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WHOLE-BODY HUMAN VIBRATION EXPERIMENTS CONDUCTED BY TWO DIFFERENT LABORATORIES IN BRAZIL: A COMPARISON OF RESULTS

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Abstract
Understanding the effects of vibration on people is very important. However, a first step in that direction is to understand how the vibration levels can be obtained. This article compares the results obtained for the same type of experiment performed by two different laboratories in Brazil, one from the Group of Acoustics and Vibration of the Mechanical Engineering Department of the Federal University of Minas Gerais (UFMG) and the other from the Civil Engineering Department of the Federal University of Ouro Preto (UFOP). They have used similar apparatus and methodology of tests. Basically, the signal processing performed to obtain the data that could be considered different. Both laboratories investigated the acceleration levels considering two distinct situations: Case A - the minimum levels of vibration the subject could feel (Perception Threshold) and Case B - the maximum levels of vibration that same subject could not feel. These are the error limits for the perception threshold levels, considered as another test. The comparison of the results shows that the results obtained from UFMG were, in general, smaller than the ones from UFOP, mainly due to the signal processing performed, since, although there was a longer duration for the whole test at UFMG, that was mainly due to the recording of the data, and not as much due to the duration of the test itself. Although only UFOP had considered the effect of posture during the tests, it can be concluded that the results are dependent on that parameter as well.

INTRODUCTION

Whole-body vibration (WBV) levels on human beings had become a concern of the modern society, since it should not be taken as an extra font of stress in every day life. Apart from their influence on comfort and performance of activities, it may also be the cause of some health problems [5, 10, 12]. Depending on the objective of the study, the evaluation of WBV is slightly different. ISO2631/1 standard [7] set some guidelines on how to measure and evaluate the levels of vibration human beings are exposed regarding comfort and perception, health, or even motion sickness. Although, as stated in [6], it may cause unnecessary confusion, it is the most used standard for WBV studies. There, depending on the direction the vibration is entering the subject, different weighting factors should be used. The same sort of procedure is proposed by another widely accepted standard for this sort of studies, the BS6841 [1]. Since the weighting factors are artificial functions, the studies presented here did not include them in their evaluations to verify the signal as it is acting on the human body.

The acceptability of vibration in buildings depends on three major factors [4]: the structural characteristics of the building, the type of excitation and the acceptable limits to vibration from the comfort viewpoint. The objective here is the last one.

So, this paper evaluates the error limits for the perception threshold obtained during two independent studies performed in Brazil. They used in essence, the same apparatus and methodology. The signal processing that was different. The results of the UFMG tests presented here were already shown before when it was made a comparison between the results obtained for men and women [2]. The main point here is to compare the average results with another similar test performed at UFOP. The paper is organized as follows: the experimental set up used at each university is presented next, followed by the methodology of the tests, where general information about the tests are presented, as well as some information about the sample used. The results are presented after that, followed by the conclusions of the work.

EXPERIMENTAL SET UPS

The set up used at each university was basically the same. For both, the subjects sat in a wooden chair with metallic feet, with backrest but no cushion, positioned over a metallic plate supported by four compression springs (see Figure 1 and Figure 2). The centre of gravity of the set-up (chair + subject) was such that it was coincident with the geometric centre of the plate, so to give the maximum excitation at the vertical direction (z-axis), avoiding in this way, undesirable rotational movements. The sinusoidal excitation was applied using a B&K 4809 shaker, with a B&K 2706 amplifier making the amplification of the signal sent to the shaker.

The coupling between the plate and the shaker was made using a flexible rope at UFMG (see Figure 3) and using a flexible steel cable at UFOP (following the same principle). At UFMG, the dimensions of the plate were 660 x 950 x 3 mm (area of 0.627 m^2) with reinforced edges, whereas at UFOP the dimensions were 700 x 1000 x 6.3 mm (area of 0.7 m^2). Since the latter was stiffer than the one at UFMG, there was no need for reinforced edges. The springs at UFMG were also made of steel and had dimensions D = 15 cm, d = 5 mm and h = 36 cm, whereas at UFOP, the springs were made of stainless steel and had dimensions D = 8.0 cm, d = 6.3 mm and h = 32.0 cm.

