

Research on optimization of test cycles for comfort to the special vehicles

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Abstract. The comfort of vehicles, regardless of their type is represent a requirement to by fulfilled in the context of current technological developments special vehicles generally move under different soil, time, or season conditions, and the land in which the vehicles move is complex and varied in the physical structure. Due to the high level of involvement in the driveability, safety and comfort of automotive, suspension system is a key factor with major implications for vibration and noise, affecting the human body. The objective of the research is related to determining the test cycles of special vehicles that are approaching real situations, to determine the level of comfort. The evaluate of the degree of comfort will be realized on acceleration values recorded, especially the vertical ones that have the highest influence on the human body. Thus, in this way the tests can be established needed to determine the level of comfort required for each particular type of special vehicle. The utility of the test cycles to optimize comfort is given to the accurate identification of the specific test needs, depending on the each vehicle.

Keywords: comfort, optimizing, vibration.

1.Introduction

Subjectively speaking, the comfort of the vehicles is closely related to a series of factors that together generate the comfort and satisfaction of those inside it and have the effect of safely moving at a satisfactory speed without producing negative reactions by point of view psycho-physiological of the body or damage to the materials and the transported technique.

The feeling of comfort is a very complex ensemble of physical and psychological physiological responses, which appear in response to the multitude of factors that act upon it, in the time to travel with the vehicle. Vehicle displacements in rough terrain often cause human body disturbances due to preponderant shocks of over 2g, which cause substantial force loads, damage to the musculoskeletal structure. Their influence is more evident when produced at the natural resonance frequency of the human body - 5Hz. About the way how affect the comfort the unevenness of roads and road shocks, at the car seat level, a number of notable Huston & Zhao researches (2000) [1] were carried out. Nar et al (2008) [2] mentions that shifts by exposure for 1 hour to such vibrations cause chronic muscle fatigue and structural damage to the spine. Matsumoto & Kunitatsu (2010) [3] mentions also as that the human body has a high degree of sensitivity at certain frequency ranges: 4-6Hz in the vertical direction and 8-12Hz in the horizontal direction. The research in the comfort domain revealed that the most important factors that have direct influence on it are: suspensions, seats and its facilities, vibrations and noise produced during the journey.



Corroborating these aspects, we can understand the importance of establishing test cycles for vehicles to determine the degree of comfort provided by special vehicles, on different road categories. In this direction, the research objectives have been established to obtain significant data on the vibrations felt at the level of the special motor vehicle structure, following the approach of real and varied routes as a physical structure, as well as the establishment of reference cycles for identify the level of comfort. These cycles will be correlated with current comfort rules and requirements, based on the analysis of recorded data, to determine new, more realistic tests valid for this type of vehicles.

2. Establishing test cycles

During the research processes, design, development and operation of the vehicles, are highlighted the necessity and the importance of the tests.

These activities contribute in a definitive way to their further and permanent improvement. The test cycles (figure 1) are of particular importance and are carried out in order to verify that the technical and qualitative characteristics of the systems are exactly fulfilled, but also to check the optimizations that can be applied later. These include tests on different ground and climate conditions.



Figure1. Testing trails: a-highway road, b-paved road, c-road with unevenness, d-road with obstacles

Thus, by optimizing the comfort test cycles, all the qualitative spectrum is constantly improved, new technical and constructive solutions are identified.

Technically speaking, the main aspect of importance for vehicle comfort is the choice of component parts of the suspension system. This is a compromise between the maneuverability and comfort of the vehicle. Special vehicles (military) is traveling in very varied terrain, time or season, much more different than those predetermined in the homologation tests.

They are moving in terrains with a very complex physical structure and involves dynamic forces much higher than expected. Because of these situations, the vehicles must ensure good maneuverability and adequate comfort. The development of the research are considering to identify correctly the routes that correspond to the realities of the displacements to which the special vehicles are subjected, the analysis of the main aspect affecting the comfort factor and the subsequent establishment of some test cycles in order to determine the passengers' comfort, for these types of vehicles. The approach of land areas with a varied structure, under the conditions imposed by the specific actions, allows the correct identification of the values that affect the state of comfort. To establish the correct cycles, vertical accelerations are of particular importance due to the negative influence on the human body. Their amplitude value is directly proportional to the discomfort created. The choice of cycles is determined by the needs and demands of special vehicles during mission trips.

