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INSTRUMENTAL ANALYSIS OF THE REINFORCED CONCRETE BRIDGES SUBJECTED TO DYNAMIC FORCES FROM THE TRAFFIC

Assoc. Prof. Dr. Eng. Nicusor DRAGAN
MECMET - The Research Center of Machines, Mechanic and Technological Equipments
"Dunarea de Jos" University of Galati

ABSTRACT

This paper proposes an approach of the experimental study of the dynamics of a reinforced concrete bridge made by a number of twenty U beams and beared by eighty identical neoprene supports (four bearings for each concrete beam). The experiments were made in site on Transylvania highway, on the viaduct situated on km 29+602,75 - km 29+801,25 by the specialists from Vibration and Acoustic Laboratory of the Research Institute for Construction Equipment and Technology - ICECON S.A. Bucharest with the help of the Research Center of Machines, Mechanic and Technological Equipments – MECMET from Dunarea de Jos University of Galati. The vibrations of the bridge were caused by passing with different speeds of a forty tons truck over an obstacle mounted on the bridge surface. The experimental data were acquired on three channels (accelerations on the axis x, y and z) by a four channel data acquisition interface from National Instrument (NI 9233) through the USB port of a PC workstation. The experimental data were processed by an adequate calculus programme developed on ICECON S.A. Bucharest on the basis of LabView® ver. 8.5 from National Instruments.

KEYWORDS: FFT analysis, eigenvalues, reinforced concrete bridges vibrations

1. INTRODUCTION

The Romanian legislation in force provides that some experimental tests have to proceed to verify the structural behavior under static and dynamic loads from traffic before putting into operation the new road bridges. The results are centralized in a database that allows processing of information by using various analytical techniques for checking, adjusting and expanding a set of design assumptions for calculating. A complete analysis should include every stage of the dynamic process.

2. PHYSICAL AND MATHEMATICAL MODELING OF THE INTERACTION TIRE - ROAD

Figure 1 shows the simplified model of a 41 ton truck with four axles used for experimental test in site. The loading and dimensional characteristics of the truck are shown in table 1.

Table 1. Load and dimensional characteristics of the truck used for dynamic tests

Axle i	Weight G_i [kN]	Axle distances d_i [m]		
		d_1	d_2	d_3
1	73	2.0	2.5	1.5
2	72			
3	129			
4	129			

The goal is to evaluate individual percussion impacts between each wheel axle and the obstacle of height **h** from the surface of the bridge. Figure 2 shows the calculus sketch of the impact percussions on point **B**, on normal direction P_n and on tangential direction P_t .

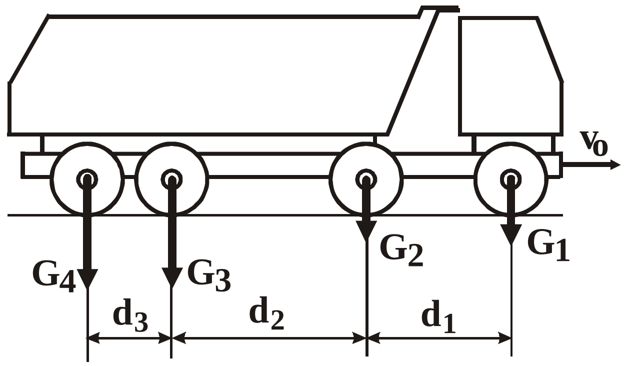

Figure 1 Dynamic loading sketch of the 41 ton truck

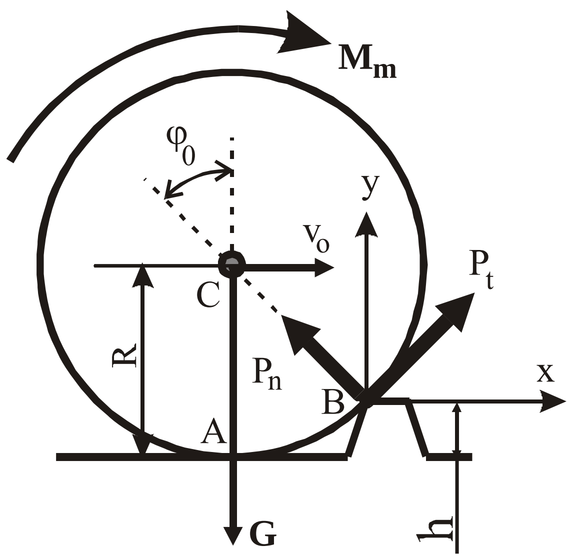

Figure 2 Calculus sketch of the impact between the wheel and the obstacle of height **h**

