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DETECTION OF DEFECTS IN THE RAILWAY TRACK THAT CAN INFLUENCE TRAFFIC SAFETY USING THE METHOD OF VIBRATION ANALYSIS OF VEHICLE-RAIL SYSTEM

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Abstract: *This paper presents a study of the vertical vibrations, on the Z axis, of a standard tank wagon, on 4 axles, Zacs type. It analyzes and compares the vibrations induced on the bogie boxes of the loaded and empty wagon at the points where the major deviations from the standard dimensions of the railway were measured. The measurements were recorded on a curved railway with a radius of curvature of 1800 m, on the ring from the Railway Testing Center from Făurei at a speed of 135km / h. The analyzed data is transposed in diagrams that reflect the influence of the railway profile in the movements of the wagon in motion in a curve.*

Key words: *safety, railway, vertical, vibrations, tank wagon, experimental analysis.*

1. INTRODUCTION

Given the current context regarding global warming, the creation of non-polluting modes of transport and rail traffic has regained the attention of local and international authorities. Rail transport can present advantages. Low energy consumption, transportation of large volumes, and low “CO2” emissions place this transport option at the top of the list when it comes to long-distance road transport.

In order for rail transport to be cost-effective, it must provide safety and commercial speed. In the case of a railway incident, the material damages are much higher than in the case of a car incident. Consequently, research and studies on traffic safety provide very important data and solutions from an economic point of view.

Thus, before the railway vehicles are put into circulation, they must go through a process of carefully studied tests and simulations in order to receive the approval of the characteristics of dynamic behavior and static tests [1].

The goal of these tests is to quantify vehicle performance under known representative operating and infrastructure conditions.

Vibrations influence passenger comfort, cargo integrity, and traffic safety. The ride quality of railway vehicles is influenced by the vibrations that occur in all freight or passenger cars [2, 3].

Irregularities in the running surfaces of rails and wheels are the main factors that cause vibrations to occur [4, 5].

When it comes to rails, there are deviations from the geometric shape of the track, irregularities on the running surface and discontinuities of the rail. The items mentioned above are the main causes that generate vibrations [6].

In order to study the vibrations, the theoretical version and the experimental version are adopted. Upon completion, the results obtained by the two methods are compared [7].

The complex oscillating system has specific vibration characteristics to the railway vehicle [8].

For the experimental version, in this case a tank wagon, the railway vehicle is equipped with sensors connected to a locomotive and tested on a railway ring under operating conditions. The data obtained has been processed and analyzed.

For the theoretical version, there are several programs ("Matlab", "Simulyng", "Ansys") that, based on the numerical model created, develop theoretical graphs for the vibration values. In order for the simulation to be as close as possible to reality, an equivalent mechanical model made up of rigid masses must be created and linked together by massless elastic and damping elements. The reality will be closer to the results if the mechanical model is more complex. The more complex the mechanical model, the more difficult it is to formulate general conclusions.

In order to obtain useful information, it is advisable to adopt a less complex model. For efficiency in railway vehicles, a mechanical model includes the suspended mass of the bogie and the mass of the vehicle box linked together by elastic and damping elements. Although numerical simulations are important, they cannot be considered without experimentally obtained data [9, 10].

Studies based on numerical simulations or measured data have shown that the vehicle's dynamic response is correlated with path irregularities [4, 5], which creates the premises to develop certain methods for monitoring the path quality or the condition of the vehicle [1, 12].

The correlation method was used to highlight the connection between the vertical and lateral axle box acceleration and the track geometry parameters processed differently based on a measurement run on a curve line [4]. The correlation between the rail weld geometry and high-frequency vibrations of the axle box acceleration and was used to develop an approach for real-time health detection of rail. Based on the Pearson correlation coefficient, the results of the numerical simulations were used for an analysis regarding the correlation between the vertical irregular track and the dynamic response of a two-axle bogie [5].

This paper presents an analysis of the vertical vibration of two bogies in a railway freight vehicle both empty and loaded based on the experimental results obtained through measurements made while in motion on an experimental track in a curve.

In fact, the RMS (root mean square) acceleration is looked at and measured on the two bogies frame above the axles for several measurement sequences at constant speed. In addition, the spectral analysis of the measured acceleration helps to identify a series of defects in the running surfaces of the wheels and rail.