At UFMG, the sinusoidal excitation was generated by an HP 35670A analyser, which also processed the response measured (see Figure 2). At UFOP, it was generated using a function generator instead, and the response measured was processed using an acquisition board connected to a computer installed with an special software (as shown schematically at Figure 4). The acquisition system was the ADS2000 IP from Lynx Technology with the acquisition controller AC2122 (8 input and 8 output channels, 16 bits resolution and 12.5 μs conversion rate) and signal conditioner AI2164. The acquisition software was the AqDados from Lynx.

Figure 1 – Photo of the chair + plate + springs used for UFOP tests

Figure 2 – Experimental set-up for UFMG tests (lateral view)

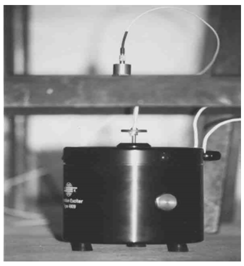

Figure 3 –Coupling between the shaker and the plate at UFMG

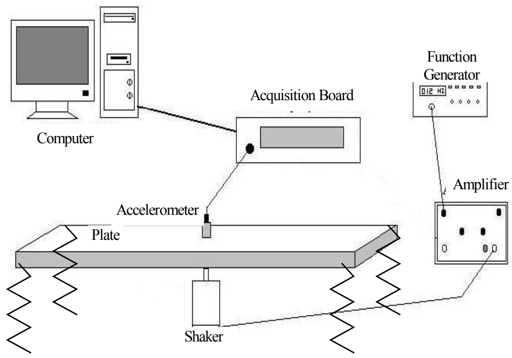

Figure 4 – Schematic drawing of UFOP set up

The responses were measured at the first point of vibration in the set up, i.e., at the geometric centre of the plate; since for buildings, one can find both standing and seated subjects and the floor will be the first point where the vibration enters the structure. A piezoelectric 353B34 PCB accelerometer (102.1 mV/g sensitivity, 0.7% transverse sensitivity and resonance frequency of 28.5 kHz) was used at UFMG, whereas an ASW-10A seismic accelerometer from KYOWA (frequency range from 0-280 Hz and 10 G dynamic range) was used at UFOP to capture the response signal.

METHODOLOGY

Experiment: General Information

For both university studies, the subjects sat in the chair, in an upright but comfortable position. The amplifier used was put as close as possible to the subject so do not interfere with the posture and consequently in the results. At UFOP, for the standing posture, the same procedure follows. Only the centre frequencies of the 1/3 octave band from 10 to 100 Hz (that is, 12.5, 16, 20, 25, 31.5, 40, 50, 63 and 80 Hz) were used for the sinusoidal vibration in the vertical direction (z-axis). The lower frequency limit of 10 Hz is related to the shaker limitation. However, for the UFMG studies, it was also not possible to get vibration at 12.5 Hz, since the signal got distorted [9]. Moreover, due to the frequency generator used at UFOP, the half frequencies of the 1/3 octave band (that is, 12.5 Hz and 31.5 Hz) could not be applied also and the full frequencies of 12 Hz and 32 Hz were used instead [4].

The experiment was, in fact, performed in two steps [4, 9] and it was based on similar experiment performed by Parson & Griffin [11]. The first experiment had the objective to obtain the minimum acceleration limit (i.e., perception threshold) that a subject could feel. The second experiment was intended to measure the uncertainty interval caused by the amplifier adjustment during the tests performed in the first step. Therefore, both experiments used the same subjects. During experiment 1, the subjects adjusted the amplitude to the first acceleration level they could feel. So, the lowest acceleration level gave the reference condition. The uncertainty interval (experiment 2) was obtained by the adjustment of the vibration signal by the subjects for two situations: Case A - the smallest vibration level the subject was sure he/she could feel, Case B - the highest vibration level that same subject was sure he/she could not feel. All subjects responded for both situations.

At both universities, the researchers controlled the frequency order' presentation for the subjects. The method of adjustment [5] was used during the experiments. So, before each section of tests, the knob of the amplifier was set to the zero position. For the UFMG results, the levels are reported as the maximum amplitude value of the Power Spectral signal at the desired frequency, expressed as its RMS value (i.e., $\sqrt{2}$ of the peak value). For the UFOP results, the levels are reported as the RMS value calculated from the time signal (as recommended by ISO 2631/1 [7]). So, the latter values should in fact be higher than the levels obtained at UFMG, mainly due to the signal processing performed.

