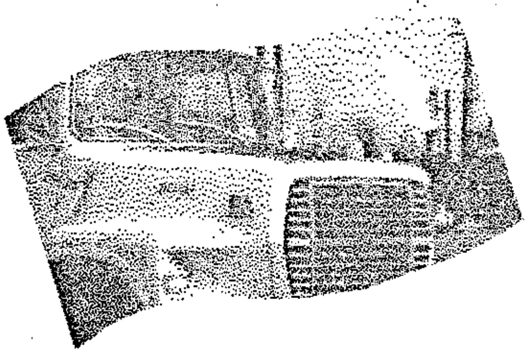
Evaluating the Exposure of Tanker Truck Drivers to Whole-Body Vibration



ÉTUDES ET RECHERCHES

Paul-Émile Boileau
Henri Scory

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REPORT

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H3A 3C2
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Internet site : www.irsst.qc.ca

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Paul-Émile Boileau et Henri Scory
Programme sécurité-ingénierie, IRSST

REPORT

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Risk Factor:
Exposure to whole-body vibration

Group of workers concerned:
Tanker truck drivers

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1.0 INTRODUCTION

The levels of exposure to whole-body vibration associated with the driving of heavy vehicles can be in the order of 9 to 16 times the levels of vibration in automobiles[1]. Clearly, the characteristics of the vibration transmitted to the driver, whether it be their intensity, frequency or direction, depend on several factors, particularly the characteristics of the vehicle, the driving speed, the road conditions and the seat itself, which is the link between the driver and the vehicle.

The potential effects of whole-body vibration on the human body are well documented in the literature and include a reduction in comfort and working proficiency while representing a health hazard for exposed workers[2]. Epidemiological studies indicate that the higher the exposure to whole-body vibration, the higher the risk of lumbar pathology[3,4,5].

It is well known that truck drivers often have to cover long distances, which could require more than 10 hours of driving in a single day. Due to these extended exposure periods, it is important to provide the driver with a work station that is well designed in order to minimize the vibration stress caused mainly by the interaction of the tires with the road surface.

The decrease in the vibration levels must take into account several factors, namely the vehicle's primary suspension, the load transported and the seat suspension, which have an effect on the intensity and the frequency of the vibrations transmitted to the driver. Attenuation of the vibrations whose frequencies are dominant in heavy vehicles (less than 5 Hz), requires that the vehicle and seat suspensions be relatively soft, which tends to affect the stability of the vehicle, as well as of the driver in relation to the vehicle. For this reason, attenuation of the vibrations can be achieved only up to a certain limit.

However, the vehicle's type of suspension and the seat itself can be chosen so as to minimize the transfer of vibration to the driver. In general, the vibrations can be absorbed by mechanical components (leaf springs, helical springs, rubber) or pneumatic ones (air springs) together with a shock absorber. The advantage of using one system over the other cannot be determined without taking into account the load transported. This is why it is necessary to evaluate the systems directly in a work environment when choosing the components that are most likely to reduce vibration exposure.

This study presents the results of vibration measurements carried out on three different models of tanker trucks in which two different seat models with air suspension were installed. These results are used to evaluate, for each of the truck/seat combinations, the severity of the exposure with respect to ISO standard 2631/1[6], and to determine which of the truck/seat combinations provides an extended exposure time under similar operating conditions. Lastly, the effect of the load on the vibration levels is also evaluated.

References appear on page 5 of this document.

2.0 CHARACTERISTICS OF THE TRUCKS AND SEATS

The main characteristics of the trucks used for the tests appear in Table 1. For each of the trucks, the same tank was used. Trucks A and B were identical except for the vehicle's primary suspension, which in one case was air suspension (truck A), and in the other, mechanical (truck B). Truck C is distinguished by its motor (Cummins 350) which is different from the Caterpillar 350 motor used in the two others.

The two air-suspension seats have a device for adjusting them to the driver's weight. In addition, a horizontal isolator (fore-aft direction) provides a certain attenuation of the vibrations in this direction. The vertical suspension mechanism is located under the seat and consists of an air spring as well as a hydraulic cylinder for shock absorption. The linkage of seat A consists of a parallelogram, while that of seat B uses a cross-linkage mechanism, as illustrated in Figure 1. The linkage is in fact a guiding device which allows seat displacement in relation to its attachment points. Hence, seat movement is maintained mainly in a vertical direction. Furthermore, the linkage comes into play in the seat dynamics by adding a stiffness to the spring components.

The two seats also differ from the standpoint of the dimensions of the seat backrest and the cushion. Although these factors may have a direct effect on the comfort felt by the driver, it is mainly the seat-suspension characteristics which determine its ability to minimize exposure to vibrations which can be the most harmful for the human body. The suspension must therefore be properly adapted to the type of vibration found in the vehicle.

In the opposite case, the seat could even amplify vibrations at frequencies to which the human body is the most likely to react. This is why the seat's vertical transmissibility (ratio of vertical vibration measured at the seat/driver interface to that measured at the cabin floor) must be obtained in relation to the frequency of the vibrations in order to determine the effectiveness of the seat in reducing vibration. Numerically, this is expressed as a transmissibility ratio which should ideally be maintained below 1.0 when expressed in scalar form, or 100 % when expressed as a percentage.