In the case of putting into production a new wagon, it must be tried and tested from all points of view. The wagon is subjected to static tests and dynamic tests.

The tests are established by the SR EN 14363-A1:2019 standard [1].

2. METHODOLOGY AND EXPERIMENTS

2.1. Presentation of the place where the tests took place

This article presents the study of Z-axis on curves, vibrations measured on an empty and loaded tank car. The testing terminal Făurei Romanian Railway Testing Center (CTFF) is a railway testing ground that allows trains to travel at a maximum speed of 200km/h. It is practically the only route in the country where you can travel at this speed. Next, the configuration of the Făurei Romanian Railway Testing Center is presented with the track switches, platforms and the other constructive elements that make it up. (Fig. 1).

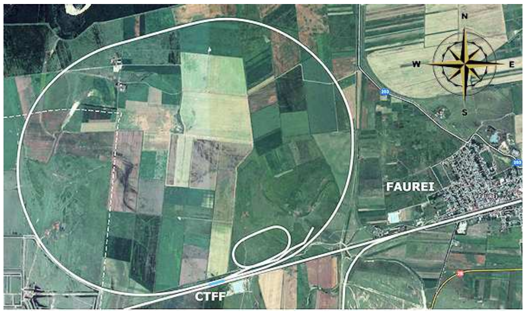

Fig. 1. Făurei Railway Testing Center (top view)(Google Earth)

The big ring has the following features:

-length 13.7km with 6 bridges and 4 level crossings;

-maximum speed 200km/h;

-two curves with radii of 1800 m and elevations of 150mm;

-the length of the alignments 1000 m and 950 m;

-single-phase alternating current of 25 kV/50 Hz rail type 60 (kg/ml).

2.2. Presentation of the tank wagon and the data acquisition system

The tank wagon has 4 axles, type Zacs (with discharge under pressure) and a total capacity of “85m^{3}”. The wagon was manufactured by REVA Simeria. Is intended for the rail transport of light petroleum products, class 3 RID (gasoline, diesel, mineral oil), as well as other products corresponding to the tank code L4 BH.

Presentation of the conditions in which the experiment was done.

The measurements were carried out on the curved portions of the terminal,

- Between km 2 and km 5
- Between km 9 and km 12
- empty tank wagon at the nominal load, having a total mass of 23200 kg;
- tank wagon loaded at normal load, having a total mass of 90,000 kg.

The speed average with which the wagon traveled was 105km/h - 135km/h.

Six accelerometers were mounted on the wagon, two of them measured the Z-axis accelerations:

1. on the wagon box in the middle of bogie 1
2. on the wagon box in the middle of bogie 2,

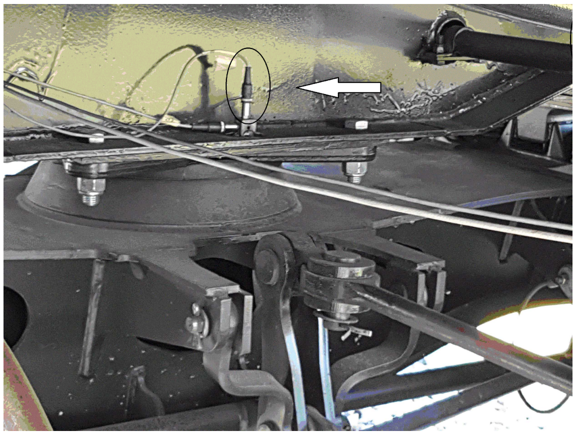

Fig. 2. Accelerometers mounted on the bogie frame

The measurements were taken in motion on a track, for which the maximum traffic speed is 135km/h, on a portion of the track in the curve and vertical alignment.

The vertical acceleration of the bogie frames, first and second, were measured for an empty and loaded rail freight vehicle.

In Fig. 3 is shown the data collection device used to measure the vertical acceleration of the bogie frames.

It includes the measurement, acquisition, and processing system components for the vertical acceleration, respectively two 4514 Brüel & Kjær piezoelectric accelerometers.

The accelerometers were set up on the bogie frame. (Fig. 2). Acceleration records were made at a constant speed over a distance of about 3km in the curve.

