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QUANTIFICATION OF THE DYNAMIC RESPONSE OF A VIADUCT LOADED BY SHOCKS FROM ROAD TRAFFIC

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ABSTRACT

The work in seismic design of bridges needs to develop physical models and mathematical theory, based on which will be assessed and quantified the dynamic response of bridge structures subjected to stress arising from road traffic or seismic activity. The need for this modeling has imposed by three requirements: ensure of the structural integrity of the bridge elements against impulsive loads, proper choice of dynamic insulation elements placed as a interface between the superstructure and the infrastructure, as well as analysis of effects on joints in these situations. This paper proposes a physical model of a general nature, enabling customization depending on the specific constructive bridge, or the way it is solicited. Customizing this model was developed for this study based on the existing viaduct Transylvania highway located between km 29 +602.75 and km 29 +801.25.

KEYWORDS: shock, viaduct, vibration, isolation

1. INTRODUCTION

Bridges and viaducts are vital structures of railway and a traffic network, that is why are embedded in their structure, systems for isolation and impulsive damping actions resulting from road traffic and the seismic activities. Because of the intense and varied demands which the dynamic isolation systems are subjected to, they degrades over time and thus they change the response to the stresses it is subjected to moment when these systems must be replaced with new ones. Determining precisely when it is needed to replace these systems is very important, because the abnormal system operations can cause unexpected movement when they are stressed by impulsive actions. Determining precisely when it is needed to replace these dynamic insulation systems, is done by monitoring in time the kinematic and energy parameters of vibration in response to the same type of requests.

In other words, at commissioning dynamic isolation systems there will be performed a series of experimental measurements to quantify the kinematics and energy parameters of the deck vibrations of a section of bridge.

At certain periods of time, these types of experimental measurements will be repeated for a comparative analysis of the targeted parameters. In this way, highlighting the differences that arise between the parameters values at different time, data provide information about normal function of dynamic isolation systems. This study will highlight the theoretical point of view of parameters, to be monitored regularly by experimental measurements.

2. DEVELOPING THE PHYSICAL AND MATHEMATICAL MODEL

To reflect the parameters of "control" it is considered a physical model with six degrees of freedom that can be custom built depending on the specific model which is being prepared. This model, presented in Fig. 1, considers a section of bridge deck as a rigid solid support through some triortogonal viscoelastic type support, Fig. 2.

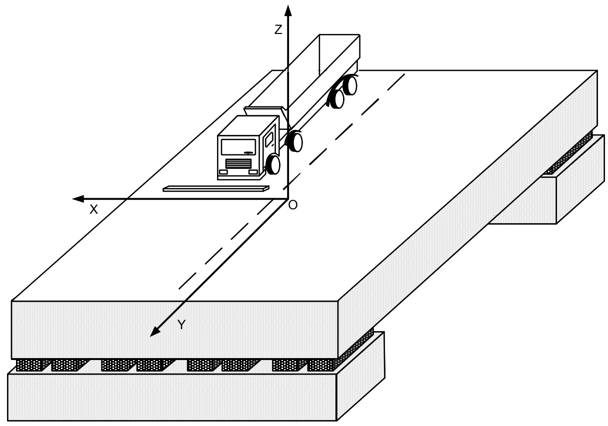


Fig. 1 A sketch section of the bridge, a passing truck over an obstacle

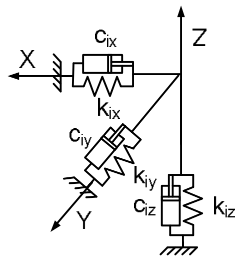


Fig. 2 Triortogonal viscoelastic type support

For this purpose, a section of bridge deck can be considered a solid rigid with triortogonal viscoelastic type links. The matrix equation system characterizing oscillatory motion can be written as follows [1]:

$$\underline{\underline{I}}\,\ddot{\underline{\underline{q}}} + \underline{\underline{C}}\,\dot{\underline{\underline{q}}} + \underline{\underline{K}}\,\underline{\underline{q}} = \underline{\underline{f}} \qquad (1)$$

$\underline{\underline{q}}$ - vector of generalized coordinates; $\dot{\underline{\underline{q}}}$ - Vector of generalized velocities; $\ddot{\underline{\underline{q}}}$ - vector of generalized accelerations; f - vector of generalized forces; $\underline{I}$ - matrix of inertia, $\underline{I}$ - depreciation matrix; $\underline{K}$ - rigidity matrix.