In the research process, a route was identified that could accommodate several areas of the comfort test, which corresponds to the actual displacements performed. The cycles chosen for the tests highlight the level of mechanical oscillations induced by the route. In the following image (figure 2) we can see the route and the topography of the terrain, during the researches.

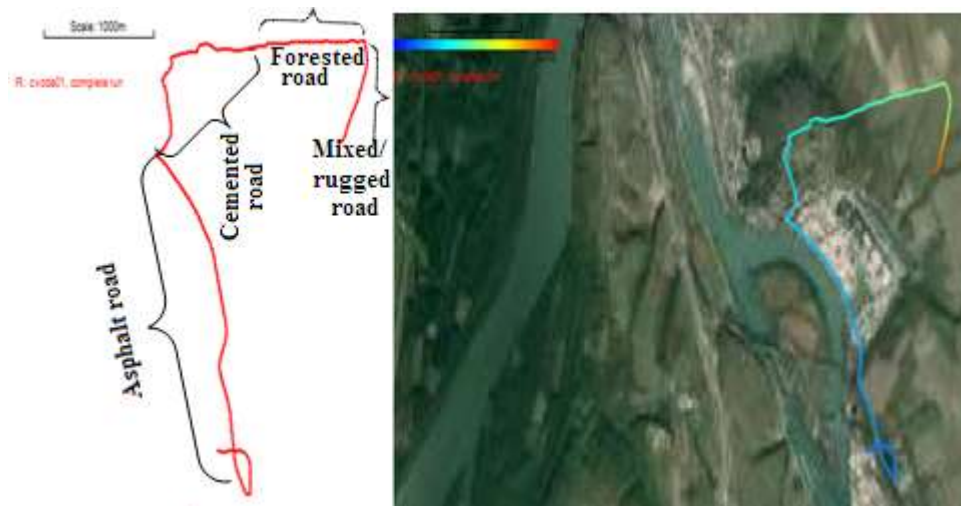


Figure 2. The route where research was conducted: Vbox-GPS / Google Map

The established cycles follow the values of the vertical accelerations recorded on each part of the field, by moving the vehicles at speeds imposed by the created situation of the action, and maintaining the safety and the minimum stability of the vehicle. Thus, the amplitudes of recorded vertical oscillations characterize the level of comfort of the vehicle's personnel, by reference to ISO 2631-1 specifications [4].

3. The making out research

For the development of the researches, an area has been established up, that comprising various sections of relief, as well as different physical structures of the terrain.

Thus, the area of Cernavoda met the requirements imposed by the research. The tests were carried out with a special VW T4 full-traction vehicle (figure 3), used by the Gendarmerie in specific tactical actions. In research development, has been foreseen that data acquisitions will follow the values of vertical accelerations by passing through a variety of terrain: asphalt with small irregularities, concrete-industrial, earth-forest, mixed-rugged.



Figure 3. Special vehicle VW T4 in rugged terrain – Gendarmerie

The physical variety of the lands (figure 4) is given by the complexity of the travels of the special vehicles during the specific actions.



Figure4. The rugged trails in which special vehicles are moving

The equipment used for the data acquisition was established in two categories: the first category is allocated for the collection of data on the topography of the land, and the second one for the recording of the accelerations specific to the sections of the land in which the travels is performed. The equipment chosen for data acquisition about vibrations is produced by RACELOGIC Technology, respectively a Vbox module with GPS antenna and triaxial accelerometers type RLVBIMU 03. In accordance with the ISO 8608 [5] for a value of the land unevenness index $w = 2$, in the following (table 1) road classes and their specific values are presented, depending on the spectral density characteristic (PSD).

Table1. The road classification according to ISO 8608

Road Class	$G_H(\Omega_0) [10^{-6} m^3/rad] (\Omega_0 = 1rad/m)$		
	Lower limit	Upper limit	Geometric mean
A	-	2	1
B	2	8	4
C	8	32	16
D	32	128	64
E	128	512	256
F	512	2,048	1,024
G	2,048	8,192	4,096
H	8,192	-	16,384

However, the value of the "w" index is not uniform for all road classes, in reality its value is up to $w = 3,5$. By changing its value, low frequencies generated by the road profile become more pronounced. This affects the more sensitive human body in this frequency range. At the same time, a small value of the index generates high frequencies, which affect the comfort and response of the vehicle suspension system [6]. The Power Spectral Density (PSD) factor reflects the vibration response of the vehicle and in fact represents the unevenness of the road, given by the planarity index "C" and the undulation "w". The estimation of parameters C and w is mentioned in the standards: ISO 8608 and EN 13036-5.