Moreover, for experiment 1 at UFMG, each frequency was presented twice to the volunteers in a random manner to avoid bias errors. So, the amplitude value for each frequency was obtained as the average value between the two measurements. For experiment 2, the results were measured only once. Also, half of them started with Case A) and half with Case B), changing the order afterwards. In order to avoid long testing time, the second experiment at UFMG was carried out in a different day, preventing in that way the subjects to get tired and the responses to get biased, since the average duration of the whole test was around 30 minutes. For the UFOP tests, each frequency was presented only once. The average duration of the whole test there was only 15 min. and for some of the volunteers, the second test was performed on the same day, after an interval between the tests of 10 minutes. There, the levels for case A are in fact taken as the levels obtained during experiment 1. They had also checked the transmissibility between the plate and the chair, considering the average results of all the volunteers tested as another test [4]. So, for some of the volunteers, all three experiments (transmissibility plus experiments 1 and 2) were performed on the same day, respecting a 10 min. interval between them. The levels were obtained by the volunteers, and not by the researchers, as mentioned. However, the major reason why the total time for the test was so different (almost 3 times longer for UFMG than UFOP) was not related to that, but to the recording of the signal by the analyser (at

UFMG) or the computer (at UFOP). The volunteers had the opportunity to change position while the signal was recorded, however, none of them moved from the experimental set up. Moreover, none of tests used the weighting function as recommended in ISO 2631/1 [7], since the important aspect of the results obtained here is exactly to verify the influence of the levels at each of the frequency studied.

Sample information and considerations

At both universities, the subjects were selected after they filled in a form stating about their general health condition as recommended in [5]. After that, the researchers then gave an explanation about the experiments and another form was filled in, given the volunteers consent. For the UFMG tests, the Ethics Committee in Research of the Federal University of Minas Gerais approved the research first [9].

For the UFMG tests, a total of 20 volunteers took part in the experiments, being 10 (ten) male and 10 (ten) female, as used by other authors [11]. The average age, height and weight of the sample used was 22.65±3.07 years, 1.74±0.08 m and 69.50±12.49 Kg, respectively. For the UFOP tests, the sample was composed by a total of 30 volunteers, being 15 (fifteen) male and 15 (fifteen) female. The sample average data was 28.8±8.61 years, 1.7±0.1 m and 65.1±11.46 Kg.

For the calculation of the sample size, Eq. (1) was used [13]:

$$n = \left[\frac{z_{\alpha/2}\sigma}{E} \right] \tag{1}$$

For a 95% confidence interval, $z_{a/2}$ = 1,96. This equation is based on the standard deviation and the expected error obtained from a pilot sample (which was composed by 10 volunteers for UFMG and 30 volunteers for UFOP). A verification of the sample size was made afterwards. For the UFMG results, the final sample size for both experiments 1 and 2 had to be below 8 subjects [9], validating the sample size used. For UFOP, even 30 volunteers were not enough for some of the tests, postures and position of the accelerometer, due to the great variability of the results.

RESULTS

Figure 5 shows all the results obtained for the seated posture during the tests performed at UFMG and UFOP, for both experiments 1 and 2. The results obtained at UFOP for the standing posture are also presented for completeness. As mentioned in the previous section, UFOP results for experiment 1 are, in fact, the same ones as for case A, explaining the overlap of the curves. The results of experiment 1 at UFMG stayed within the responses for case A and B, as expected, expect at 31.5 Hz and 40 Hz. The reason for that may be explained by the fact that the experiments were made separately, in different days. However, as more and more volunteers were included in the sample, the tendency was to have the results of experiment 2 as the limits for experiment 1 [2, 9]. Although the limits for the UFMG tests were lower than at UFOP, mainly due to the signal processing performed, it is interesting the note that the results of experiment 1 for the seated posture at UFOP stayed within the values of cases A and

B (experiment 2) for the standing posture, apart from 20 and 63 Hz, which stayed below the values obtained for case B, and 50 Hz, which stayed above case A.