3.0 METHODOLOGY

3.1 Measurement Procedure

In each of the three tanker trucks used in this study, two different types of seat models were tested, giving six truck/seat combinations. Except for the tests with truck C, all measurements were performed over a well-defined path between the Petro Canada refinery in eastern Montreal and St-Jean-sur-Richelieu. The trip was made with the tank fully loaded. For the return trip, the tank was empty. During the trip, certain sections of road were identified during which the vibratory signals were actually recorded. The path included sections of highway and city streets. The sections of road used are identified in Table 2 for the outward trip (sections 1 to 6, full load) and for the return trip (sections 7 to 12, empty). In the tests with truck C, a different route was used; the results obtained can therefore not be compared with those obtained for the two other trucks.

To obtain measurements that are as uniform as possible, the same driver and the same tank were used for the tests, for each of the truck/seat combinations. In addition, the same routes were used (except for truck C) when the truck was fully loaded (35000 to 39000 L of gasoline) and when it was empty.

3.2 Vibration Measurement and Analysis

For each truck/seat combination, the measurements were made at the seat/driver interface in each of the x (front-back), y (lateral), and z (vertical) directions. Furthermore, a measurement was made in the vertical direction at the cabin floor, directly under the seat. This allows the seat (and driver) transmissibility to be evaluated in the vertical direction.

A triaxial piezoelectric accelerometer (B&K 4321) was used as a sensor at seat level, while a uniaxial accelerometer (B&K 4381) attached to a magnet was used as a sensor at the floor. The vibrations were measured according to ISO standard 2631/1, in the frequency range from 1 to 80 Hz. A telemetry system consisting of four channels was used to carry the vibration signals from the truck to a mobile laboratory (van) moving behind the tanker truck. In this way, all signals were recorded on magnetic tape for subsequent analysis. Figure 2 shows the measurement and data-acquisition system.

The analysis consisted of obtaining, for each of the measurement channels connected to the seat, the frequency spectrum of the vibrations in the 1-80 Hz range, and of comparing the measured levels with the limit proposed in ISO 2631/1 standard for the "fatigue-decreased proficiency"[6]. This limit is chosen because it represents the vibration levels which could result in increased fatigue, both physical and mental, thus representing a safety risk, particularly for a driver who must remain extremely vigilant while driving. In addition, this limit is the best guide to use because no cause-effect relationship exists which is capable of establishing a direct connection between exposure to whole-body vibration and specific pathologies.

The vibration level measured at the dominant frequency in the spectrum (once it has been frequency weighted to take into account the variation in the sensitivity of individuals as a function of frequency) is used to determine the severity of the exposure in relation to the prescribed limit. Since the effective exposure time can vary from day to day (different routes, varying traffic, variations in climatic conditions, etc.), the limit proposed is used to estimate the daily exposure time that would be permitted, taking into account the measured level of vibration, so that the fatigue-decreased proficiency limit is not exceeded. This is done for each of the sections of the route. The segments are then combined in order to estimate the time that would be permitted when each workday is represented by the vibration levels measured during the full-load trip, the empty trip, and the two-way trip. The procedure used is the one defined in ISO standard 2631/1 (section 4.4.3) to estimate an equivalent exposure time when daily exposure is characterized by different levels of vibration distributed over several partial exposure times.

Lastly, the results are used to identify which seat, truck and seat/truck combination allows maximum exposure time, while respecting the limits in ISO standard 2631/1.

4.0 RESULTS AND DISCUSSION

4.1 Analysis by Individual Segments

Table 3 presents the results of vibration measurements for the truck A/seat A combination. The analysis of the vibrations measured at the seat in the three directions (x, y and z), shows that the vibrations in the vertical direction are generally predominant; the exposure time permitted before reaching the fatigue-decreased proficiency limit is generally under 10 hours per day. In the other directions, the permitted time is generally greater than 10 hours along the x axis, and 20 hours along the y axis. These results are almost identical for the other truck/seat combinations and show the importance of the vertical vibrations, which are predominant. Furthermore, only those results obtained from vertical vibrations are chosen as indicators of the efficiency of one shock absorbing system (seat/truck) over another.

Figures 3 and 4 illustrate graphically the results of the measurements carried out on each of trucks A and B, for each of the 12 road sections, when the truck is fully loaded and when it is empty. A comparison is then made, for each section, of the exposure time permitted when the truck is equipped with seat A as compared to seat B. With few exceptions, for all the sections, seat B provides the longest exposure time, both for truck A and for truck B. In addition, a comparison between identical road sections, when the truck is fully loaded and when it is empty, indicates that truck A tends to provide a longer exposure time when the truck is empty than when it is fully loaded (i.e., lower level of vibration when empty than fully loaded). The opposite seems to occur in truck B (mechanical suspension), in which the exposure levels are highest when the truck is empty. This type of behavior can be explained by the fact that the vehicle's primary mechanical suspension must, to be effective, be somewhat pre-loaded which, in the case studied, would be supplied by the weight of the gasoline in the tank. Air suspension, however, has the advantage of adjusting to the weight that it has to support.

4.2 Analysis by Combination of Sections

Since there are several periods of vibration exposure during a workday and their time and intensity can vary, an average of the vibrational energy is required to better characterize the true daily exposure to vibration. Figures 5, 6, 7, and 8 present the frequency spectra obtained by combining, for each of the truck/seat combinations, the sections for which the tank is empty and fully loaded. The overall weighted acceleration is presented near each graph, indicating the weighted vibrational energy between 1 and 80 Hz. The dominant frequency of the weighted spectrum is also indicated by a dotted line on the figures.

The analysis of these spectra produces the same results as those obtained by using the segment analysis, particularly: 1) that seat B results in less vibration exposure than seat A; and 2) that the levels of vibration exposure are lower when truck A is empty than when fully loaded, whereas the opposite is true for truck B.