The duration of a measurement sequence is three seconds. The maximum speed during the measurements was 135km/h on an empty wagon and 115km/h on a loaded wagon.

Data acquisition was performed simultaneously on the six channels of the acquisition equipment (Fig. 3) at a sampling frequency corresponding to a frequency band of 1.6 kHz. The article analyzes the data from channels 4 and 6, in which the vibrations on the Z axis were recorded.

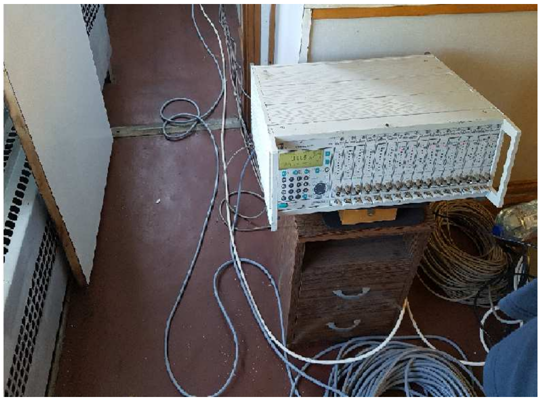

Fig. 3. The data acquisition system from the laboratory wagon

2.3. Presentation of experimentally obtain data

Recordings of acceleration were made at constant velocity. Results of tests are presented in the graphs in the following figures. Figure 4 contains the vibration values recorded by the accelerometer mounted on the box of the first bogie, in the case of the empty wagon.

Figure 5 contains the vibration values recorded by the accelerometer mounted on the box of the second bogie, in the case of the empty wagon.

The vibrations recorded in the case of the loaded wagon are shown in figure 6 for the first bogie and in figure 7 for the second bogie.

The vibration of the wagon is random, to describe such a vibration the RMS is used.

