THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICHAL ENGINEERING, ISSN 1224-5615
2012

THE NONLINEAR BEHAVIOR IDENTIFICATION OF THE DYNAMIC INSULATION SYSTEMS USED IN VIADUCT STRUCTURE

PhD. Eng. Adrian LEOPA
"Dunarea de Jos" University of Galati,
Research Center for Mechanics of Machines and Technological Equipments

ABSTRACT

Because of the destructive effects of seismic movements on bridges and viaducts, it was required to embed the structure of seismic devices with the role of maintaining structural integrity and post-seismic functionality. Prolonged use of seismic energy dissipation devices by viscous effects, under dynamic loads from traffic leads to changes in their dynamic response to seismic actions requests. This study analyzes the dynamic behavior modification of seismic devices with the energy dissipation by viscous effects, following the loadings from road traffic or seismic loading. These methods can be used in predictive maintenance activities of the optimal operation of structures such as bridge or viaduct with seismic elements integrated.

KEYWORDS: bridge, degradation, nonlinear vibration, viscous effects

1. INTRODUCTION

Bridges and viaducts are civil engineering that ensures passage of ground communication channels over an obstacle. Taking into consideration the vital character of the bridges, it is necessary to identify a viable solution to protect these targets against natural hazards by seismic actions and man-made actions by the stress from road traffic. Seismic design of bridges is required for two fundamental requirements:

- to prevent loss of life, secured by a judicious design, so that under the effect of seismic loads, structure are not local or global collapse;
- damage or destruction of the structure that leads to the impossibility of ensuring land traffic, and hence the significant economic losses.

Regarding the seismic problems, in terms of energy approach, it is noted that from the earthquake energy filtered structure Fig. 1, a part is actually dissipated, while the other turned in the applications of structural elements, namely: (i) energy transmission structure is a function of the disturbing relationship between signal frequency and dynamic characteristics of the structure, in fact it depends on mass and stiffness (fundamental frequency), (ii) structural capacity [1]. To avoid the destructive effects of bridges, loading by dynamic actions from seismic activities or traffic, a number of passive systems are used to perform dynamical isolation. One such category is represented by viscoelastic passive systems such as lead rubber bearings or rolling bearings rubber. It is known that elastomers from these systems undergo structural changes leading to changes in dynamic response, through the dynamic actions and the action of atmospheric factors. These changes are reflected in the nonlinear behavior of these systems, with significant influential dynamic response of the system where they are located. In order to prevent the use of passive isolation systems for bridges and viaducts outside the optimum operating parameters, it is necessary to elaborate a methodology able to detect early changes in the dynamic response of these devices. This methodology involves the identification and quantification of functional parameters, features passive isolation systems for bridges and viaducts, able to provide information about the state of “normality” in the functioning of the devices concerned.