These results are interpreted in Table 4 on the basis of the fatigue-decreased proficiency limit in ISO standard 2631/1 for each of the six truck/seat combinations. The daily permitted exposure time is indicated, based on the combination of the vibration segments when the tank is empty and fully loaded and when the two routes (i.e., both way) are taken into consideration. It is observed that for the same truck, seat B always provides the longest exposure time without exceeding the prescribed limit. This seat can thus allow an exposure time up to 1.8 times the time permitted with seat A. In addition, it is noted that the best truck/seat combination for reducing exposure to whole-body vibration, from among the combinations studied, is truck A used in conjunction with seat B. According to the results, slightly more than 12 hours of daily exposure could be allowed with such a combination. In general, the limit proposed for 8 hours of daily exposure cannot be met by 3 of the 6 truck/seat combinations studied.

The transmissibility curves for the seat/driver system are presented in Figures 9, 10 and 11, for trucks A, B, and C, equipped with seats A and B. These curves once again clearly indicate that for each truck, seat B provides a greater attenuation of vibrations than seat A, particularly at low frequencies (under 3.2 Hz). In this zone, however, the vibrations are amplified by the seat/driver system, but with the amplification much less pronounced for seat B than for seat A.

5.0 CONCLUSION

From this study of vibration exposure in tanker trucks, a seat model with air suspension could be identified, which provides, in combination with a vehicle whose primary suspension is air suspension, sufficient vibration attenuation to allow the limit suggested in ISO standard 2631/1 to be respected for slightly more than 12 hours of daily exposure. Consequently, the truck A/seat B combination proved to be the most promising in reducing exposure to whole-body vibration, at least in the 6 truck/seat combinations tested and for the routes chosen.

Seat B, with its cross-linkage mechanism, proved superior to seat A in reducing vibration exposure in the three models of trucks studied. These results lead us to believe that seats with cross-linkages are probably those most likely to reduce vibration exposure. The effect of the load on the levels of vibration transmitted to the driver was observed. For truck A equipped with air suspension, the vibration exposure is slightly greater when the tank is full than when it is empty, the suspension adjusting to the load. For truck B equipped with a mechanical suspension, the exposure dose is maximum when the tank is empty, this suspension having to be pre-loaded to be effective.

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TABLE 1: TRUCK CHARACTERISTICS

Truck	Year	Type of Primary Suspension	Type of Motor
A	1987	Air	Cat 350
B	1987	Mechanical	Cat 350
C	1987	Air	Cummins 350

TABLE 2: IDENTIFICATION OF THE ROAD SEGMENTS USED DURING THE TESTS*

	Segment Number	
	Full Load	Empty
• Highway	1	12
• City Streets (Montréal)	2,3	10,11
• Jacques Cartier Bridge	4	9
• Highway 10	5	8
• Highway 35	6	7

* Not applicable to the tests conducted with truck C

TABLE 3: ESTIMATES OF EXPOSURE TIME PERMITTED COMPUTED FROM MEASUREMENTS WITH THE TRUCK A/SEAT A COMBINATION ON DIFFERENT ROUTE SEGMENTS

	Exposure Time Permitted *(h)		
Segment Number	X-Axis	Y-Axis	Z-Axis
1	10	22,6	7,5
2	24	16,8	5,1
3	19,5	14,3	4,0
4	19,5	24	4,6
5	16,1	21	6,4
6	24	24	6,7
7	15,4	24	14,4
8	13,8	21,6	8,1
9	10,3	22,4	12,9
10	16,3	21,1	9,2
11	16,7	24	8,9
12	16,9	20,7	6,8

* Fatigue-decreased proficiency limit

TABLE 4: EXPOSURE TIME PERMITTED FOR EACH OF THE TRUCK/SEAT COMBINATIONS

Combination	Exposure Time Permitted *(h)		
Truck / Seat	Tank Full	Tank Empty	Round Trip
Truck A / Seat A	5,5	9,1	6,7
Truck A / Seat B	10,1	16,6	12,2
Truck B / Seat A	8,8	8,7	8,8
Truck B / Seat B	11,9	9,0	10,3
Truck C / Seat A	4,8	4,4	4,6
Truck C / Seat B	6,8	5,4	6,2