The rigid movements based on the generalized coordinates are defined as follows:

X - lateral forced vibration (sliding);

Y - forced longitudinal vibration (forwarding);

Z - vertical forced vibration (lifting);

φ_x - forced vibration in pitch (pitching);

φ_y - forced vibration roll (rolling);

φ_z - forced gyration vibration

The main elastic supports of elastic axes are parallel to the axes of bearing reference. In this case, the movements represented by the coordinate's variation corresponding to the six uncouple degrees of freedom, as follows:

- coupled translational motion along the X axis and rotation around the Y axis (X,φ_y);
- coupled translational motion along the Y axis and rotation around the X axis (Y, φ_x);
- translational movement around the Z axis z (φ_z)independent of the other ways
- rotation around Z axis independent of the other ways.

In this case, the system of differential equations becomes:

a) Couple mode (X, φ_y):

$$\begin{cases} m\ddot{X} + \dot{X}\sum\limits_{1}^{16} c_{ix} + \dot{\phi}_y \sum\limits_{1}^{16} z_i c_{ix} + \\ \qquad + X\sum\limits_{1}^{16} k_{ix} + \phi_y \sum\limits_{1}^{16} z_i k_{ix} = 0 \\ J_y\ddot{\phi}_y + \dot{X}\sum\limits_{1}^{16} z_i c_{ix} + \dot{\phi}_y \sum\limits_{1}^{16}\left(c_{iz}x_i^2 + c_{ix}z_i^2\right) + \\ \qquad + X\sum\limits_{1}^{16} z_i k_{ix} + \phi_y \sum\limits_{1}^{16}\left(k_z x_i^2 + k_x z_i^2\right) = e_x F_z \end{cases} \qquad (2)$$

$$\begin{cases} m\ddot{Y} + \dot{Y}\sum\limits_{1}^{16} c_{iy} - \dot{\phi}_x \sum\limits_{1}^{16} c_{iy} z_i + Y\sum\limits_{1}^{16} k_{iy} - \\ \qquad - \phi_x \sum\limits_{1}^{16} k_{iy} z_i = F_y \\ J_x\ddot{\phi}_x - \dot{Y}\sum\limits_{1}^{16} z_i c_{iy} + \dot{\phi}_x \sum\limits_{1}^{16}\left(c_{iy}z_i^2 + c_{iz}y_i^2\right) - \\ -Y\sum\limits_{1}^{16} z_i k_{iy} + \phi_x \sum\limits_{1}^{16}\left(k_{iy}z_i^2 + k_{iz}y_i^2\right) = -e_y F_z \end{cases} \qquad (3)$$

c) Shift on OZ axe is

$$m\ddot{Z} + \dot{Z}\sum_{1}^{16} c_{iz} + Z\sum_{1}^{16} k_{iz} = -F_z \qquad (4)$$

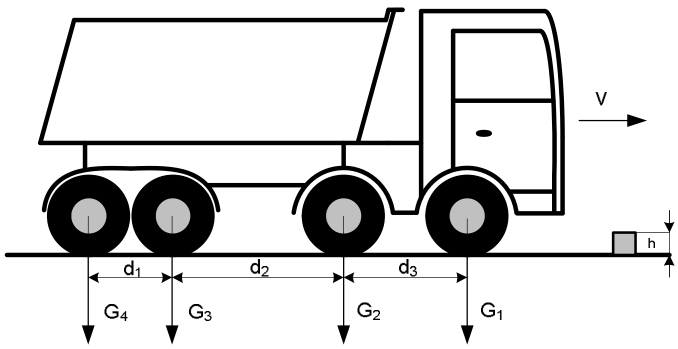
d) Rotation around OZ axe is

$$\begin{aligned} & J_z\ddot{\phi}_z + \dot{\phi}_z \sum_{1}^{16}\left(c_{ix}y_i^2 + 2c_{iy}x_i^2\right) + \\ & + \phi_z \sum_{1}^{16}\left(k_{ix}y_i^2 + 2k_{iy}x_i^2\right) = e_x \cdot F_y \end{aligned} \qquad (5)$$

m - weight of the deck, k_{ix}, k_{iy}, k_{iz} - dynamic stiffness isolation systems on three system directions considered as reference; $k_z=650\cdot10^6$ N/m; c_{ix}, c_{iy}, c_{iz} - damping coefficients of dynamic systems contained in the three system directions considered as reference; $c_z=1.5\cdot10^6$ Ns/m; F_y - force application on horizontal direction of the bridge deck; F_z - force application on horizontal direction of the bridge deck, e_x - distance on OX direction between the center of the mass of the bridge section and point of impact e_x = 2 m, e_y - distance on OY direction between the center of mass of the bridge section and the point of impact, e_y =- 2 m, e_z - distance on OZ direction between the center of the mass of the bridge section and the point of impact; e_z =- 1.4 m.