The percussions can be calculated with the following formulae

$$P_t = \frac{mv_0}{3}\left(1 - \cos\varphi_0\right) = \frac{Gv_0}{3g}\left(1 - \cos\varphi_0\right) \quad (1)$$

$$P_n = mv_0 \sin\varphi_0 = \frac{G}{g} v_0 \sin\varphi_0 \quad (2)$$

where v_0 is the speed of the truck, G is the axle load, m is the axle mass and g is the gravitational acceleration.

The impact angle φ_0 can be calculated with the following relation:

$$\varphi_0 = \arccos\left(1 - \frac{h}{R}\right) \quad (3)$$

Considering that the impact time is Δt, the percussion forces in the point **B** on the directions **Bn** (normal force) and **Bt** (tangential force) are:

$$F_n = \frac{P_n}{\Delta t} = \frac{mv_0}{\Delta t} \sin\varphi_0 \quad (4)$$

$$F_t = \frac{P_t}{\Delta t} = \frac{mv_0}{3\Delta t}\left(1 - \cos\varphi_0\right) \tag{5}$$

The percussion forces in **B** on the directions **Bx** (horizontal force) and **By** (vertical force) can be calculated as follows:

$$\begin{aligned} F_x &= -F_n \sin\varphi_0 + F_t \cos\varphi_0 = \\ &= -\frac{mv_0}{\Delta t}\sin^2\varphi_0 + \frac{mv_0}{3\Delta t}\left(1-\cos\varphi_0\right)\cos\varphi_0 \end{aligned} \tag{6}$$

$$\begin{aligned} F_y &= F_n \cos\varphi_0 + F_t \sin\varphi_0 = \\ &= \frac{mv_0}{\Delta t}\sin\varphi_0\cos\varphi_0 + \frac{mv_0}{3\Delta t}\left(1-\cos\varphi_0\right)\sin\varphi_0 \end{aligned} \tag{7}$$

After calculations, the simplified relations of the percussion forces in **B** can be written:

$$F_x = \frac{mv_0}{3\Delta t}\left(\cos\varphi_0 + \cos 2\varphi_0 - 2\right) \tag{8}$$

$$F_y = \frac{mv_0}{3\Delta t}\left(\sin\varphi_0 + \sin 2\varphi_0\right) \tag{9}$$

If we consider the relation (3) for the impact angle φ_0, the percussion forces in **B** become:

$$F_x = \frac{mv_0}{3\Delta t}\frac{h}{R}\left(2\frac{h}{R} - 5\right) \tag{10}$$

$$F_y = \frac{mv_0}{3\Delta t}\frac{h}{R}\left(3 - 2\frac{h}{R}\right)\sqrt{2\frac{R}{h} - 1} \tag{11}$$

Table 2. Percussion forces for $\Delta t = 0.01s$ (front axle)

Speed v_0 [km/h]	Percussion force [kN]	
	F_x	F_y
10	-804.622	2,552.329
20	-1,609.244	5,104.658
30	-2,413.867	7,656.986
50	-4,023.111	12,761.644

Considering the radius of the wheels of the truck $R = 600mm$, the figures from table 2 show the values of the percussion forces between the front axle of the truck ($m \equiv m_1 = 7440kg$) and the standardized obstacle with $h = 40mm$, for different transport speeds. The values for the forces were calculated for the speeds of the truck: 10km/h, 20km/h, 30km/h and 50 km/h. All values from table 2 were calculated on the hypothesis of constant speeds v_0, no traction ($M_m = 0$ in the figure 2) and an impact time duration of 0.01 s.