* Fatigue-decreased proficiency limit

FIGURE 1: SEATS LINKAGE CONFIGURATIONS
A) PARRALLELOGRAM, SEAT A, AND (B) CROSSLINKAGE MECHANISM, SEAT B

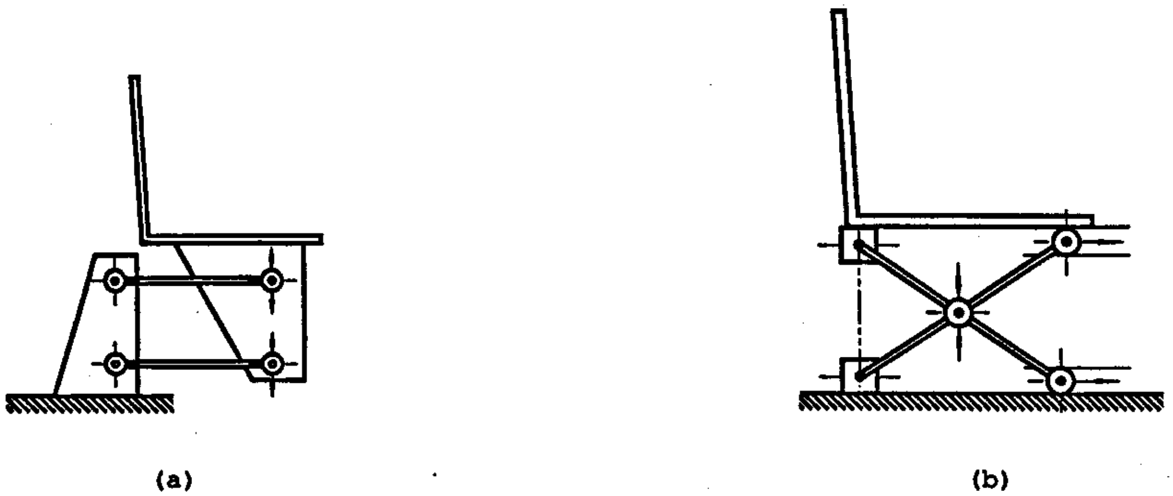


FIGURE 2: DATA ACQUISITION AND ANALYSIS SYSTEM

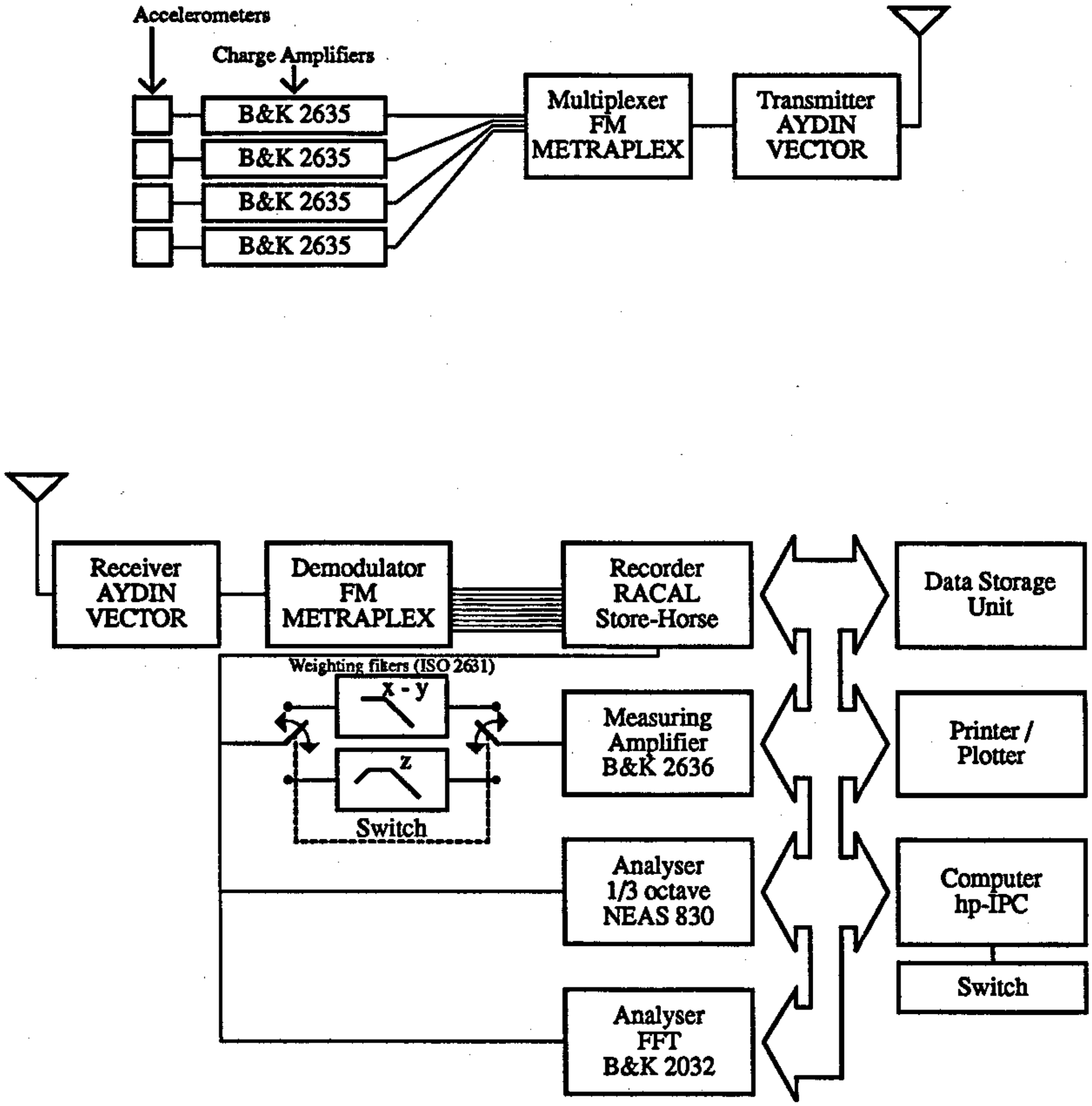
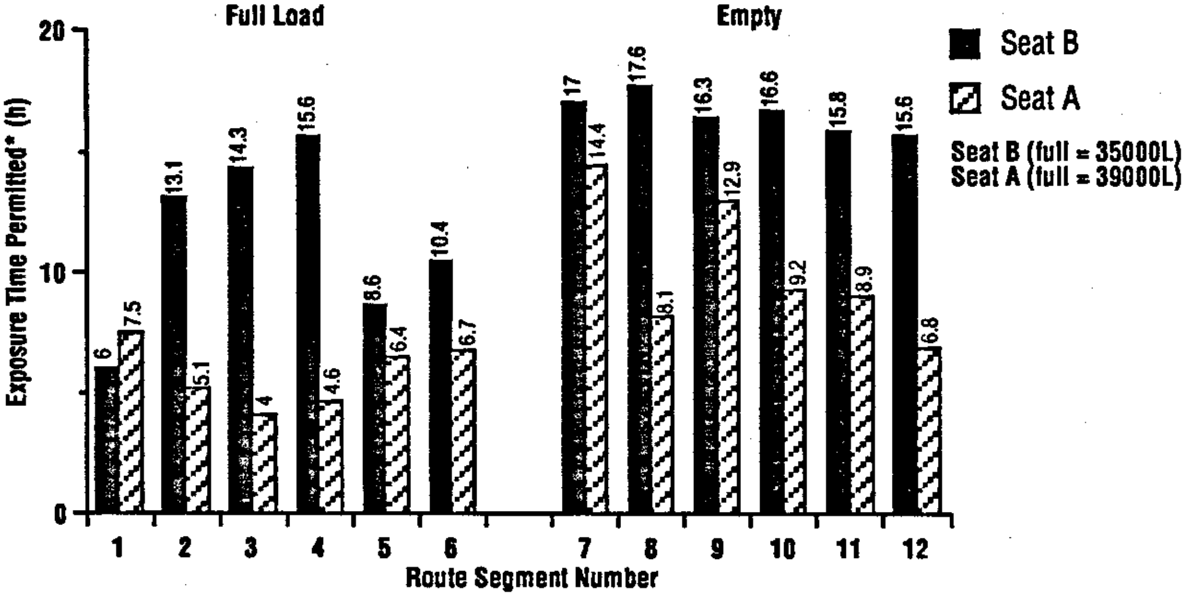