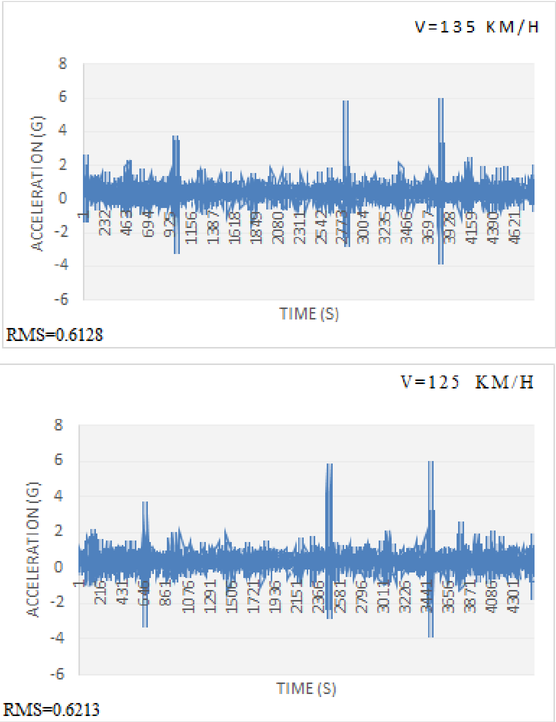

Fig. 4. Acceleration recorded on an empty wagon, at first bogie

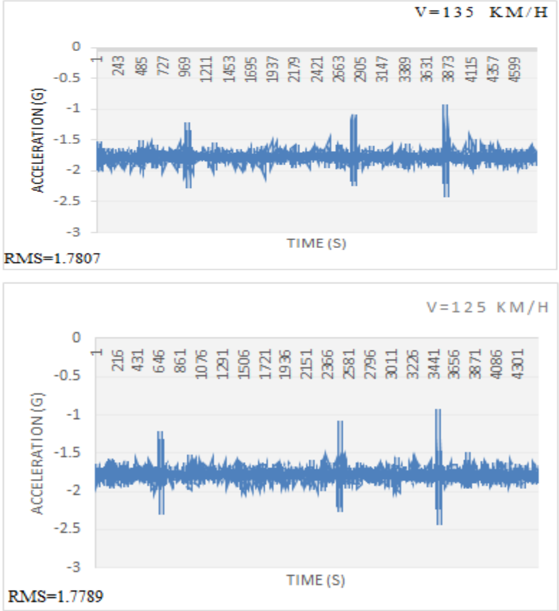

Fig. 5. Acceleration recorded on an empty wagon, at second bogie

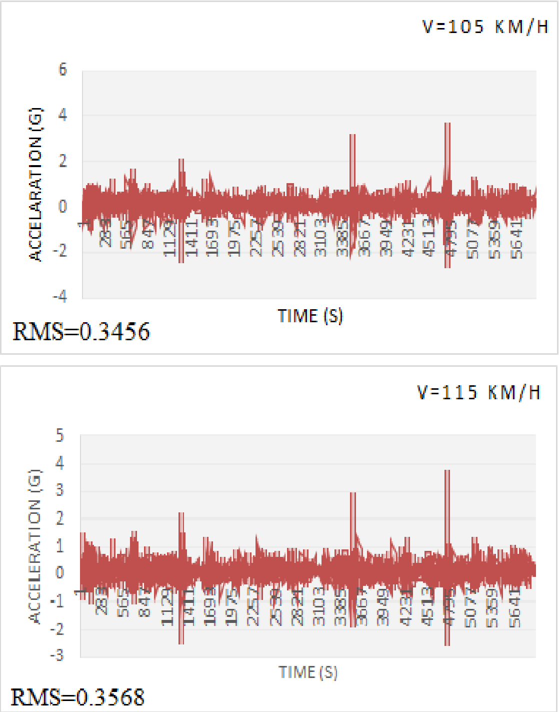

Fig. 6. Acceleration recorded on a loaded wagon, at first bogie

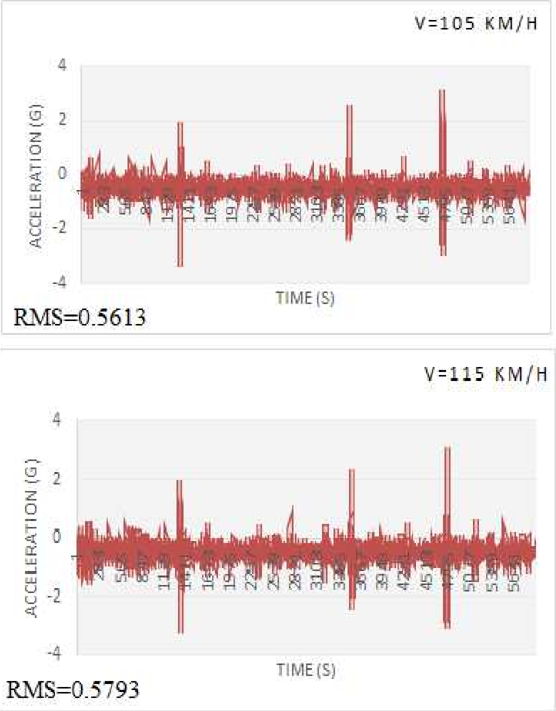

Fig. 7. Acceleration recorded on a loaded wagon, at second bogie

3. INTERPRETATION OF EXPERIMENTAL RESULTS

An analysis of the vibration, on the Z axis, characteristics on bogie frames 1 and 2 based on the resulting experiment is presented in this section. Figs. 4, 5, 6 and 7 show the accelerations recorded on a portion of the curve at different velocities to the bogie frame 1 and 2 for both empty and loaded wagons.