3. EXPERIMENTAL TEST. METHOD AND EQUIPMENT

Dynamic tests were made in site on the Romanian highway A3 (Transylvania highway), on the viaduct situated on km 29+602,75 - km 29+801,25 (Targu Mures – Cluj road section) by the Research Institute for Construction Equipment and Technology - ICECON S.A. Bucharest; the dynamic actions were generated by a running four axle 41 ton truck over standardized height h = 4 cm obstacles on the road; running speeds were 10km/h, 20km/h, 30km/h and 50 km/h.

The experiments were conducted in two different situations: with traction and without traction (with disconnected gear clutch) on the axle 2.

The standardized obstacles (STAS 12504-86) were fixed on the viaduct surface with chemical anchors (see figure 3).

Figure 3 Truck running over the obstacle

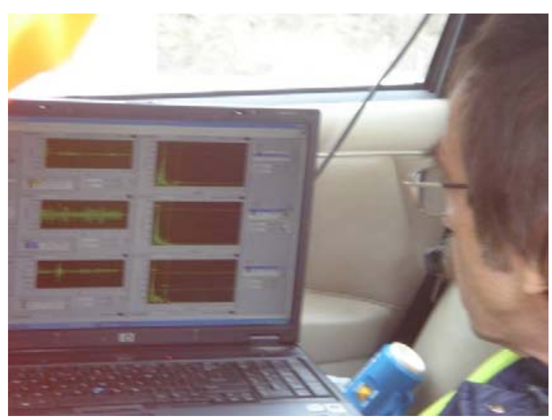

Figure 4 LabView® frequency analyzer

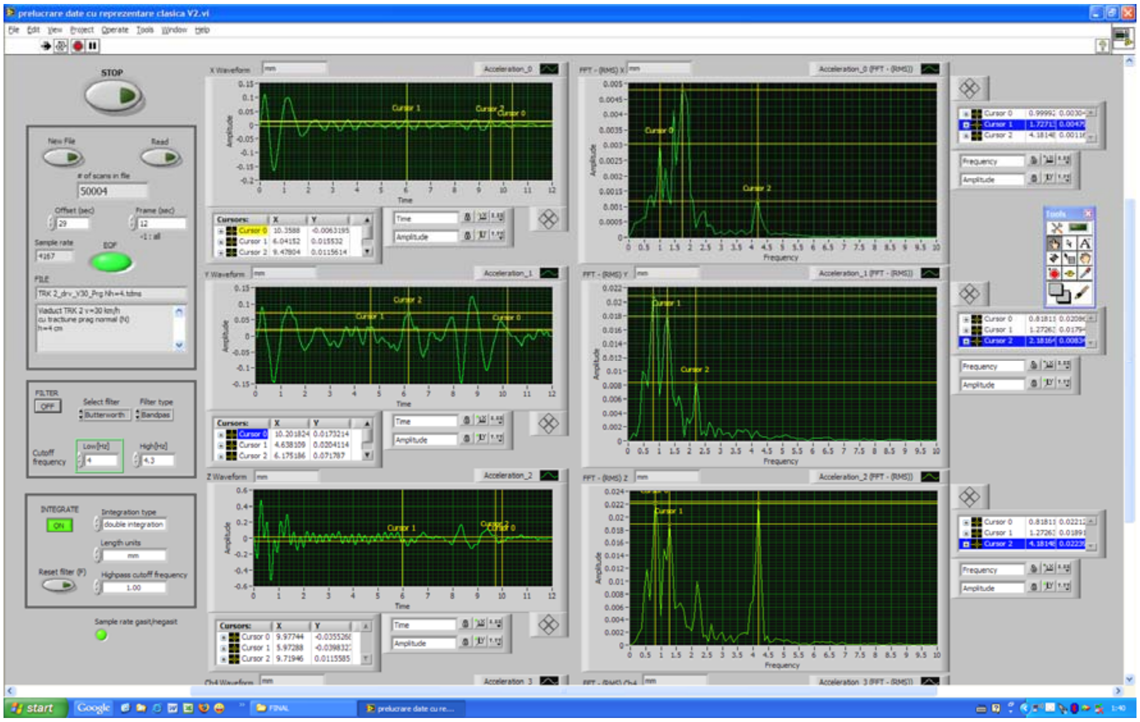

Figure 5 Acceleration - time and frequency domain analyzer ($v_0 = 30km/h$ with traction)