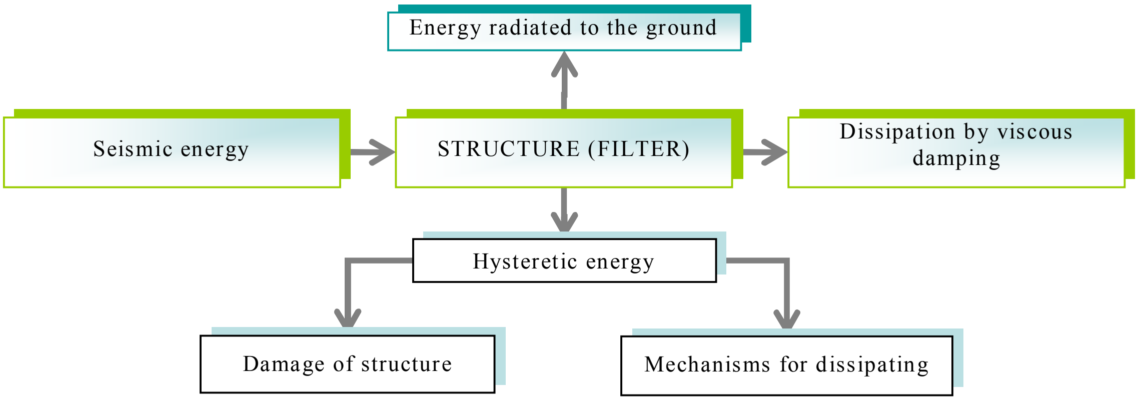

Fig. 1 Transmission of seismic energy

2. PHYSICAL AND MATHEMATICAL FORMULATION

On the commissioning of isolation systems for bridges and viaducts, will be performed a series of experimental measurements to determine the characteristic parameters for operation in the optimal parameters of the system. Repeated experimental determinations prescribed intervals, for analysis of comparative data, to assess changes in structural and functional characterization of the dynamic isolation systems of viscoelastic type. In order to identify the parameters that characterize the normal functioning of passive isolation systems, will be considered a mechanical system with two degrees of freedom [3] corresponding to the soil - pile – deck, Fig. 2. This is a theoretical model the aim of the modeling being to highlighting of these parameters. To establish the system excitation is considered a truck weighing 41 tons, passing over an obstacle with a height of 40 mm at a speed of 20 km/h, Fig. 3, 4 and 5.

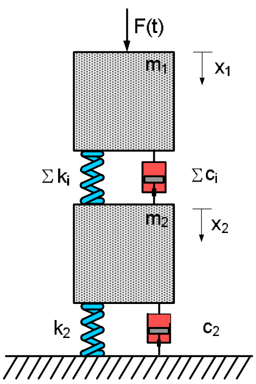

Fig. 2. Model calculations with two degrees of freedom

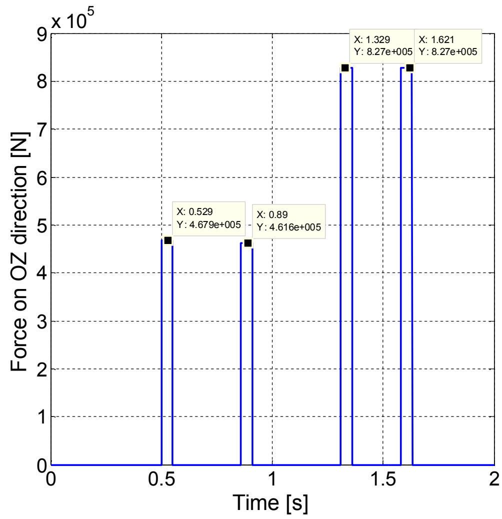

Fig. 3. Four rectangular pulse train - F(t)

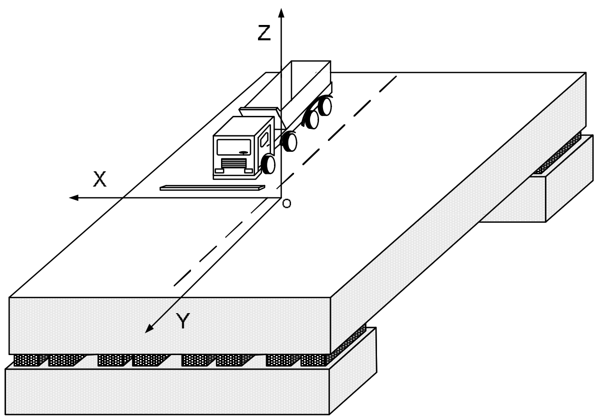

Fig. 4. A sketch section of the bridge, a passing truck over an obstacle

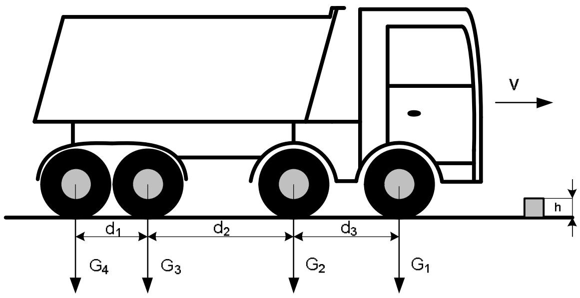

Fig. 5. The truck used for dynamic testing

Under these assumptions, the system vibration is described by the following system of differential equations:

$$\begin{cases} m_1\ddot{x}_1 + \sum\limits_{i=1}^{n} c_i\left(\dot{x}_1 - \dot{x}_2\right) + \sum\limits_{i=1}^{n} k_i(x_1 - x_2) = F(t) \\ m_2\ddot{x}_2 + \sum\limits_{i=1}^{n} c_i\left(\dot{x}_2 - \dot{x}_1\right) + c_2\dot{x}_2 + \\ \qquad + \sum\limits_{i=1}^{n} k_i(x_2 - x_1) + k_2x_2 = 0 \end{cases} \qquad (1)$$

where: n=8, number of the isolation systems; m_1 - the deck weight distributed on the bearing, m_2 - mass of the bridge pier, k_i, c_i - rigidity and damping coefficient of the isolation system, k_2, c_2 – stiffness and the damping coefficient of the soil, F - force excitation, x_1, x_2 - movements of the deck and pier bridge. Solving this system was performed using numerical method of Runge Kutta fourth order, through the module dedicated to this method in the MATLAB software package version 7.0. Solving the system of differential equations assumed the following numerical values of the considered parameters of mechanical system, [2]: $k_1=650\cdot10^6$ N/m; $c_1=8.75\cdot10^8$ Ns/m; $m_1=4.96\cdot10^6$ kg; $m_2=2\cdot10^6$ kg; $k_2=30\cdot10^9$ N/m; $c_2=1.5\cdot10^8$ Ns/m; m_1= 7440 kg; m_2= 7339 kg; m_3= 13149 kg; m_4= 13149 kg; d_1= 1,5 m; d_2= 2,5 m; d_3= 2,0 m; h= 40 mm.

3. IDENTIFICATION AND INTERPRETATION OF THE INFLUENCE PARAMETERS

To identify changes induced dynamic response of the nonlinear behavior of the system by dynamic isolation systems, will be undertaken a comparative analysis of influence of vibration parameters of motion, as follows: linear elastic and damping forces and nonlinear elastic forces (2), linear damping forces.

$$F_{el} = k_1(1+\beta x^2)x, \beta = 14.9\cdot10^{12}\ 1/m^2 \qquad (2)$$

Graphic representations are compared to reveal the changes in dynamic response, as a result of the nonlinear behavior of passive isolation systems.

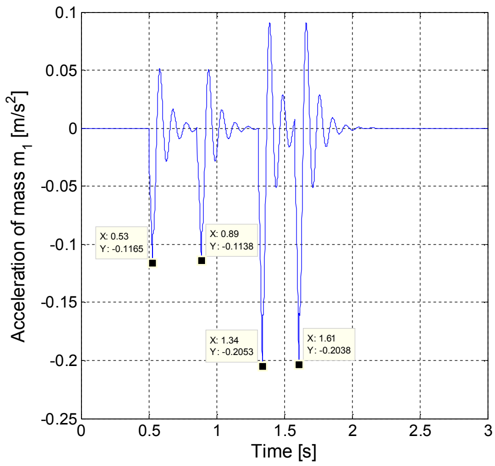

Fig. 6. Acceleration of mass m_1 – linear case

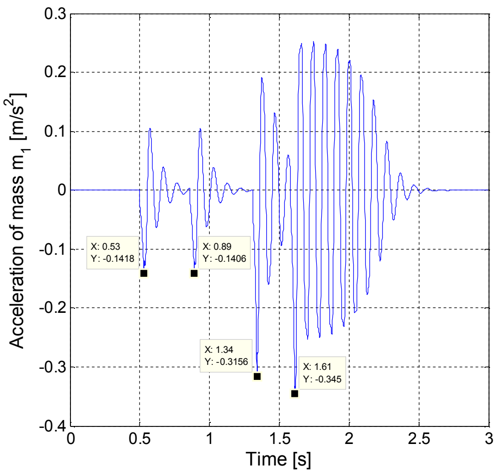

Fig. 7. Acceleration of mass m_1 – nonlinear case

Representations of acceleration mass m_1 show for the nonlinear case a during damping acceleration signal with 0.45s more than in the linear case, Figs. 6 and 7. From the same representation, an increase of the maximum value was observed, from 0.20 m/s^2 in linear case to 0.34 m/s^2 in nonlinear case.