For a vehicle traveling on a rough road with a speed (v), the road non-uniformity relation (PSD) can be described by an equivalent mathematical function in the spatial domain $G_H(\Omega)$ in the time domain $G_H(\omega)$:

$$G_H(\omega) = G_H(\Omega)/v \quad (1)$$

where: ω = angular frequency [rad/s]; $\Omega = \omega v$.

Knowing that the frequency of excitation in the time domain is given by the relationship:

$$f = \frac{\omega}{2\pi} = \frac{v}{\lambda} \quad (2)$$

and that, vibrations generally propagate through the structure of vehicles with frequencies ranging from $f = 0.5$ -15 Hz, and the human body is very sensitive on the intervals: $f = 1$ -2 Hz; 4-8Hz; 10-12Hz, we can say that this range is covered by waves which satisfies the relationship:

$$0,5Hz \leq \frac{v}{\lambda} \leq 15Hz \quad (3)$$

During the research, the speed of movement showed a lot of variations but, according to the recorded data, for the areas of land of which particular interest, were registered the maximum travel speed $V_{\max} = 59$ km/h and the average $V_{\text{mid}} = 27,4$ km/h. Reconstructing the relationship (3) we can find the value of the wavelength of the frequencies generated by the road in which the vehicle moved, on the vibration interval:

- for V_{\max} : 59km/h

$$16,38 \text{ m/s} = 15Hz \cdot \lambda \Rightarrow 1,092m^{-1} \quad (4)$$

$$16,38 \text{ m/s} = 0,5Hz \cdot \lambda \Rightarrow 32,76m^{-1} \quad (5)$$

- for V_{mid} : 27,4km/h

$$7,61 \text{ m/s} = 15Hz \cdot \lambda \Rightarrow 0,507m^{-1} \quad (6)$$

$$7,61 \text{ m/s} = 0,5Hz \cdot \lambda \Rightarrow 15,22m^{-1} \quad (7)$$

On the basis of the values obtained, we can understand that for the sections of road where the travel speed was higher, the road roughness did not generate significant oscillations for the vehicle, so it did not create a high degree of discomfort. In comparison, the much more difficult route that generated totally different approach situations, the λ values were high, which shows a great discomfort. Analyzing the data from the following graph (figure 5) we can see the influence of the factor λ on the movement of the vehicle through the rough areas of the land where the travel was made.

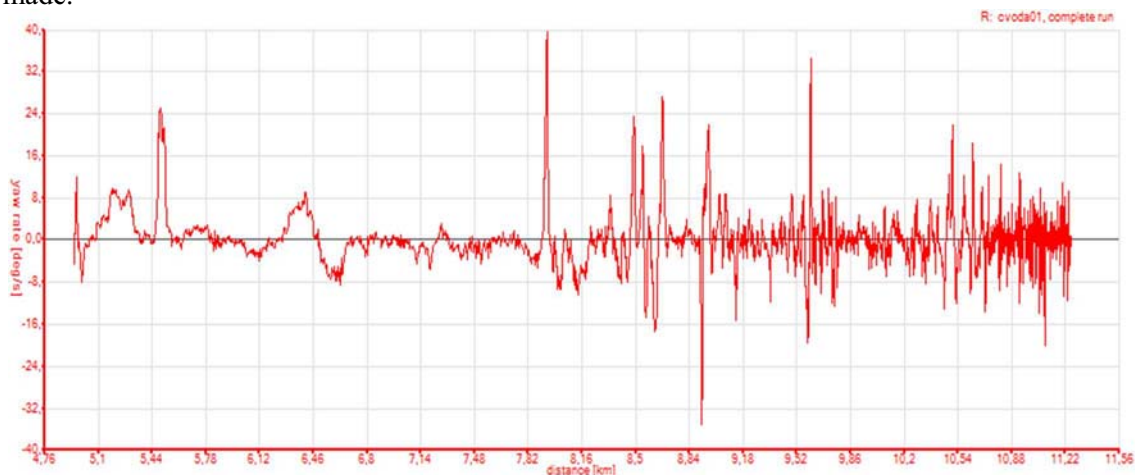


Figure5. The speed under which the vehicle it transits the roughness of the road

4. Results and data analysis

Road is structure with the most important for the vehicles, from a dynamic point of view.