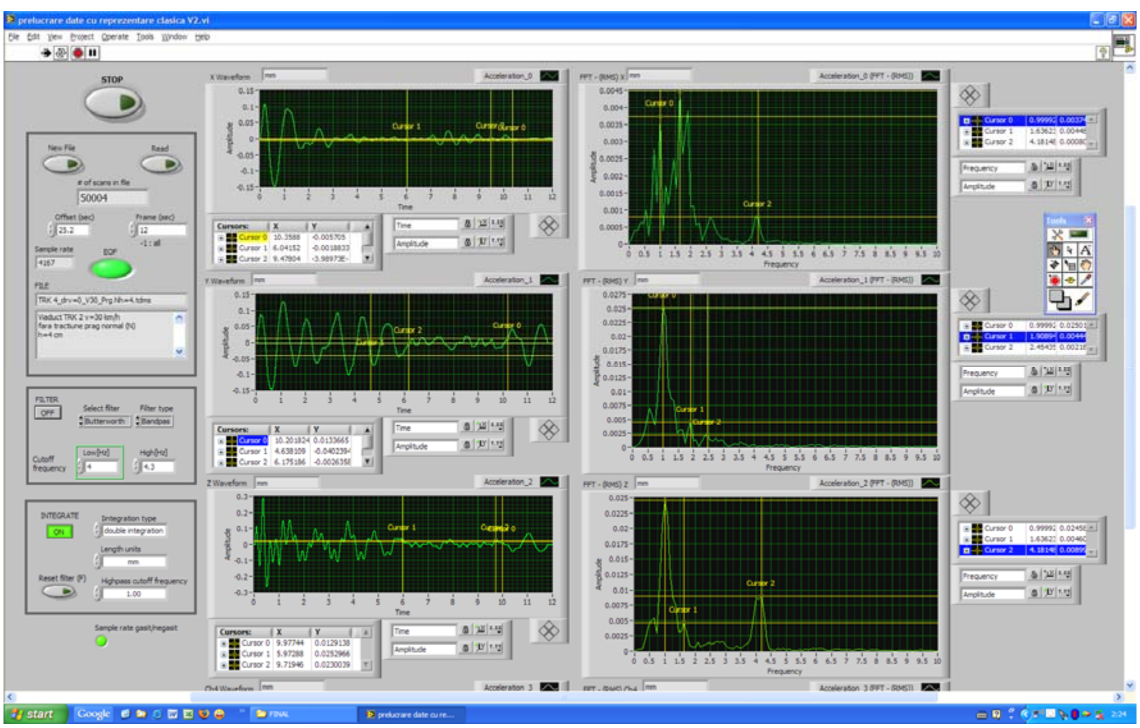

Figure. 6 Acceleration - time and frequency domain analyzer ($v_0 = 30km/h$ no traction)

Viaduct structure dynamic tests were performed by recording the accelerations of the structure at the running of the truck across the standardized obstacles located in the middle cross section of the viaduct central arch (between P2 and P3 piers). The experimental data were acquired on three channels (accelerations on the axis x, y and z) by a four channel data acquisition interface from National Instrument (NI 9233) through the USB port of a PC workstation. The experimental data were processed by a adequate calculus programme developed on ICECON S.A. Bucharest on the basis of LabView® ver. 8.5 from National Instruments (as in fig. 4).