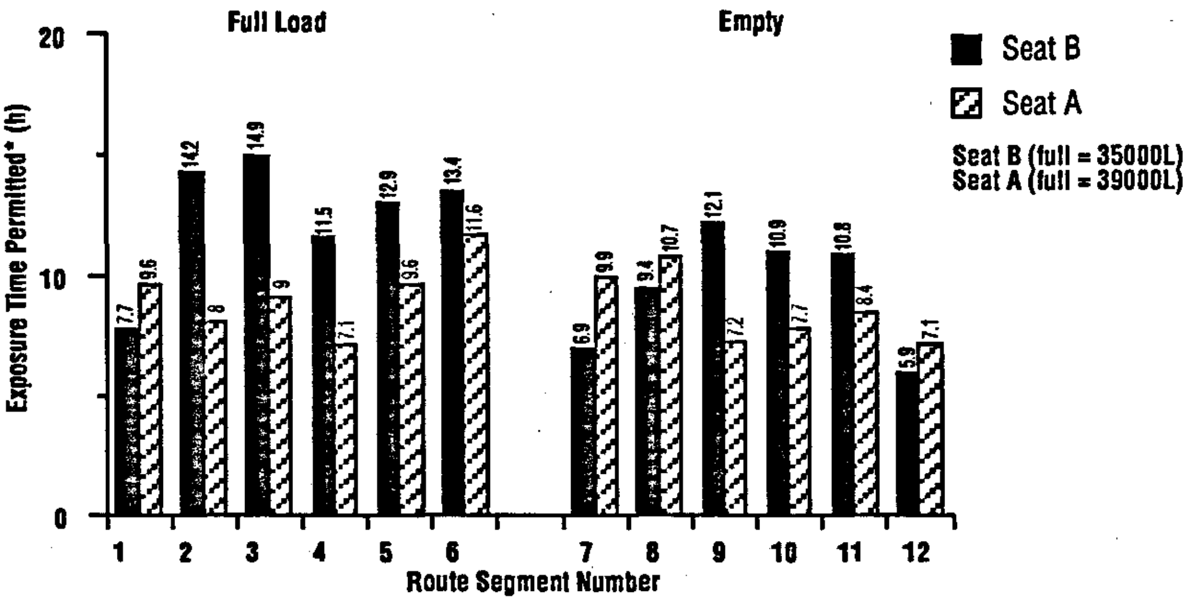
FIGURE 3: EXPOSURE TIME PERMITTED WHEN DRIVING TRUCK A (PNEUMATIC SUSPENSION) USING TWO DIFFERENT SEATS (VERTICAL VIBRATION)



fatigue-decreased proficiency limit

(ISO 2631 / 1)

FIGURE 4: EXPOSURE TIME PERMITTED WHEN DRIVING TRUCK B (MECHANICAL SUSPENSION) USING TWO DIFFERENT SEATS (VERTICAL VIBRATION)



fatigue-decreased proficiency limit

(ISO 2631 / 1)

FIGURE 5: FREQUENCY SPECTRA OF THE VERTICAL VIBRATIONS FOR THE TRUCK A/ SEAT A COMBINATION WHEN THE TANK IS EMPTY AND FULL