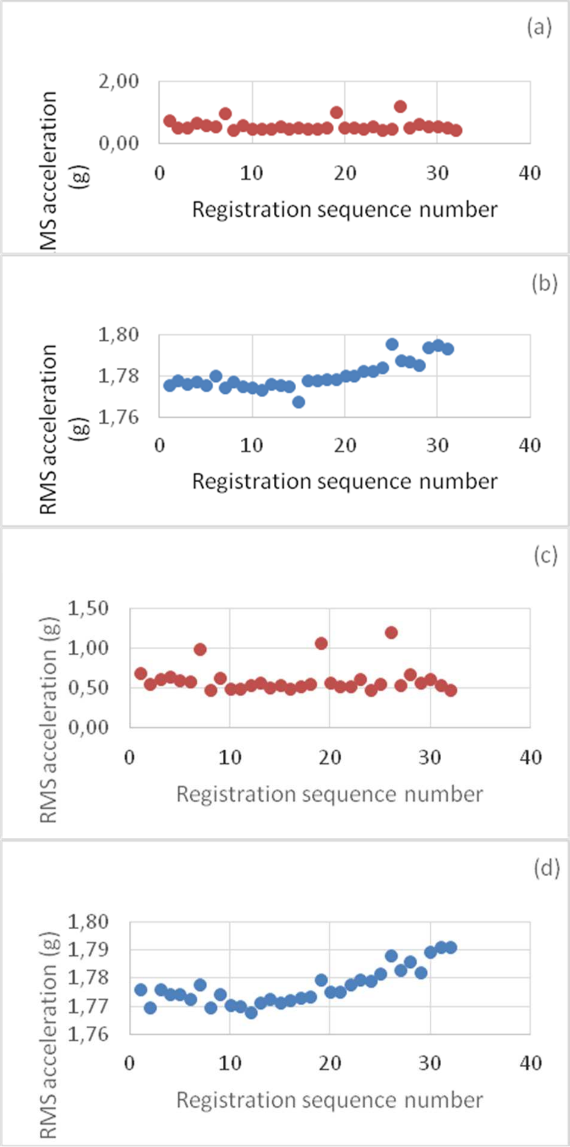

Fig. 8. The RMS acceleration for empty wagon at velocity 125km/h at first bogie frame (a), at second bogie frame (b), at velocity 135km/h at first bogie frame (c) and second bogie frame (d)

The RMS acceleration is marked on the charts. In all the charts, it is observed that the RMS accelerations, measured on the frame of bogie 1 is about twice lower than that measured on the frame of bogie 2. In addition, the results show that the acceleration is negative for the second bogie. For small RMS speed variations, the acceleration has close values.

The measured intervals are divided into equal intervals for which the RMS is calculated. Fig. 8 shows the RMS acceleration of bogie frame 1 for 32 measurement sequences at a constant speed of 125km/h and 135km/h with the wagon empty. For bogie 1, the RMS acceleration is scattered between 0.446g and 1.2236g, while for bogie 2, the range is 1.7726g - 1.8041g. At the speed of 135km/h, on the frame of bogie 1, the RMS acceleration is 0.4825g - 1.2072g - and 1.7707g - 1.7972g - at bogie 2. The dispersion of the measured acceleration is due to the variability of the amplitude of the defects along the track. In the case of the empty wagon on the first bogie in the sequence 7, 19, 26, the RMS accelerations have values from 0.9978g to 1.2245g, the values of the other sequences are between the values min 0.4475g and maximum 1.0200g. On the second bogie the value of the sequences 1-6 varies from 1.7754, sequence 7 suddenly increases to 1.7804g. The RMS acceleration from bogie 1 is on average 2 times lower than the RMS acceleration from bogie 2.

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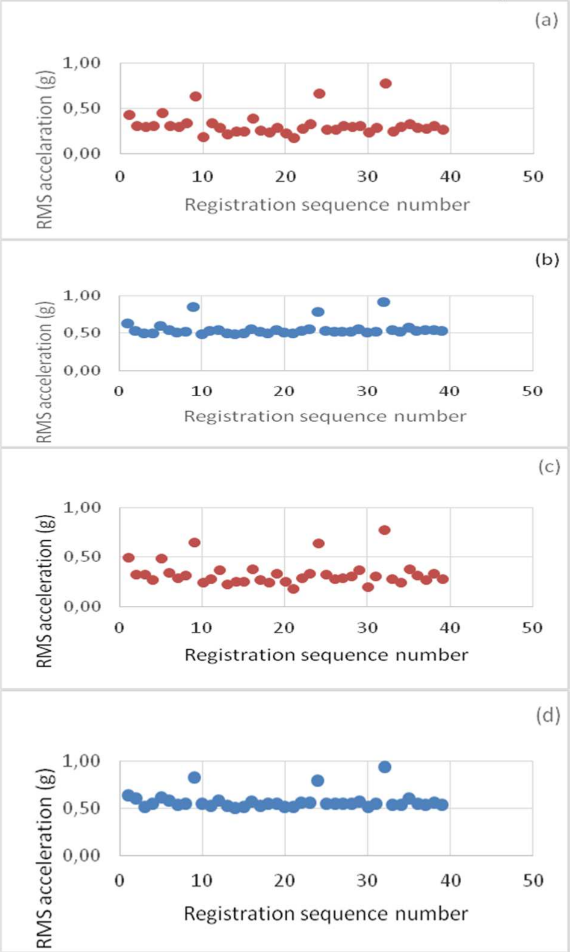

