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EXPERIMENTAL ANALYSIS OF A VIBRATION ISOLATION SYSTEM BASED ON CONSTRAINED PENDULUM DEVICE

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Abstract: *This paper is a study based on which we can obtain important and useful informations in the domain of analysis of the behavior in dynamic regime of the pendulum systems used with functional role of dynamic absorber. Based on theoretical analysis and on experimental validation of the specific dynamics for a pendulum isolator, can be determined an optimal configuration of this system type, which can ensure the efficiency of dynamic isolation for the variation domain of excitation.*
Keywords: *pendulum system, dynamic absorber, vibration isolation*

1. INTRODUCTION

The researches in the domain of insulation and of protection against negative effects of vibrations or seismic waves (tectonic movements, accidental or controlled explosions) are undertaken in several directions:

- the protection against source which generates disturbances;
- the protection on the propagation path of disturbances;
- the protection to the receiver (to the destination);
- the combined protection.

If in terms of vibration mitigation, the multitude of possibilities and practical means provide a wide range of solutions to reduce the undesirable effects, in terms of antiseismic protection are usable only the solutions which are applied to the receiver (to the destination).
Regarding the achievement and the implementation of protection measures against vibration or seismic waves, they can be of active, semiactive or passive type.
Internationally are developed, implemented and used systems, devices and elements for insulation and protection against vibrations and seismic waves, covering, in terms of constructively and functionally, the entire typological range.
Nationally, the concerns in the domain of insulation and antiseismic protection occupy an important place in research programs both nationally and at the level of research teams from universities and specialized institutes, and are well defined, grouped around some research collectives at the faculties and research institutes. The justification of increased interest for this area is generated through the geotectonic configuration of the earth crust in the area of our country.

2. THEORETICAL APPROACHES

This paper aims to develop a theoretical analysis and an experimental validation of the specific dynamics of pendulum insulator and its influence on mitigating the effects of vibrations transmitted to an elastic structure.
The paper proposes to consider for analysis the general case of a system with dynamic pendulum absorber, restricted with elastic linkage in the articulation of pendulum system.
The system developed is a complex one with two degrees of freedom, shown in Figure 1, and the connection of the elastic elements to the system is made at the top thereof. In the pivot point denoted by k_3 has been

introduced a torsion spring element. This component produces the restriction of the movement of the pendulum absorber.

The mass m_1 simulates the behavior of a structure type system and can be considered as it is double restricted. Rigidities of the two spring elements have been denoted with k_1, respectively k_2.

The system of pendulum absorber type is formed by a rod, hinged at the top and a lumped mass, placed at the bottom of the bar. The base assumptions on which was founded the calculus are:

- the assumption of small oscillations, which is the base for the simplified mathematical calculus (according to this hypothesis the amplitude of the pendulum system does not exceed $4-5^0$);
- the movement of the considered system takes place in one plane (the XOY plane);
- the component of bar type of the dynamic pendulum absorber system was considered a rigid rod (without deformations);
- the lumped mass located on the bottom of the rod was considered rigid, symmetrical ($J_{propriu} = 0$) and without relative movements to the rod;
- the base mass of the complex system has only one degree of freedom (displacement on horizontally direction, denoted with x).

For the presented case was considered the calculation of natural pulsations and of amplitudes corresponding to degrees of freedom of the system, which are interest parameters to obtain results to highlight the opportunity of structures isolation using additional systems of dynamic pendulum absorber type.

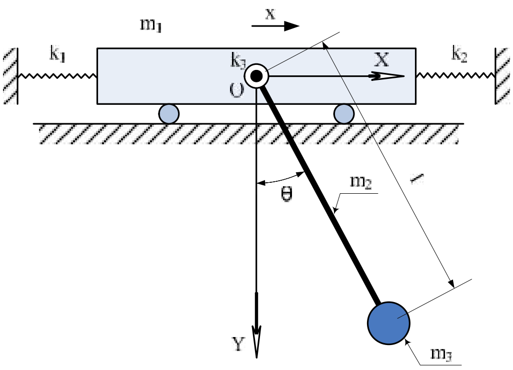

Figure 1: The general case of a dynamic absorber restricted system, with restriction in the joint

Given the assumptions of the case at hand, the system of differential equations is written like this:

$$\begin{cases} (m_1 + m_2 + m_3)\ddot{x} + l\left(\dfrac{m_2}{2} + m_3\right)\ddot{\theta} + (k_1 + k_2)x = 0 \\ l\left(\dfrac{m_2}{2} + m_3\right)\ddot{x} + l^2\left(\dfrac{m_2}{3} + m_3\right)\ddot{\theta} + \left(\dfrac{1}{2}m_2 gl + m_3 gl + k_3\right)\theta = 0 \end{cases} \tag{1}$$