Due to this, features such as vehicle viability and comfort are influenced by the road type and its irregularities as well as the speed of travel. Ensuring comfort regarding the vibration for the driver and transported persons depends on the entire shock and vibration damping system. Taking into account the profile of the routes in which the travel was made and their physical characteristics, we can understand that the vertical, but also the longitudinal or lateral accelerations were completely different. Also, in this respect, we can say that the accelerations have manifested differently from the front axle at the rear axle. The wheels, not go in aligned way on the unevenly road profile so the values on the right side of the vehicle are different from those on the left. In the following (fig. 6), can be observed along the route the values of longitudinal, lateral and vertical accelerations, in accordance with the altitude of the terrain.

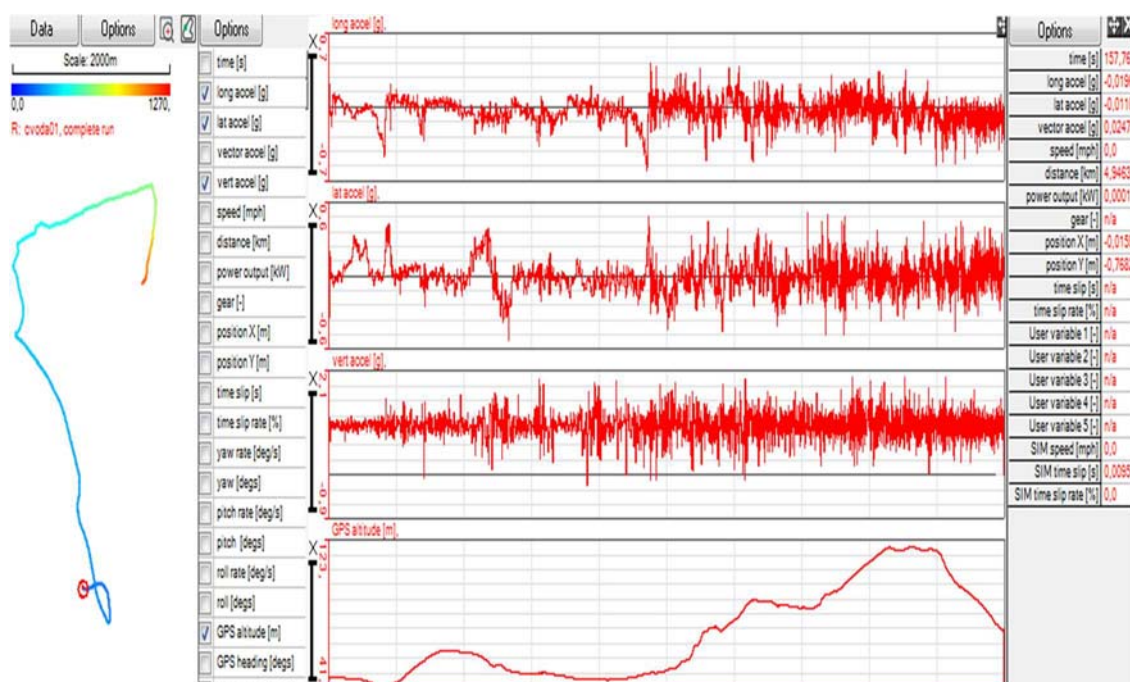


Figure 6. The acceleration values recorded according to the altitude of the terrain

By analyzing the route, the vertical acceleration values of each section of the road were identified and compared. Each route, as shown in the following picture (figure 7), clearly revealed the discomfort created by the personnel through the recorded values.