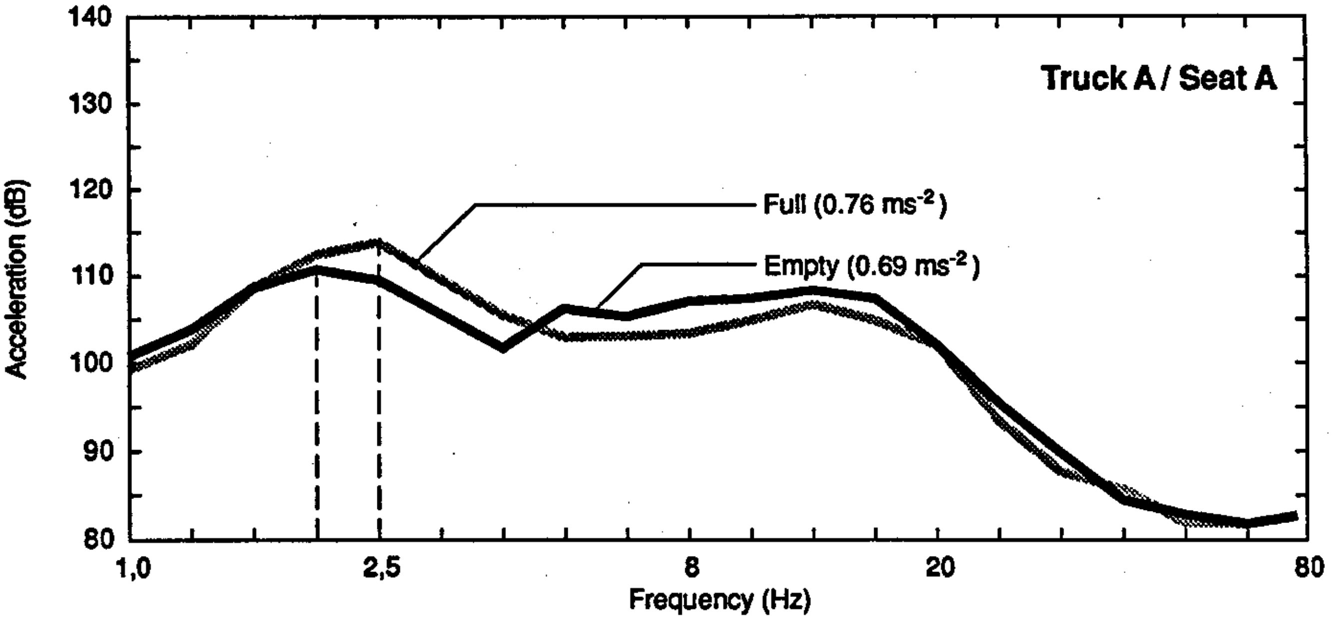


FIGURE 6: FREQUENCY SPECTRA OF THE VERTICAL VIBRATIONS FOR THE TRUCK A/ SEAT B COMBINATION WHEN THE TANK IS EMPTY AND FULL

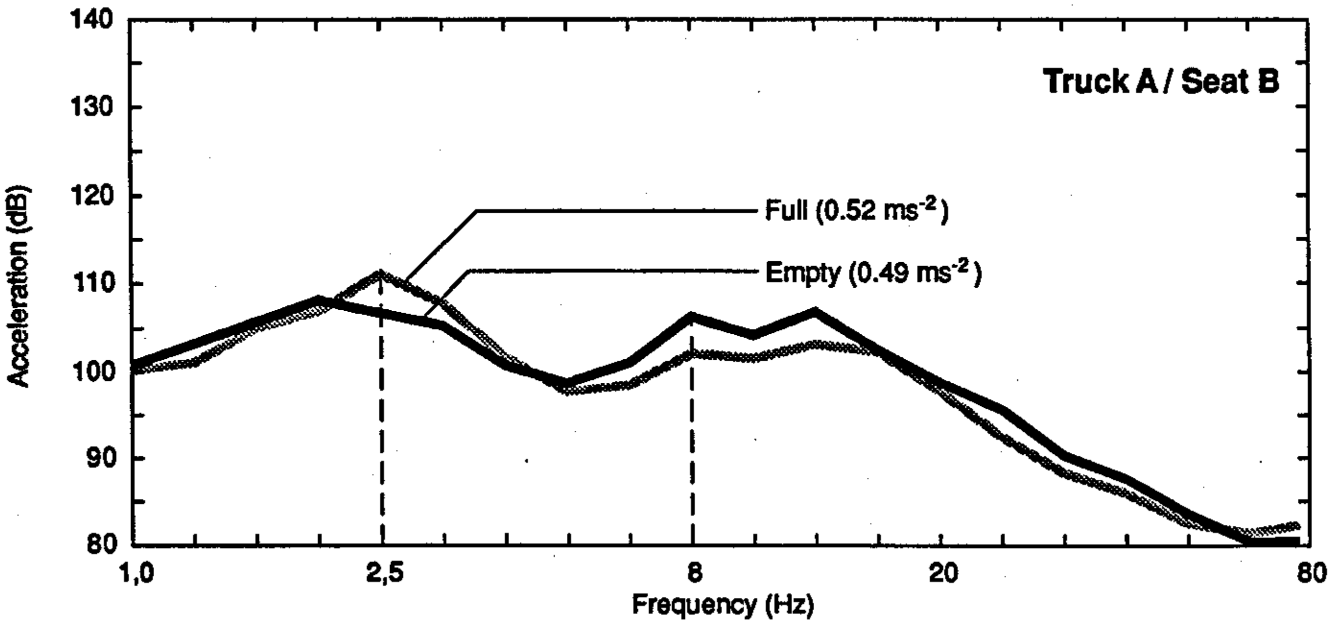


FIGURE 7: FREQUENCY SPECTRA OF THE VERTICAL VIBRATIONS FOR THE TRUCK B / SEAT A COMBINATION WHEN THE TANK IS EMPTY AND FULL