In the system of equations (1) have been made the following notations:

$$\begin{cases} C_1 = m_1 + m_2 + m_3 \\ C_2 = \dfrac{m_2}{2} + m_3 \\ C_3 = k_1 + k_2 \\ C_4 = \dfrac{m_2}{3} + m_3 \\ C_5 = \dfrac{1}{2}m_2 gl + m_3 gl + k_3 \end{cases} \tag{2}$$

The solutions of the system are written as:

$$\begin{cases} x = A\sin pt \\ - \; = B\sin pt \end{cases} \tag{3}$$

The system of differential equations becomes:

$$\begin{cases} \left(-p^2C_1 + C_3\right)A - p^2lC_2B = 0 \\ -p^2lC_2A + \left(-p^2l^2C_4 + C_5\right)B = 0 \end{cases} \tag{4}$$

To obtain the unique solution must be met the condition:

$$\left(-p^2C_1 + C_3\right)\left(-p^2l^2C_4 + C_5\right) - p^4l^2C_2^2 = 0 \tag{5}$$

After solving the equation are obtained the natural pulsations:

$$p_1 = \sqrt{\frac{\left(C_1C_5 + l^2C_3C_4\right) + \sqrt{\left(C_1C_5 + l^2C_3C_4\right)^2 - 4C_3C_5\left(C_1C_4l^2 - l^2C_2^2\right)}}{2\left(C_1C_4l^2 - l^2C_2^2\right)}} \tag{6}$$

$$p_2 = \sqrt{\frac{\left(C_1C_5 + l^2C_3C_4\right) - \sqrt{\left(C_1C_5 + l^2C_3C_4\right)^2 - 4C_3C_5\left(C_1C_4l^2 - l^2C_2^2\right)}}{2\left(C_1C_4l^2 - l^2C_2^2\right)}} \tag{7}$$

Considering that on the system acts an harmonic excitation with the amplitude F_0, are obtained the corresponding amplitudes for the two degrees of freedom of the system:

$$A = \frac{-p^2l^2C_4 + C_5}{p^4l^2\left(C_1C_4 - C_2^2\right) - p^2\left(l^2C_3C_4 + C_1C_5\right) + C_3C_5}F_0 \tag{8}$$

$$B = \frac{p^2lC_2}{p^4l^2\left(C_1C_4 - C_2^2\right) - p^2\left(l^2C_3C_4 + C_1C_5\right) + C_3C_5}F_0 \tag{9}$$

3. CASE STUDY

To identify and analyze the working regimes of dynamic pendulum absorber was used for study a simplified structure, to a reduced scale, of an elastic construction, P + 1 type (see Figure 2). Structural columns were considered vertical elastic elements, configured such that the movement of assembly to be restricted only to take place in the longitudinal vertical plane.

The pendulum absorber system is fixed to the upper by means of a cylindrical hinge. The cylindrical hinge is achieved through a removable connection so that it can be changed if are imposed length values higher or lower than the values of the initial configuration. The mass of the pendulum is mounted on the lower end of the rigid rod by means of a removable joint, so that there is the possibility of a continuous adjusting of the length of the oscillation arm.

Figure 2 presents the constructive details of the structure and of the pendulum absorber system.

Figure 2: The constructive details of the structure and of the pendulum absorber system

The dynamic excitation is applied to the upper level, with a unidirectional vibration generator, mounted so that the movement into the system take place horizontally, in the longitudinal plane of the assembly.
The experimentation plan involved a set of tests in which the structural system is in forced vibration, without the functioning of the pendulum absorber and with the dynamic exciter in a varied working regime. This corresponds to the case in which no exists any isolation system to vibrations / seismic waves (of any type in general, and in this case of pendulum absorber type). The structure moves under the effect of external disturbing dynamic actions. This case represents the reference base for subsequent analysis of the behavior of an isolation system.
The parameters of the structure and of the pendulum absorber were kept constant during the experiment, with the following values:

- the pendulum mass $m_2 = 0.8$ kg;
- the mass of the pendulum rod $m_1 = 0.4$ kg;
- the length of the pendulum rod $l = 0.252$ m.

The three diagrams have the following meaning: excitation signal - the acceleration recorded on the mobile equipment of the exciter; response signal - the acceleration recorded on the upper level of the structure; excitation signal unanswered - the acceleration recorded on the mobile equipment of the exciter of which was removed the component due to the structure movement.