Fig. 9. The RMS acceleration for loaded wagon at velocity 105km/h at first bogie frame (a), at second bogie frame (b), at velocity 115km/h at first bogie frame (c) and second bogie frame (d)

Fig. 9 shows the RMS acceleration for the loaded wagon of the bogie frame for 39 measurement sequences at a constant speed of 105km/h and 115km/h.

The influence of the variability of defects along the track on bogies vibrations is well visible here having the RMS acceleration.

The RMS accelerations in the case of the wagon loaded at bogie 1 at sequences 9, 24, 32 have higher values from 0.6322g – 0.7831g, the other values are 0.2463g – 0.4588g. At bogie 2, at the same sequences, 9, 24, 32 there are higher values from 0.8462g - 0.9094g, the other values are from 0.4917g - 0.6321g.

In all the graphs above, there are 3 peaks of the values at the same points.

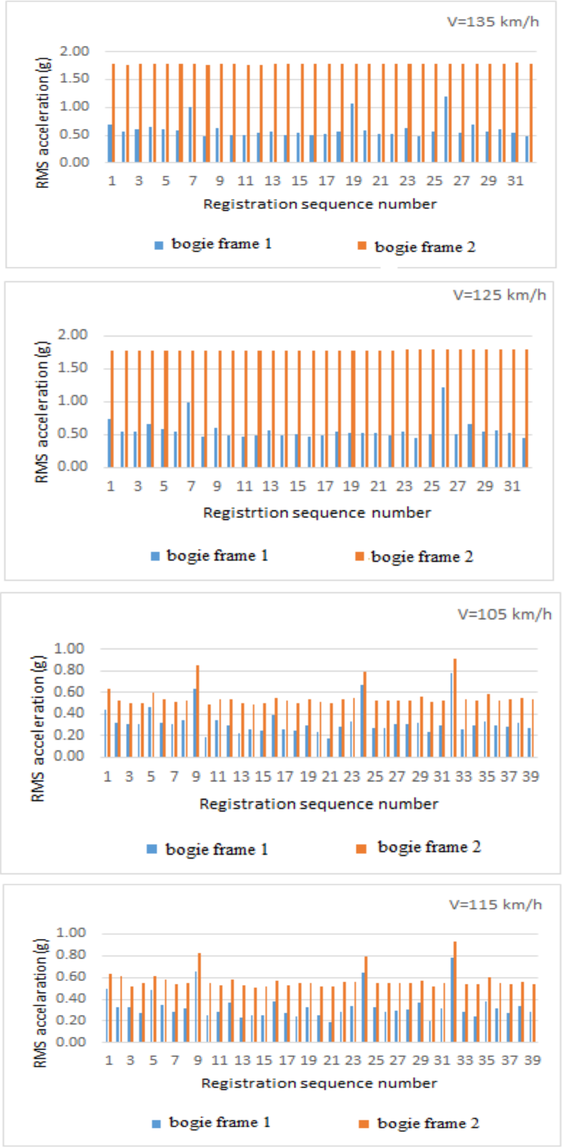

Fig. 10. The RMS acceleration of empty wagon and loaded wagon of the bogie frame 1 above bogie frame 2.

In figure 10, the first 2 graphs, when the wagon is empty, the RMS acceleration from the second bogie has values close to 1.7715g - 1.7914g, even if the acceleration value from bogie 1 varies depending on the railway profile min 0.4413g and max 1.2226g. When the wagon is loaded, Fig. 10 the last 2 graphs, the RMS acceleration values have the same characteristics at bogie 1 and bogie 2. In the sequences 9, 24, 32 in the points where there are large values, the difference between the values from the 2 bogies decreases.