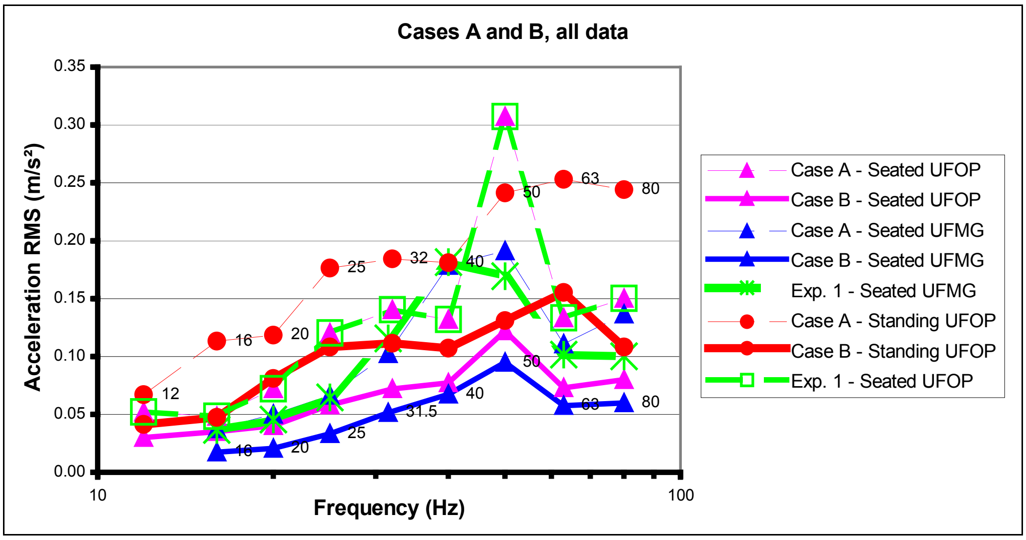

Figure 5 – UFOP and UFMG results for experiments 1 and 2 (seated and standing)

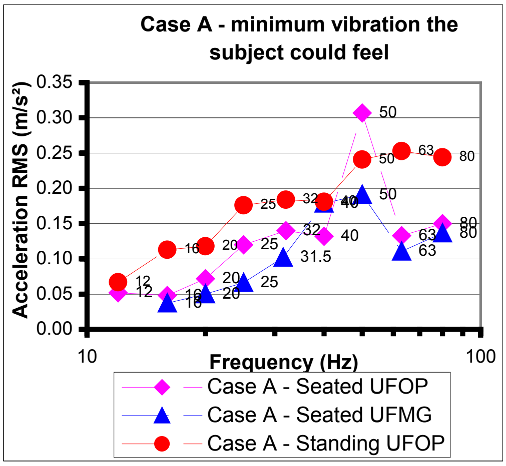

Figure 6 – Case A comparison UFOP x UFMG (seated and standing)

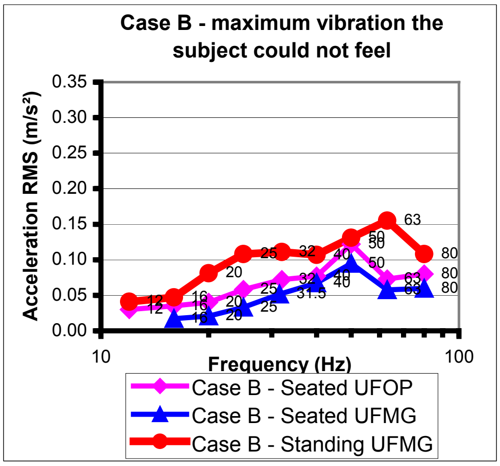

Figure 7 – Case B comparison UFOP x UFMG (seated and standing)

Since a lot of data was presented in Figure 5, Figure 6 and Figure 7 present the results comparison for experiment 2 only (cases A and B, respectively), for the tests performed at UFOP and UFMG, in order to provide a more detailed analysis. Also, the same colours and symbols used in Figure 5 are used now for a better visualization. Both figures used the same scale to easy the comparison of the results between the two situations. When looking at the results for both cases A and B presented for the seated posture, the ones obtained at UFMG are, on average, lower than the ones obtained at UFOP. Only at 40 Hz for Case A that the UFOP results were higher than the UFMG results, as it can also be seem in Figure 8. One of the reasons for this behaviour at 40 Hz for the UFMG results may be the high transmissibility of the set up. Also, as mentioned before, the accelerations reported are the Power Spectral RMS for UFMG and the time signal RMS for UFOP. So, such differences should be really expected. Although the time to acquire the results for both tests was almost 3 times higher for UFMG than for UFOP (30 min for UFMG, against 10 min for UFOP), the authors attribute the difference to the signal processing, since during the test itself, both used more or less the same time, being this longer duration mainly related to the recording of the signal, during what the volunteers could be in a more relaxed position. When looking at the results obtained at UFOP for the seated and standing posture, the standing results are much higher than the seated ones, apart from 50 Hz for case A. Also, when looking at the sample used (as presented in the previous section), the average age for UFMG was lower than the one from UFOP. In previous studies at UFMG, age proved to have a strong influence on the results obtained [3].