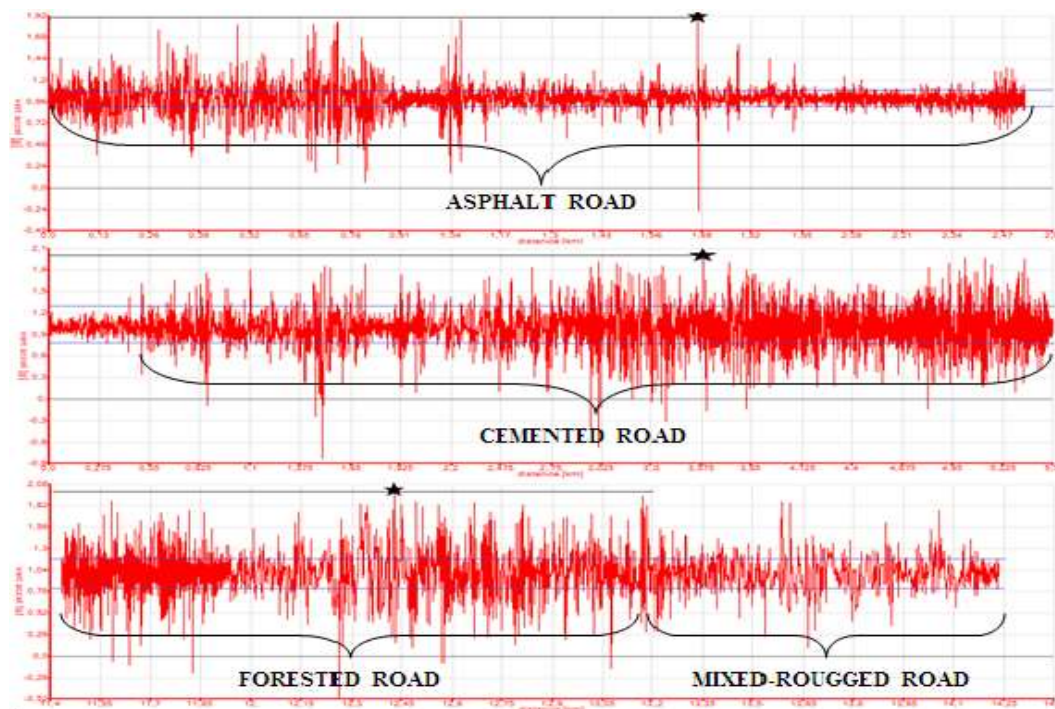


Figure 7. Vertical (unfiltered) accelerations recorded on each section of road

The level of mechanical oscillations amplitude was more pronounced in the concrete road sector, due to the speed of the vehicle. High values also occurred in the forest and mixed-road sectors, but they were lower due to the limited speed of the vehicle during the movement of the vehicle on the route. Thus, the accelerations were predominantly in the range of 1.2-1.5 m/s^2 with multiple manifestations in the frequency range of 1.8 m/s^2 . These values demonstrate a very high degree of discomfort and a risk to the health of the body. In the same way, the forestry section indicated many vertical acceleration values of 1.2 m/s^2 , which is also a high level of discomfort. In this case the travel speed was lower due to the pronounced ground deviations. However, discomfort also manifested itself in this case. The asphalt road sector was of no particular importance, except for a small portion where the road was built by overlapping asphalt layers, which created non-uniform displacement.

In according with ISO 2631-1 (Annex C) and BS 6841 [6], in the following table (table 2) can be observed weighted values of the accelerations and how their influence on the people comfort.

Table 2. Guidelines ISO 2631 and BS 6841 for vibration and human perception

Values (m/s^2)	Perception
<0.315	Not uncomfortable
0.315–0.63	A little uncomfortable
0.5–1.0	Fairly uncomfortable
0.8–1.6	Uncomfortable
1.25–2.0	Very uncomfortable
>2.5	Extremely uncomfortable

The ISO 2631-1 standard specifies that after the value 1,25 m/s^2 RMS, status uncomfortable is increasing. Therefore, in the conditions of the route that was taken during the research driver has felt different conditions of discomfort.

The sensitivity of the body to vibration depends on the direction and the character of the oscillatory movement, but also on the subjective perceptions of each individual.

The oscillations produced by the vehicle during the travel represent a lot of movements, in different directions, having different frequencies and amplitudes, even in the case of simple sinusoidal excitations. In the following (figure 8), can also be observed the values of the recorded longitudinal / lateral accelerations depending on the terrain: asphalt-concrete-forest-mixed, the speed of the vehicle and the altitude of the terrain.