The used transducer was a triaxial accelerometer Bruel&Kjaer type 003 4506 B series 10145, fixed in the middle sectional plane of arch no. 3 of the viaduct (between P2 and P3 piers); the axis of the transducer are oriented as follows:

-x axis: parallel with the longitudinal axis of the viaduct

-y axis: horizontal transverse axis of the viaduct

-z axis: parallel with the vertical axis of the viaduct

Experimental data processing was performed with a complex frequency analyzer developed form of virtual instrumentation based on LabView® software platform ver. 8.5 from National Instruments. Acceleration signals were recorded under the form of binary files and analyzed in time domain and frequency domain (by FFT analysis virtual instrument).

Figures 5 and 6 show (as an example of using virtual method instrumentation and analysis of the vibration parameters) the display of the virtual LabView® analyzer used by the authors to process the recorded signals from the triaxial accelerometer Bruel&Kjaer in two cases:

1) impact between tires of the 2-nd axle and the normal obstacle ($h = 40mm$) at constant speed of $v_0 = 30km/h$ with traction;

2) impact between tires of the 2-nd axle and the normal obstacle ($h = 40mm$) at constant speed of $v_0 = 30km/h$ no traction (the gearbox decoupled from the engine).

At the left side there is the time domain variation of the accelerations on the axis x, y and z; at the right side there is the frequency domain (FFT analysis) of the accelerations.

4. EXPERIMENTAL RESULTS

The dynamic experimental tests have been performed in September 2009, on the viaduct km 29+602,75 - km 29+801,25 on the Romanian A3 motorway on the contractual basis with its contractor Bechtel.

There was performed a set of tests, in order to determine the dynamic response of the viaduct subjected to traffic actions (shocks, vibration) generated by the crossing of a heavy truck over two types of obstacles.

There were sixteen experiments differentiated by:

- four different speeds: $10km/h$, $20km/h$, $30km/h$, $50km/h$
- two types of traction on driving axle 2: with traction, no traction
- two types of obstacles: $h = 4mm$ (standardized), $h = 8mm$ (no standardized)

Figures 7 an 8 show the representations of the accelerations on the longitudinal direction on time domain and on frequency domain for $10km/h$, $h = 4mm$ with traction and a total duration of 10 seconds of FFT analysis.

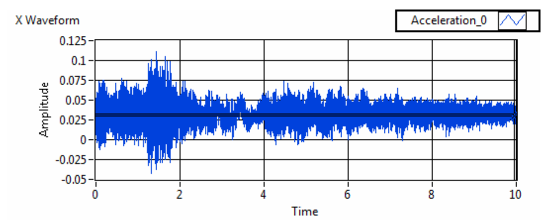

Figure 7 Longitudinal acceleration - time representation ($v_0 = 10km/h$ with traction)

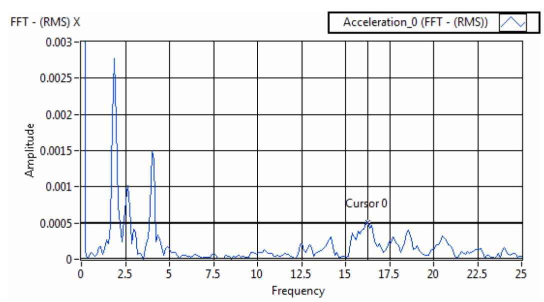

Figure 8 Longitudinal acceleration - frequency representation ($v_0 = 10km/h$ with traction)

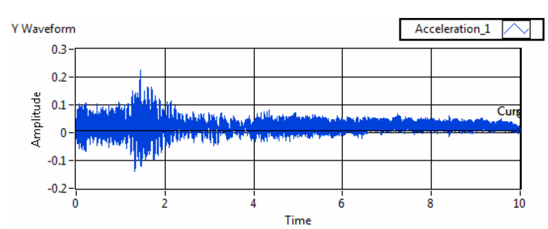

Figure 9 Lateral acceleration - time representation ($v_0 = 10km/h$ with traction)