Analysing Figure 8 in more detail, it is interesting to note that at some frequencies, for instance, at 25 Hz, 31.5 Hz (and 32 Hz) and 63 Hz, the ratio between the results for each university for case A and case B produced almost the same value, since the ratio between these ratios is around unit. That shows that the difference between the tests performed at each university is more or less constant at those frequencies. Also, the ratio for case B is, on average, smaller than for case A, apart from at 50 Hz, showing that the discrepancies are smaller in this case. The signal processing performed in obtaining the data shown, that can be regarded as being the major difference between the two university results. Figure 9 shows the ratio between cases A and B, for each university now. It has to be remembered that at UFMG, the frequencies below 16 Hz could not be measured. It is interesting to note that, apart from 40 Hz, the ratio calculated for each case between the universities (Figure 8) or the ratio calculated between the cases for each university (Figure 9) produced approximately the same behaviour, although for the former, the values are higher.

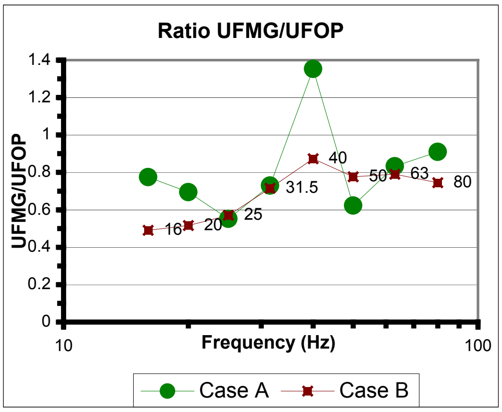

Figure 8 – Relationship UFMG/UFOP for cases A and B (seated)

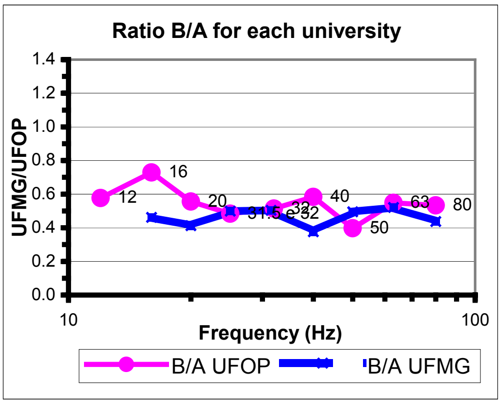

Figure 9 – Relationship Cases B/A for UFOP and UFMG (seated)

CONCLUSIONS

This paper presented the results obtained during two independent tests performed in Brazil (at UFOP and UFMG), where the main objective was to obtain the error levels during the measurement of the perception threshold of people exposed to sinusoidal vibration. The signal processing performed to represent the data shown was different. At UFOP, that was the RMS value of the time signal for each sinusoidal frequency of the 1/3 octave band from 12.5 to 80 Hz. At UFMG, that was the Power Spectral RMS amplitude for each sinusoidal frequency of the 1/3 octave band from 16 to 80 Hz. The results shows that the values obtained at UFMG were, on average, smaller than the ones obtained at UFOP. Also, for UFOP results, the amplitudes for the standing subjects are higher than for the seated subjects, stressing that the posture plays an important role on the levels obtained. Although the transmissibilities of both set-ups are different, they had influenced the results more or less in the same manner. Since the intention of the tests was to obtain the perception threshold levels at dwellings and there, both standing and seated subjects are present, the results obtained at UFMG would be a more conservative approach to be considered, although the ISO2631/1 recommends the used of the RMS value of the time signal.

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