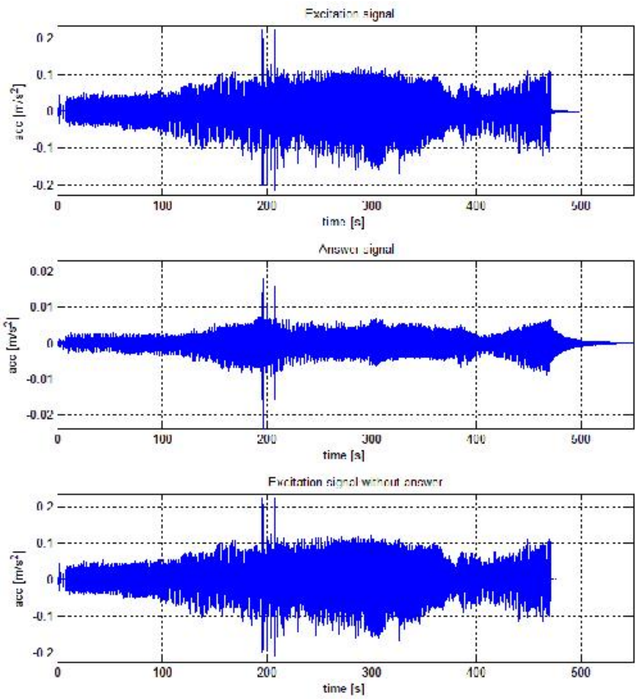

Figure 3: The recorded acceleration signals

In Figure 4 are presented the signals recorded on the mobile element of the exciter and on the upper level of the structure, in the useful domain for analysis of 20 ... 480 s. For each signal is presented the original version and the filtered version (f <10 Hz). Analyzing the spectral structure of each acceleration signal is observed that the signal produced by the exciter contains a number of significant harmonics as amplitude, while the response of the structure contains only the fundamental component with a significant value in the spectral analyzed domain 0 ... 10 Hz.
In figure 5 is shown a detail of the signals in Figure 4, time from t=50 s to t=200 s. This time period corresponds to the increase of the exciter frequency. The spectral trends identified in the diagrams in Figure 4 are maintained in this case. A comparative analysis of the two diagrams corresponding to the input and output signals, filtered in the time domain, highlights the fact that, with the increase of the excitation dynamic regime (see the input signal), the answer of the structure is also intensified. Basically, without an auxiliary system for dynamic isolation of the dynamic effects induced in structure, this "follows" the excitation. For this reason it was made the previous assertion that this second test corresponds to a reference case and, compared with the rest of the experimental measurements, may reveal or not the implementation effect of the dynamic isolation system of pendulum type (or any other type, generally).

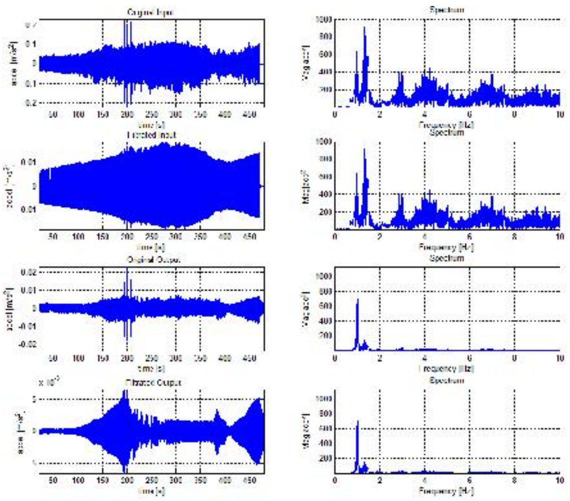

Figure 4: The recorded acceleration signals and the spectral compositions, in the time domain 20-480 s

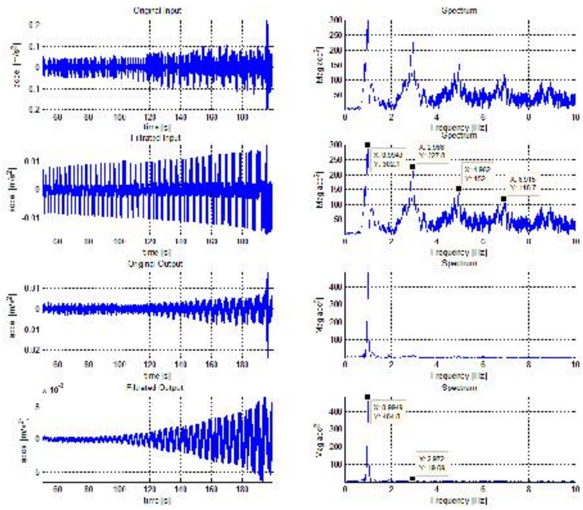

Figure 5: The recorded acceleration signals and the spectral compositions, in the time domain 50-200 s

Given that the structure subjected to dynamic tests is a system with an input and an output, and the fact that are available both excitation signal - the input and the response - the output, can be assessed the transfer function. In figure 6 is shown the diagram of the transfer function, obtained with signals from figure 4. This transfer function, own of the considered structure, was drawn on the interest area in terms of specific values of seismic or vibratory actions with major effect on buildings (0 ... 20 Hz).