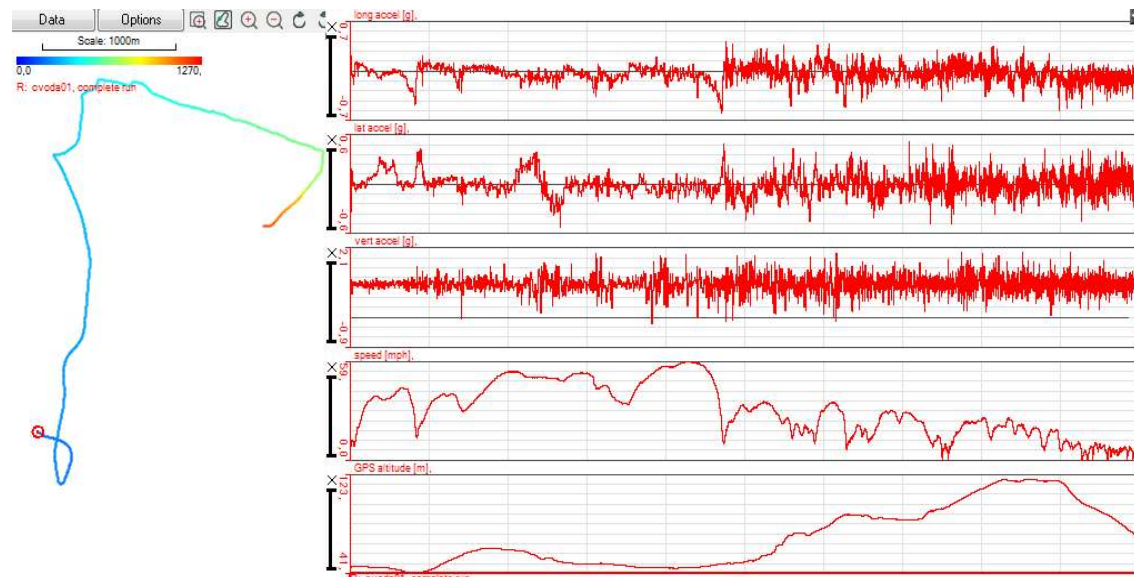


Figure8. Longitudinal / lateral accelerations recorded relative to the speed and altitude of the terrain

According to the above image (figure 8), we can understand that the altitude of the terrain created problems to travel with the speeding due to its physical characteristics. Also, the structure of the ground through physical irregularities has limited the uniform movement of the vehicle, generating frequent crossings over obstacles, which has created a high level of discomfort to staff, especially through the generated shocks. The portion of concrete road and forest road indicated significant comfort problems through the high and constant values of vertical accelerations. In accordance with the international standard VDI 2057, the following table (table 3) presents the scale of subjective perceptions of comfort.

Table3. Thresholds of perception and subjective appreciation of comfort

Step	The threshold of perception "K"	Subjective appreciation
A	0,1	It does not feel
B	0,25	Appearthe first sensations
C	0,63	Minimum level of sensations
D	1,6	It feels good
E	4	He feels strong
F	10	Very strong level of perception
G	25	Very strong level of perception
H	63	Very strong level of perception

Factor K sets the human body's tolerance limits to periodic vibrations for the frequency range of 0.5-80 Hz. The VDI 2057-1 standard recommends in practice the summation of the squares of the partial comfort indices of the n different variations.

$$K = \sqrt{\sum_{i=1}^n k^2 i} \quad (8)$$

where: k_i = partial comfort index; n = number of component vibrations.

The evolution of vertical accelerations recorded throughout the test cycles can be seen in the following figure (figure 9). Consistent with this, we can say that the reference values for determining the level of comfort are those included in the concrete and forest road section, which have accelerations predominantly above the value of the comfort threshold: 1.2 m/s^2 .