The spectral representation of acceleration reveals for the nonlinear case reveal the appearance of significant spectral components around the frequency of 33 Hz, figs. 15 and 16.

The acceleration amplitude of mass m_2, show for the nonlinear case a longer duration of amortization than in the linear case, with the value of 0.45 s, Figs. 10 and 11. The acceleration amplitude decreases for the nonlinear case from 0.12 m/s^2 to 0.15 m/s^2 value corresponding to the linear case.

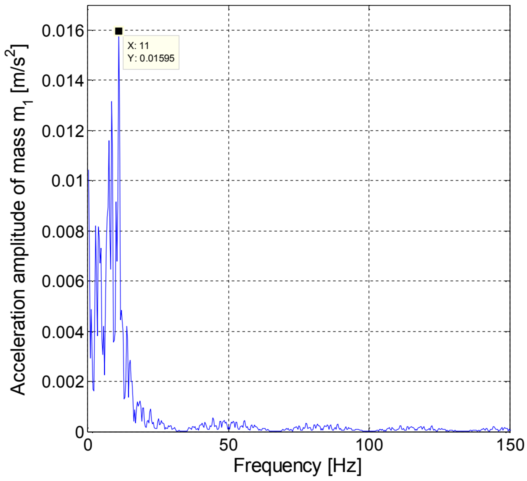

Fig. 8. Spectral representation – linear case

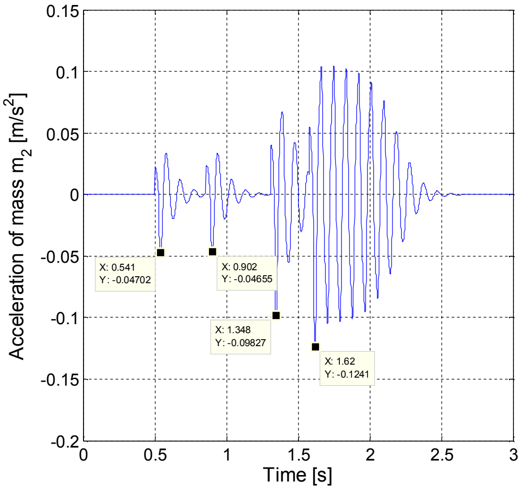