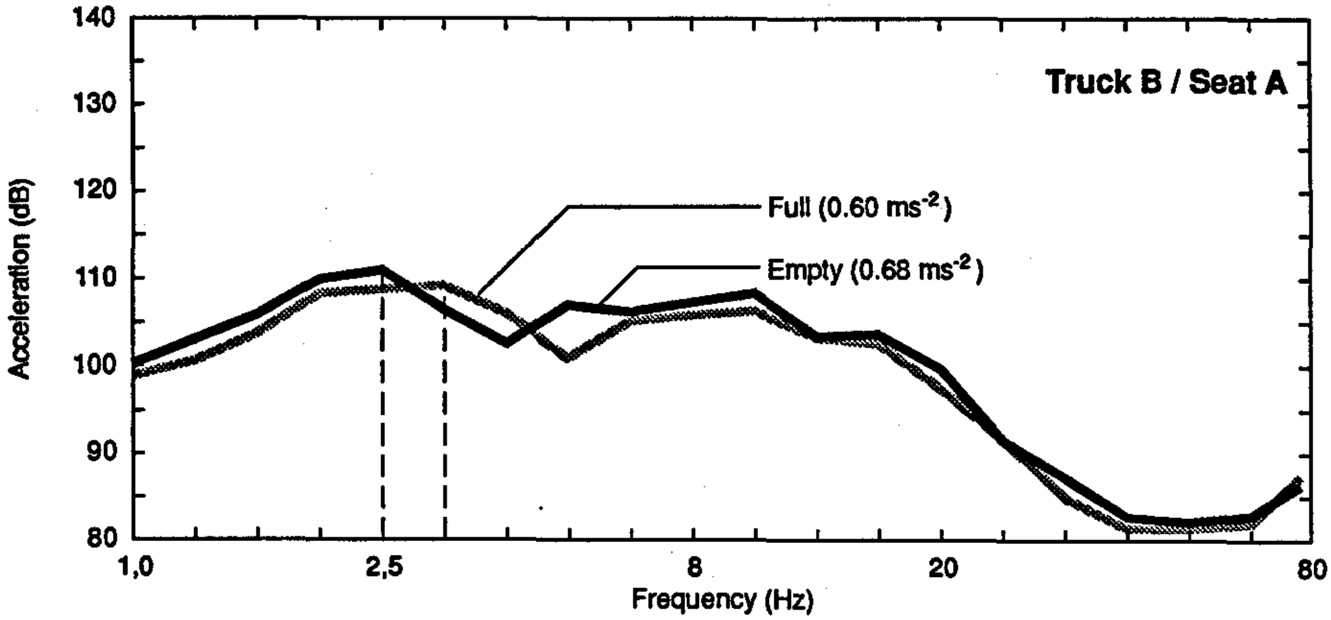


FIGURE 8: FREQUENCY SPECTRA OF THE VERTICAL VIBRATIONS FOR THE TRUCK B / SEAT B COMBINATION WHEN THE TANK IS EMPTY AND FULL