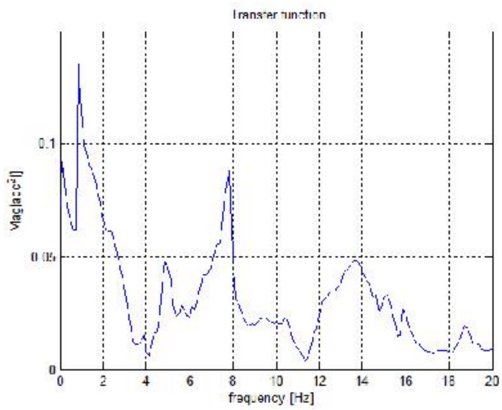

Figure 6: The transfer function of the structure

In the conditions exposed in the previous paragraph is relevant the assessment of spectrograms corresponding to the input and output signals in / from the system, so that exists the opportunity of the description for the evolutions of spectral components at any time of dynamic tests. In the absence of any dynamic insulation system, these spectrograms offer the possibility of assessment and analysis of the transitory regimes for a structure subjected to disturbing actions.

The two spectrograms corresponding to excitation signals and to structural response signals, are shown in figure 7. The processing was carried out for the entire period of the signal, in the frequency range of 0 ... 20 Hz. There is a constant value for the fundamental frequency of the structure in the entire analyzed period and, at the same time, a deviation in frequency - an increase or a decrease - of the other components which are present in the evaluated spectrum. In reality, one or the other components of the structure or the components of the vibrations generator are temporary excited, depending on the dynamic regime parameters, and the existence of these movements generates the occurrence of the values in the characteristic spectrum. In terms of structure, its movement occurs permanently, due to the transitory regime, which is maintained by the continuous changes of the excitation parameters. In the characteristic spectrum appears permanently the component with fundamental frequency.

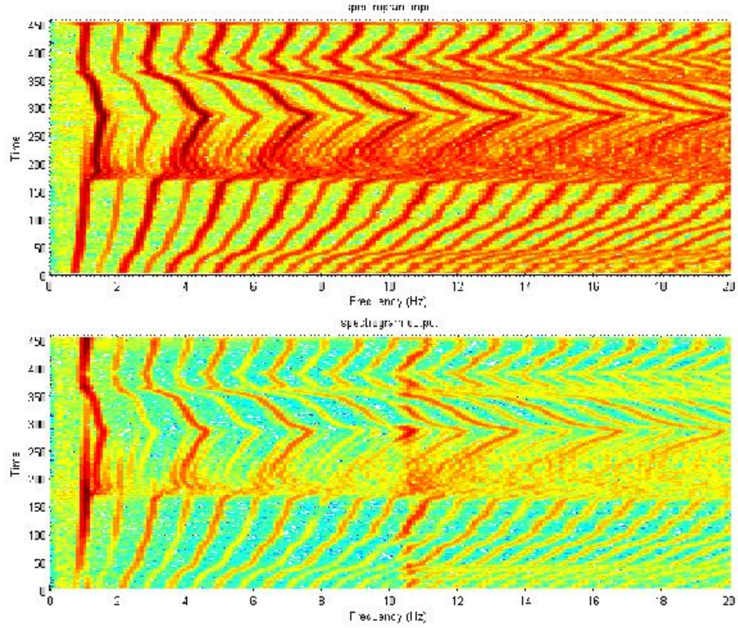

Figure 7: The recorded acceleration spectrograms

4. CONCLUSIONS

The set of tests was proposed and realized in order to provide the necessary support for evaluation of the efficiency for a system of dynamic pendulum type to reduce the dynamic of base structure, in terms of quality. This situation (when pendulum system was not used) was necessary to ensure the reference regarding the evolution of the structure subjected to dynamic disturbing actions, intense and varied.
There is a danger that the pendulum system initially implemented to reduce the structural dynamic, to amplify this dynamic, in certain conditions depending on the nature of disruptive excitation and on the specific values of its parameters.
The behavior of such a system to reduce the dynamic effects induced by an external disturbance in a structure, must be characterized on the basis of some informations about the behavior in time and the spectral evolution of the involved components, so as to be identified as far as possible, the danger of some structural resonances with bad results in the evolution of the dynamic for the entire assembly.

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