Fig. 11. Acceleration of mass m_2 – nonlinear case

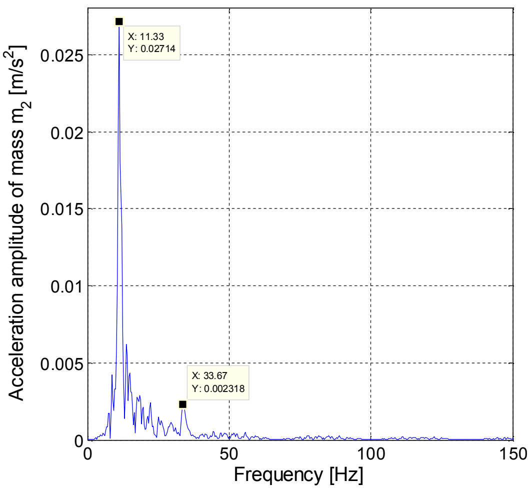

Fig. 9. Spectral representation – nonlinear case

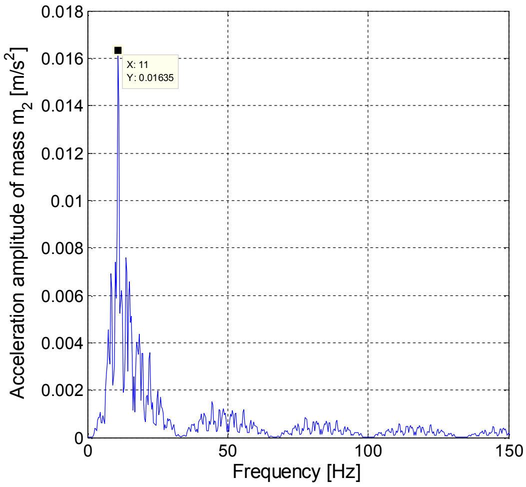

Fig. 12. Spectral representation – linear case

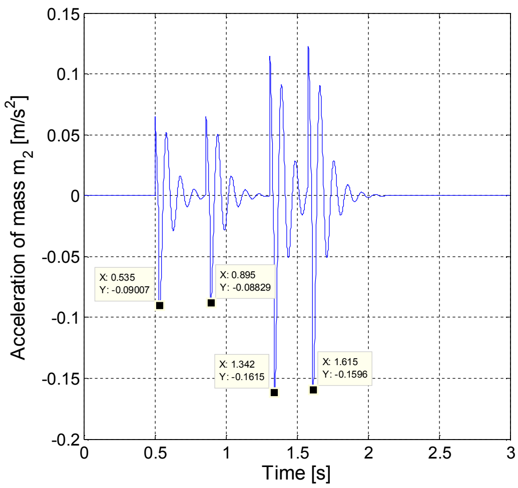

Fig. 10. Acceleration of mass m_2 – linear case

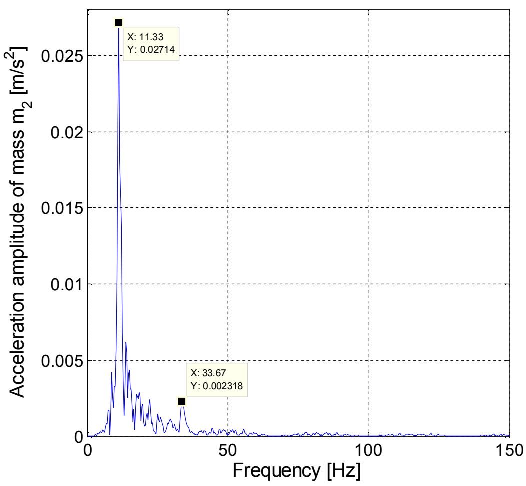

Fig. 13. Spectral representation – nonlinear case

From the spectral representation of the acceleration signal of mass m_2 is identified for the nonlinear case the significant spectral components around 33 Hz, figs. 12 and 13.