4. DEFINING THE PARAMETERS OF DYNAMIC REQUESTS

To establish the system excitation is considered a truck weighing 41 tons, Fig. 3, passing over an obstacle with a height of 40 mm at a speed of 20 km/h. This application corresponds to the dynamic measurements performed on the "Transilvania" highway the viaduct located between km 29 +602.75 and km 29 +801.25. The simulation characteristic data are summarized in the following table:



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

Fig. 3 The truck used for dynamic testing

On each axle passing over the considered barrier there are two forces solicitation directions, OZ and OY, acting on the bridge deck:

$F_{1z}=4.6793\cdot10^5$ N; $F_{2z}=4.6157\cdot10^5$ N;
$F_{3z}=8.2699\cdot10^5$ N; $F_{4z}=8.2699\cdot10^5$ N;
$F_{1y}=-1.4751\cdot10^5$ N; $F_{2y}=-1.4551\cdot10^5$ N;
$F_{3y}=-2.6071\cdot10^5$ N; $F_{3y}=-2.6071\cdot10^5$ N.

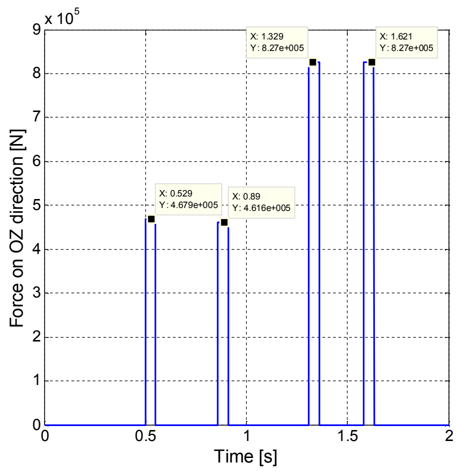


Fig. 4 The loads on the vertical direction

Considering the shape's excitation pulse resulted at the passing of the wheel over the obstacle of rectangular shape and impact duration of 0.03s, in Fig. 4 is represented the excitation functions shape both vertically and horizontally [3].

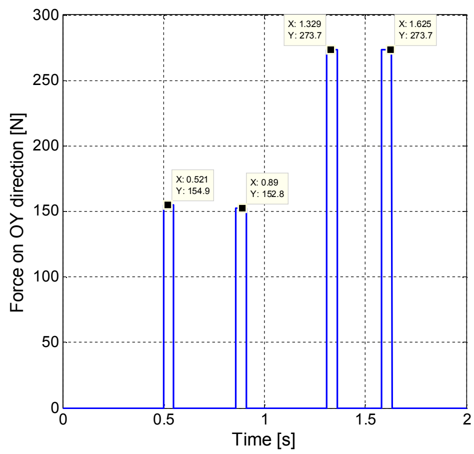


Fig. 5 The loads on the horizontal direction

The case considered as a section of the viaduct, has the following characteristics, [2]: m = 992000 kg, J_x = $120.533\cdot10^6$ $Kg\cdot m^2$, $J_y=15.133\times10^6$ $Kg\cdot m^2$, $J_z=134.091\times10^6$ $Kg\cdot m^2$.

5. DYNAMIC RESPONSE ANALYSIS OF PARAMETERS FOR MOVING THE DECK LIFT

The equation characterizing this motion is described by the following relation:

$$m\ddot{Z} + \dot{Z}\sum_{1}^{16} c_{iz} + Z\sum_{1}^{16} k_{iz} = -F_z \qquad (6)$$

Solving these second order differential equations was performed using MATLAB software package, aiming the evolution of the following parameters:

- Moving direction OZ: representation in time and frequency, Figs. 6-7;
- Acceleration in the direction OZ: representation in time and frequency, figs. 8-9;
- The energy dissipated by damping, Fig. 10;

Representation in phase plan characterizes the stability of motion, Fig. 11.