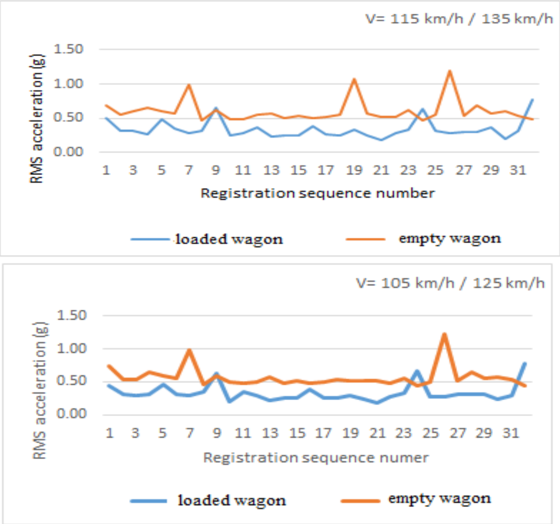

Fig. 11. The RMS acceleration of bogie frame 1 and bogie frame 2 of empty wagon above loaded wagon.

In the points with large variations, the difference between the 2 values is 0.2g. In the other sequences, the value measured from the second bogie frame is double the value from the first bogie frame. In the case of RMS acceleration measured on the same bogie when the wagon is empty and loaded, the characteristics are the same, only the value differs, Fig. 11. When the wagon is loaded, the value is higher. Depending on the traffic speed and the time when the higher values appeared, a check was made on the measurements made with the track measuring wagon (Fig. 12) and on the railway, at the calculated points.

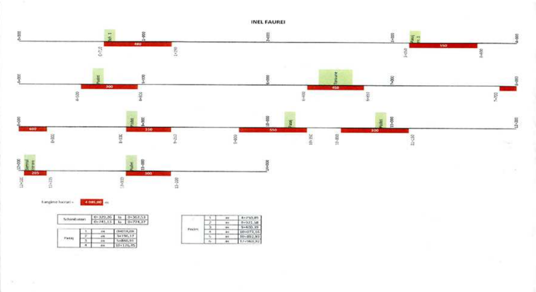

Fig. 12. The graphic configuration of the railway line

4. CONCLUSIONS

The vertical vibrations of the bogie frame of a tank wagon both empty and loaded were analyzed, in this paper.

The analysis was based on RMS acceleration for several measurement sequences of empty and loaded situations. The results showed that the RMS acceleration is about two times higher in the second bogie frame than in the first bogie frame. Additionally, RMS has shown to increase acceleration with speed. The RMS acceleration analysis for several measurement sequences at the same speed has made visible the influence of track defects on the bogie vibrations. Due to the variability of amplitude defects along the track, the RMS acceleration is not equal to the same speed. They are dispersed over the range of approximately 0.03g to 0.9g. Based on the spectral analysis of the measured accelerations, rail defects have been identified. The highest values were recorded when passing over a joint rail.

Moving over a passage and a footbridge did not generate such high values. Future research may aim to analyze the correlation between the vibrations of the 2 bogies based on the measured acceleration. The correlation between the accelerations measured on the bogie frames can be the basis for the development of a method for monitoring the state of the vehicle's primary suspension.

5. ACKNOWLEDGMENT

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DETECTAREA DEFECTELOR LA CALEA FERATĂ CARE POT INFLUENȚA SIGURANȚA CIRCULAȚIEI PRIN METODA ANALIZEI VIBRAȚIILOR SISTEMULUI VEHICUL-ȘINĂ

Articolul prezinta un studiu al vibratiilor verticale, pe axa Z, ale unui vagon cisterna standard, pe 4 osii, tip Zacs. Analizează și compară vibrațiile induse pe cutiile boghiurilor pentru vagonul încărcat și gol, maia ales în punctele în care au fost măsurate abaterile majore de la dimensiunile standard ale căii ferate. Măsurătorile au fost înregistrate pe o cale ferată curbă cu raza de curbură de 1800 m, pe inelul de la Centrul de Testare a Căilor Ferate din Făurei cu o viteză maximă de 135km/h. Datele analizate sunt transpuse în diagrame care reflectă influența profilului căii ferate în mișcările vagonului pe o cale ferată, în curbă.

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