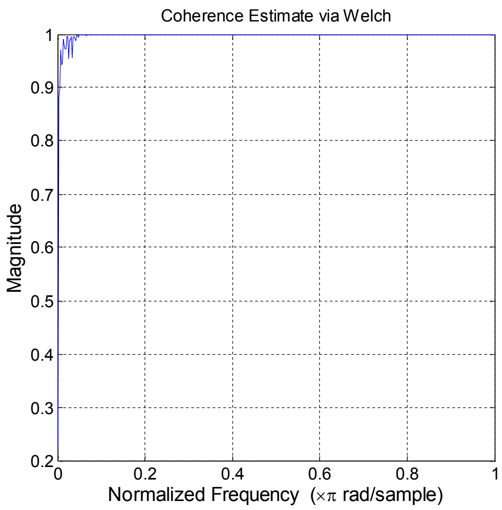

Fig. 14. Acceleration coherence – linear case

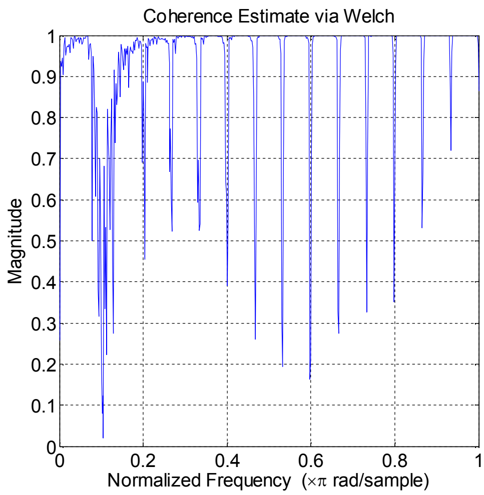

Fig. 15. Acceleration coherence – nonlinear case

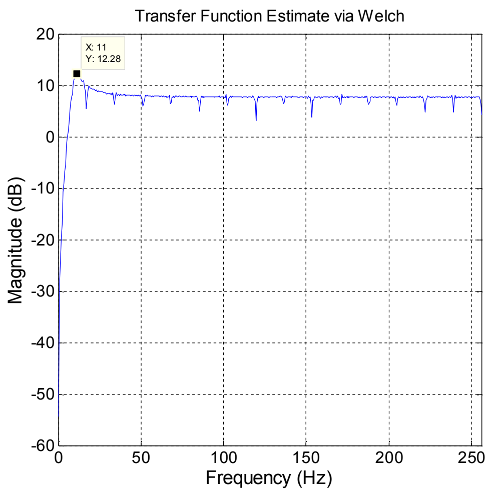

Fig. 16. Transfer function – linear case

An explanation of the improper correlation of the two acceleration signals, Figs. 14 and 15, (input respectively output signals) is the functional parameters of viscoelastic shock system variations, such as the appearance of elastic and/or damping nonlinearities.

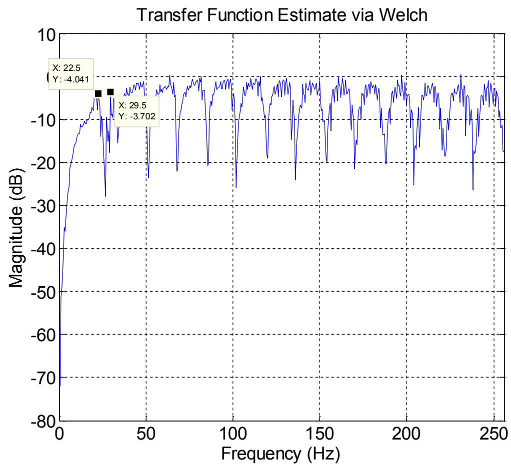

Fig. 17. Transfer function – nonlinear case

Signal transfer, from deck to pile, is on extended spectral components, contrary to the linear case. Thus, if for the linear case it distinguished an important energy transfer for the frequency value of 11 Hz, in the nonlinear case this value is to 22.5 Hz.

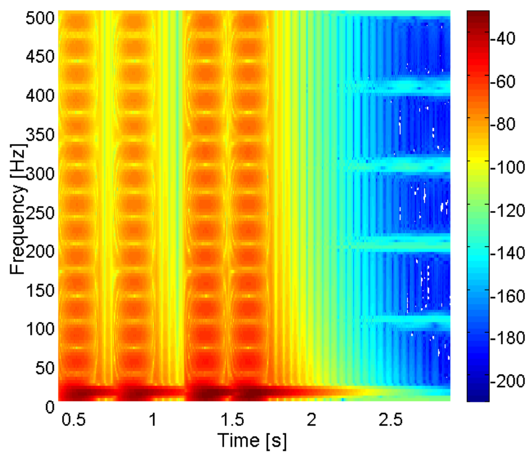

Fig. 18. The acceleration signal spectrogram's of mass m_1 – linear case

A useful representation to identify spectral participation of each excitation pulse is the spectrogram of signal displacement, presented in several forms in Figs. 18-19. This kind of representation proves its usefulness especially in cases where the mechanical system load is made by multiple excitations. It is noted that for high frequency vibrations, the excitations three and four from the train of pulses are responsible.