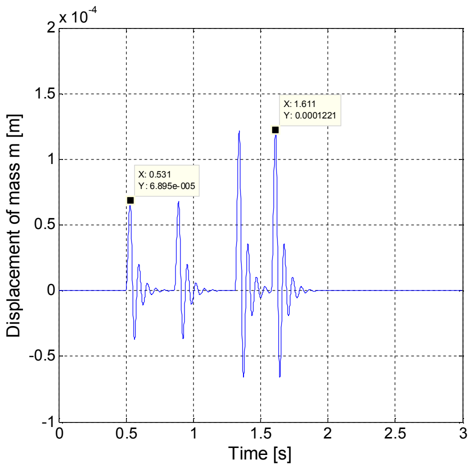


Fig. 6 Displacement on mass m

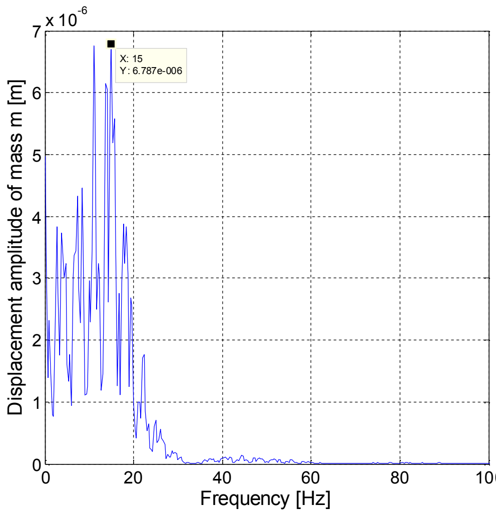


Fig. 7 Spectral representation of displacement

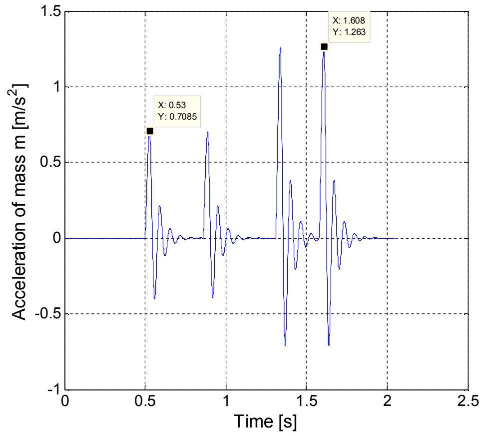


Fig. 8 Acceleration of mass m

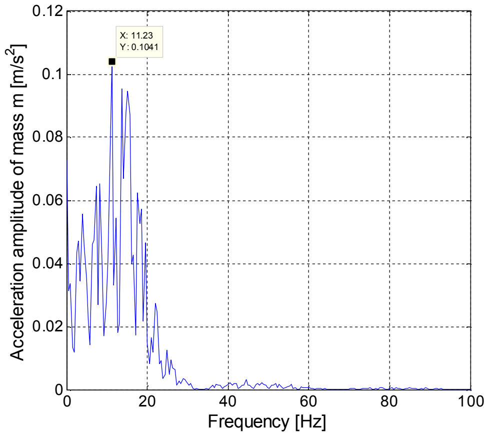


Fig. 9 Spectral representation of acceleration

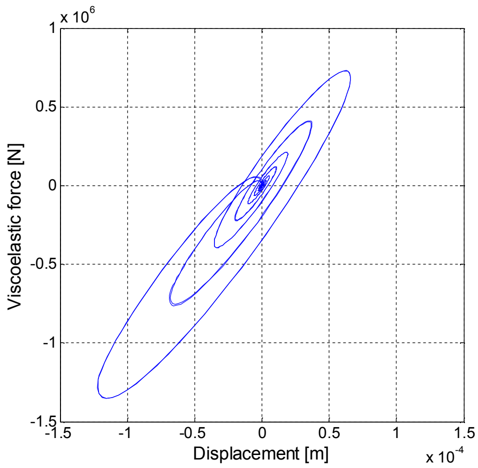


Fig. 10 Hysteresis loop, W=264J

From these representations we can conclude the following aspects:

- Displacement on OZ direction has the maximum value of 0.00012 m and the spectral representations indicate the dominant component in the range of 11-15 Hz, Fig. 6-7;

- Acceleration of oscillatory motion in the OZ direction has maximum value at 1.26 m/s^2, and the spectral band of the dominant components is situated in the range of 11-15 Hz, Fig. 8-9;
- The energy dissipated over the considered period is 264 J, since the movement values are reduced on the OZ direction. Fig. 10;
- Representation in the phase plane shows that the movement is stable, Fig. 11.

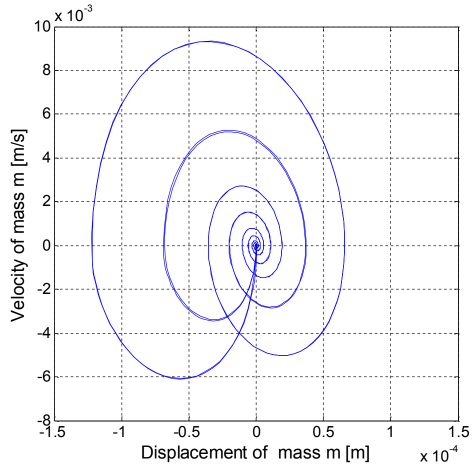


Fig. 11 Phase plane representation

A useful representation to identify spectral participation of each excitation pulse is the spectrogram of signal displacement, presented in several forms in Fig. 12-15. 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 are responsible the excitations three and four from the train of pulses.

