reading the text (□) - without attenuators (▩) - with attenuators

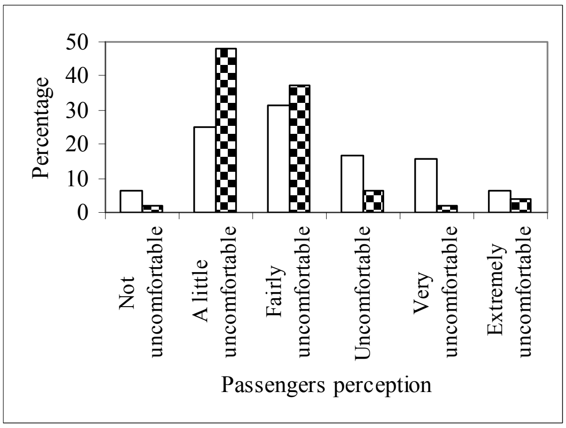


Figure 21. Perception of writing the text (□) - without attenuators (▩) - with attenuators

Linking these results with those obtained when measuring accelerations (Fig. 18 and 19), it is found that for passengers for whom were obtained greater accelerations (passenger no. 2 and passenger no. 6 - passengers placed in the back of the bus) and questionnaire results were placed within Very uncomfortable-Extremely uncomfortable.

In conclusion, the position inside the minibus it is very important for passengers' comfort.

3. CONCLUSION

The three topics approached in this work are interrelated, leading to finding out how the vibrations transmitted by a vehicle affect the comfort of travellers.

In the first part, determination of vibro-elastic characteristic of damping materials in terms of elasticity, a total of 34 materials were studied, in terms of mechanical vibration propagation. Accelerations were measured on both sides of the material, then calculating the maximum and minimum transmissibility values of each material for a 16-5000Hz frequency range. It was found that the best transmissibility was obtained for rigid polyurethane foam (the attenuator used in the subsequent experiments) and microfibres (for which transmissibility has values ranging from 0.12÷9, for frequencies between 31.5÷50 Hz) at low frequencies.

These results are particularly important, knowing that the vibrations which act directly on the human body have low frequencies. In the second part of the paper, determination of vibrations accelerations at the floor, armrest, backrest, lumbar spine and wrist during minibus ride, acceleration measurements were made on 6 people finding that the weighted acceleration a_w decreased in average by 14% due to the attenuator's placement under the body. Such a decrease of the weighted acceleration value is very important and it is desirable that vehicle seats to be redesigned with such attenuators to increase the passengers' comfort. This improvement in comfort could be observed in the third part of the study, following the survey which was conducted on 48 passengers. This survey was conducted as a questionnaire which contained 8 questions divided into 4 parts with questions related to:

1. general background of the participants (gender, age, education, professional activity);
2. a short reading test for quantifying the difficulties of reading while the minibus is running
3. a short writing test for quantifying the difficulties of writing while the minibus is running
4. feeling from disturbances from vibration in the minibus

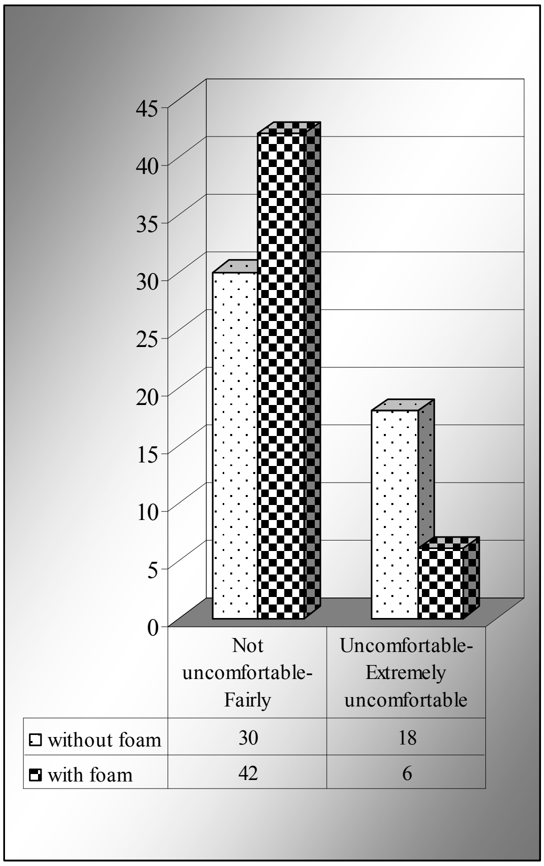


Figure 22. Number of passenger of reading a text (□) – without attenuators, (▓) – with attenuators

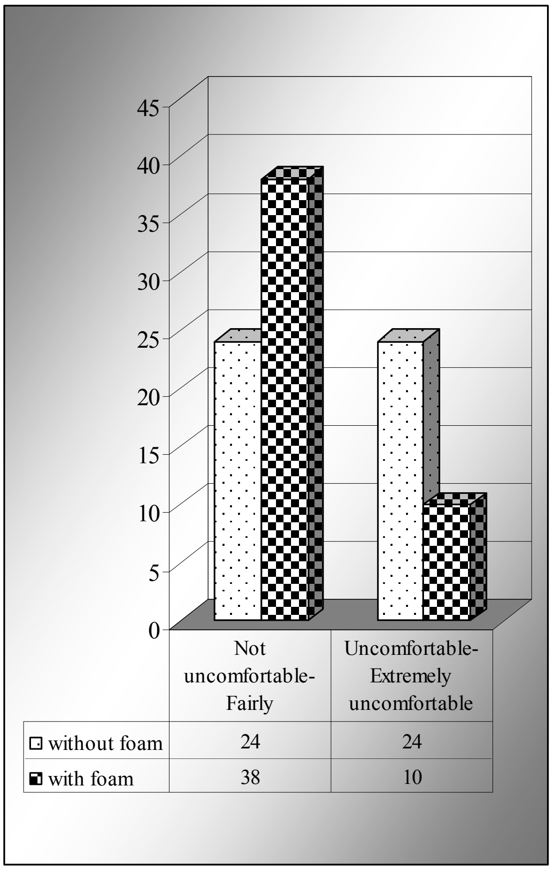


Figure 23. Number of passenger of writing a text (□) – without attenuators , (▓) – with attenuators

Following the questionnaire it was confirmed that the used attenuators significantly decreased the value of weighted acceleration a_w, this leading to an increased comfort for all passengers, in terms of reading and writing.

The figure 22, shows that for a total of 12 passengers the reading conditions have improved, passing from perception *Uncomfortable - Very uncomfortable - Extremely uncomfortable* to *Not uncomfortable - A little uncomfortable - Fairly uncomfortable*. The figure 23, shows that for a total of 14 passengers the writing conditions have improved passing from perception *Uncomfortable - Very uncomfortable - Extremely uncomfortable* to *Not uncomfortable - A little uncomfortable - Fairly uncomfortable*.

It should be noted that the times when the 48 passengers responded to the writing and reading request, corresponded to different portions of the road. This means that the experimental conditions were not perfectly reproducible.

Also, the experiment was not conducted with the same people every day, which means that each person's sensitivity is reflected in part on the result of the questionnaire.

Another observation to be made in this third chapter of the work is a psychological one: when a person seats in a chair with attenuators, immediately said he feels more comfortable.

In conclusion, from the made measurements, it was found that mounting attenuators on the vehicle seats leads to a decrease of the weighted acceleration a_w thus increasing passengers' comfort.

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