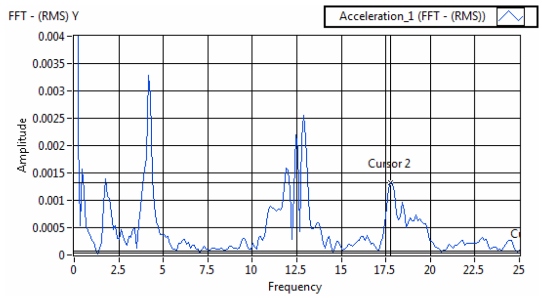

Figure 10 Lateral acceleration - frequency representation ($v_0 = 10km/h$ with traction)

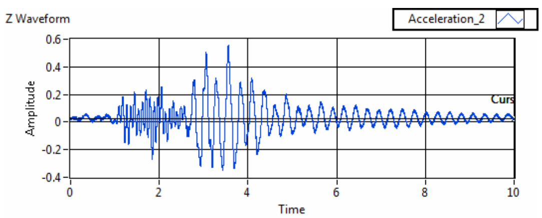

Figure 11 Vertical acceleration - time representation ($v_0 = 10km/h$ with traction)

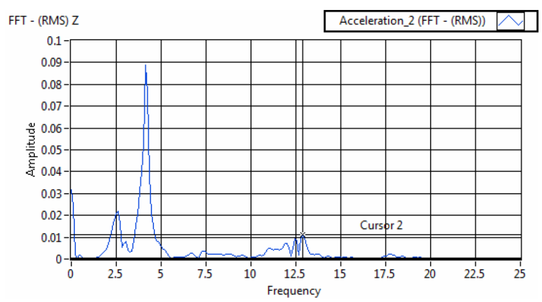

Figure 12 Vertical acceleration - frequency representation ($v_0 = 10km/h$ with traction)

Figures 9 and 10 show the representations of the accelerations on the lateral direction on time domain and on frequency domain for $10km/h$, $h = 4mm$ with traction and a total duration of 10 seconds of FFT analysis.

Figures 11 and 12 show the representations of the accelerations on the vertical direction on time domain and on frequency domain for $10km/h$, $h = 4mm$ with traction and a total duration of 10 seconds of FFT analysis.

The figures from table 3 show the values of the significant frequencies of the impact obstacle-obstacle ($10km/h$, $h = 4mm$ with traction, 10 seconds of FFT analysis) and the accelerations amplitudes on each direction; these values can be „read" on fig. 7 to 12.

Table 3. Spectral amplitudes of the viaduct ($10km/h$, $h = 4mm$, with traction)

Direction	Frequency [Hz]	Acceleration amplitude [m/s^2]
Longitudinal X	1.85439710	0.00277870
	2.61797238	0.00101257
	4.03604075	0.00150578
	16.14416301	0.00050625
	16.25324519	0.00050838
Lateral Y	0.43632873	0.00157861
	1.74531492	0.00139880
	4.14512294	0.00328516
	11.88995789	0.00158535
	12.43536881	0.00220311
	12.87169754	0.00256224
	17.78039575	0.00132513
Vertical Z	2.61797238	0.02182016
	4.14512294	0.08893210
	11.99904008	0.00697046
	12.43536881	0.00946318
	12.87169754	0.01104032

5. CONCLUSIONS

Based on the parameters which were determined, we can calculate the logarithmic decrement Δ and the fraction of critical damping ζ at natural frequencies (which are significant on the frequency domain analysis) and their corresponding spectral amplitudes.

From table 3, we can conclude that:

-the significant accelerations are on vertical direction

-the dynamic response of the viaduct is on the natural frequencies grouped around: 0.5 Hz, 2.0 Hz, 4.0 Hz, 12.0 Hz, 16.0 Hz and 18.0 Hz.

It is very important that the time analysis is long enough so FFT is relevant and realistic [1], [2].

REFERENCES

[1] **Darabont, Al., Iorga, I., Ciodaru, M.,** *Măsurarea zgomotului şi vibraţiilor în tehnică*, Editura Tehnică, Bucureşti, 1983

[2] http://sine.ni.com/nips/cds/view/p/lang/en/nid/207574