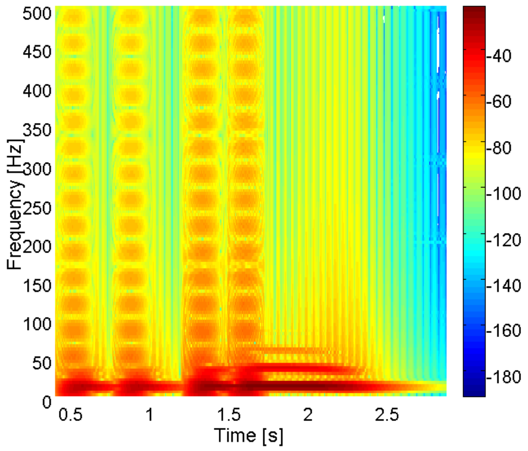

Fig. 19. The acceleration signal spectrogram's of mass m_1 – nonlinear case

4. CONCLUSIONS

From the comparative analysis of graphical representations of the parameters influence these conclusions can be drawn:

- Time representation of acceleration does indicate significant changes, Fig. 6, 7 and 10, 11.
- Frequency representation of acceleration signals reveals new spectral frequency components, a phenomenon specific to this behavior of nonlinear dynamic systems isolation, Fig. 8,9 and 12, 13;
- Transfer function of acceleration signal from the deck to the pile, is accomplished on another area of spectral components, unlike the linear case in which the transfer was well-defined, Fig. 16, 17;
- Coherence functions have multiple frequency ranges, for which the two acceleration signals do not correspond; this is specific phenomenon for nonlinear viscoelastic systems behavior of passive isolation, Fig. 14, 15.

ACKNOWLEDGMENTS

This work was supported by UEFISCDI (CNCSIS-UEFISCSU), project number PN II-RU code 597/2010, no. 42/09.08.2010.

REFERENCES

[1] **Casarotti, C.**, Bridge Isolation and Dissipation Devices, *European School for Advanced Studies in Reduction of Seismic Risk*, 2004.

[2] **Dragan, N.**, *Analiza experimentală a dinamicii podurilor din beton armat supuse acţiunilor din traffic*, *SINUC*, Bucuresti, 16–17 decembrie, 2010, ISBN–978–973–100–144–9.

[3] **Leopa, A.**, *Influenta comportării neliniare a sistemelor vâscoelastice asupra izolării dinamice a fundatiilor de masini*, PhD thesis.

[4] *Final report on testing for Transylvania highway viaduct*, ICECON SA, 2009.

[5] **Leopa, A., Nastac S.**, *Dynamic Behaviour of Foundations in Linear and Nonlinear Elastic Characteristics Hypothesis*, WSEAS Transactions on Applied and Theoretical Mechanics, 4 (3), 2008, 145-154.

[6] **Leopa, A., Debeleac, C.**, *On shock inertial excitation methods for concrete viaduct dynamic testing*, The 10th International Conference on Vibration Control, Czech Republic, 2011, 57-62.

[7] **Leopa, A.**, Evaluation *of environmental pollution by mechanical vibrations from the technological equipment with anti-vibration systems with degraded viscoelastic links*, Journal of Science and Arts, No. 1 (12), 2010, 67-72.

[8] **Leopa, A., Nastac, S., Dragan, N., Debeleac, C.**, *Considerations on the influence of viscoelastic behavior of nonlinear systems bearing on the dynamic constructions response*, International Conference on Structural Engineering Dynamics, Tavira, Portugalia, 2011.

[9] MATLAB, *High-Performance Numeric Computation and Visualisation Software. Reference Guide*, The MATWORKS Inc., Natick, Massachusetts, 1992.

[10] **Awrejcewicz, J., Andrzejewski, R.**, *Nonlinear Dynamics of a Wheeled Vehicle* Springer - Verlag, Berlin 2005.

[11] **Awrejcewicz, J., Dzyubak, L.**, *Influence of hysteretic dissipation on chaotic responses*, Journal of Sound and Vibration, 284, 2005, 513-519.

[12] **Awrejcewicz, J., Tomczak, K., Lamarque, C.-H.**, *Controlling system with impacts*, International Journal of Bifurcation and Chaos, 9 (3), 1999, 547-553.