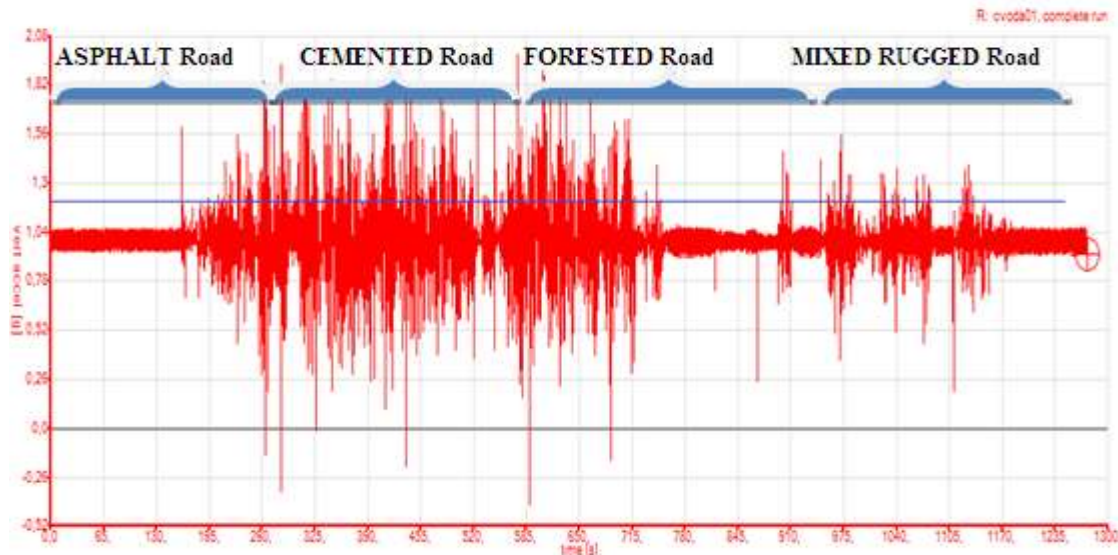


Figure9. Vertical accelerations recorded throughout the entire route

After result of the general analyzes we can see in the following table (table 4) the random vibration values recorded after filtration and mediation.

Table4. The values of random vibration recorded in the all sectors of road

Road tipe	Direction "x"		Direction "y"		Direction "z"	
	Peak acc. m/s^2	Peak acc. m/s^2	Peak acc. m/s^2	Low acc. m/s^2	Low acc. m/s^2	Low acc. m/s^2
Asphalt	0,26	0,1	0,49	0,1	1,56	1,04
Concrete	0,56	0,1	0,55	0,12	1,82	1,2
Forested	0,3	0,12	0,6	0,1	1,98	1,3
Mixed / stone	0,47	0,13	1,2	0,49	1,56	1,16

From the above we can understand that on some portions of the route the lateral and horizontal vibrations are slightly elevated, which signifies a feeling of inconvenience at the threshold of acceptance. However, due to the structure of the land, these types of vibrations were received by the structure of the vehicle by summing them up. So, the feeling of inconvenience due to vertical vibrations is was also amplified by these. To deepen the phenomenon and more accurately determine the degree of inconvenience, VDV_{total} is the most appropriate index for assessment at the level of the seat structure. It can be established with the help of the following relationship, indicated by the international standard BS 6841:

$$VDV_{total} = (VDV_{xs}^4 + VDV_{xy}^4 + VDV_{xz}^4 + VDV_{xb}^4)^{1/4} \quad (9)$$

where:

VDV_{xs} , VDV_{xy} , VDV_{xz} , = vibrations on the three directions in the seat cushion;

VDV_{xb} = longitudinal vibrations (x) received at the seat backrest.

Compared to the standard test methods, which, although providing for trails with different characteristics: bumps, inclinations, physical structure, the research presents more relevant aspects of the travels due to the values recorded on each part of the road. These include the real terrain and conditions in which the journeys are made, the speed of travel, aspects that are very different from those currently set as a reference for this category of motor vehicles.

The defining aspects of research are:

- travel speed - is on the limit of safety, all most of the time;
- the route followed - is the shortest way to reach the goal, regardless of structure and obstacles.

Its features are very different from the standard ones.

If for normal journeys within cities the methods established by the norms are fully satisfactory, in analyzing the degree of comfort of the staff in case of displacements in rugged areas, it is necessary to approach some more challenging routes as a structure and as a methodology of realization. The optimization of these comfort test cycles is necessary due to the infrastructure in the areas where journeys the special vehicle, but also because of the structure of the terrain.

5. Conclusions

Vehicle comfort is a very complex feature at present, due to the many factors involved in generating it.

Road roughness information is very important in assessing the vehicle's dynamic response, so in appreciating the comfort of the staff. For the research carried out are of importance, the specifications of the road classes on which the displacements (B-G) is performed.

By using the artificial road profile derived from PSD, we can study the vibration response of the vehicle and optimize the suspension parameters. The correct identification of some road sectors that corresponds to the actual movements of special vehicles makes it possible to understand correctly the phenomena that occur during the journey.

Determining accurately the acceleration values induced by routes allows the establishment of comfort limits by reference to existing international standards. Determining the degree of comfort in relation to the land being approached facilitates the optimization of the test cycles at the most realistic level of the trips.

The correct identification of the vibrations phenomena that occur at the level of the structure of special vehicles, during the travel to actions through very rough terrain and their reporting to the biological manifestation of the human body allows us to correctly understand the negative effects they produce.

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