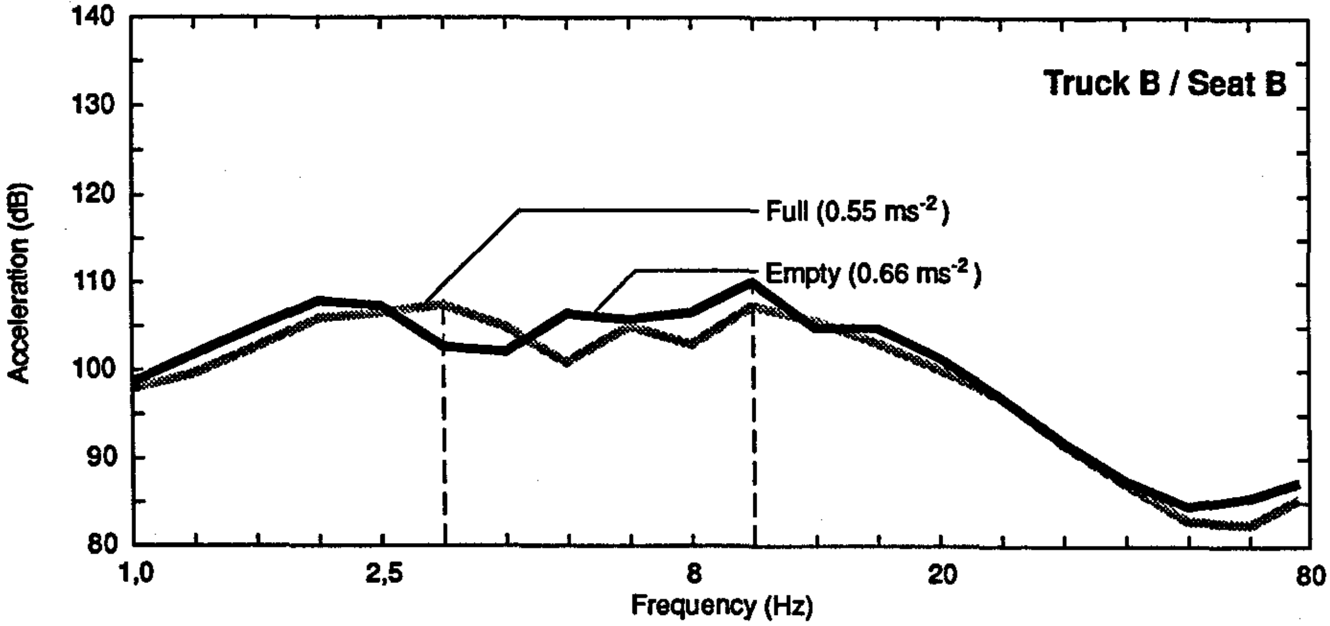


FIGURE 9: VERTICAL TRANSMISSIBILITY CURVES MEASURED WITH TRUCK A

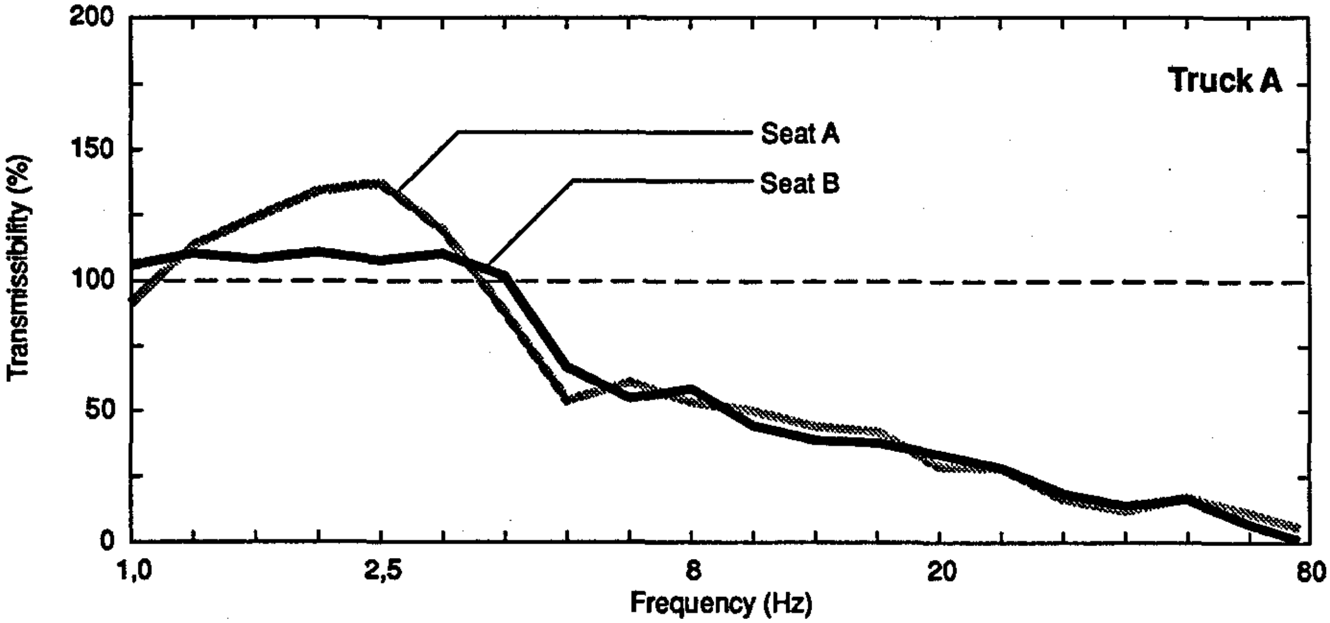


FIGURE 10: VERTICAL TRANSMISSIBILITY CURVES MEASURED WITH TRUCK B

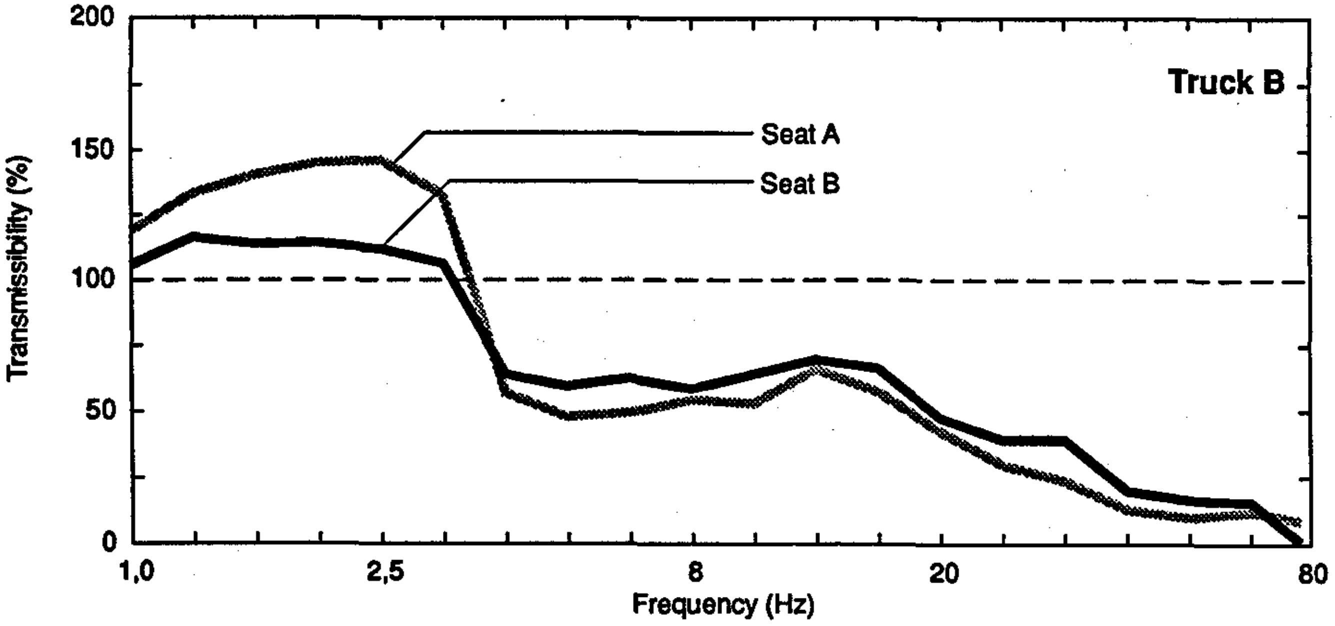


FIGURE 11: VERTICAL TRANSMISSIBILITY CURVES MEASURED WITH TRUCK C