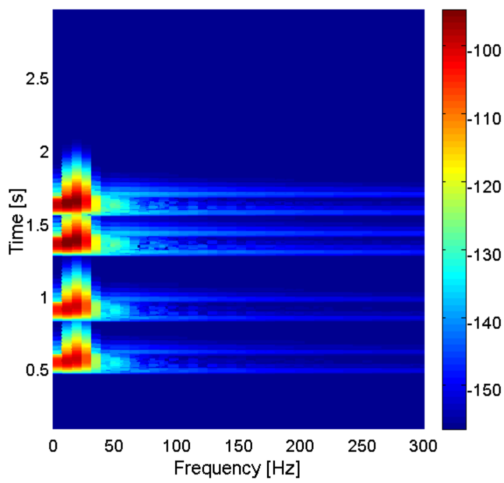


Fig. 12 2D spectrogram of displacement signal

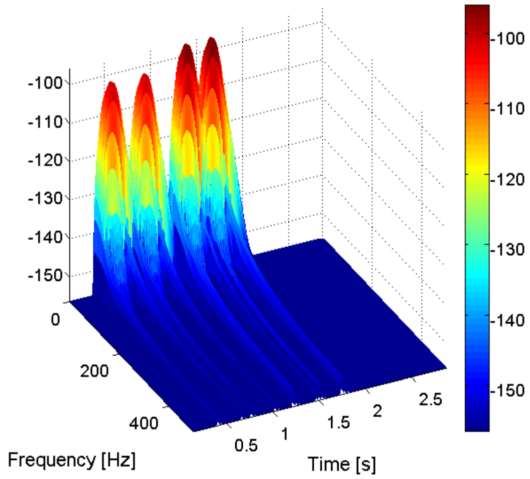


Fig. 13 3D spectrogram of displacement signal

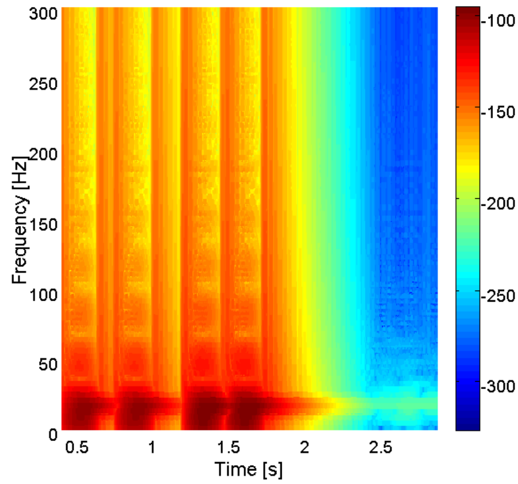


Fig. 14 2D spectrogram of displacement signal

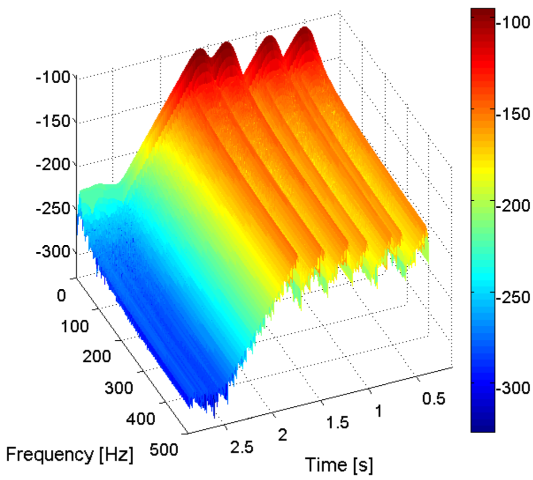


Fig. 15 3D spectrogram of displacement signal

6. CONCLUSIONS

This study shows one way of characterizing the dynamic response of a bridge or viaduct it is section, if loaded by loads from road traffic. The utility of the dynamic study is demonstrated by the following aspects:

- characterization of the dynamics of these systems allows for the proper choice of isolation systems against dynamic actions from road traffic;
- based on the comparative quantification of the dynamic parameters established by this study there can be characterized the operating conditions of devices, and therefore it is established their level of degradation.

This study can be completed by the dynamics characterization of the considered section of bridge on the other degrees of freedom, obtaining in this way a more complete characterization of the considered case.

ACKNOWLEDGMENTS

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