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FUNCTIONAL CORRELATIONS REGARDING PASSIVE ISOLATION OF SYMMETRICAL SYSTEMS

Aurora POTÎRNICHE, Silviu NĂSTAC

Abstract: *The paper deals with the passive isolation for a rigid structure building insulated on anti-seismic elastic devices. The basic hypothesis is that according to the structure presents geometrical and insulation configurations symmetries. This allows the decoupling of the eigenmodes and thereby, is simpler to evaluate the impact of the dynamic forces transmitted through the terrain-structure path during the earthquake. The classical theory of the vibration isolation is the base for evaluate the isolation degree for the considered structure. As an excitation factor it was considered the complex signal of an earthquake defined through the ground motion acceleration. The analysis that was made in the paper reveals the need to identification and evaluation requirements for the functional correlations between the reference parameters of the considered structure and the characteristics of the isolating and insulating devices.* ***Key words:*** *anti-seismic devices, vibration isolation, eigenmodes, isolation degree.*

1. INTRODUCTION

In the anti-seismic design, for the protection of the buildings to vibrations, is important to achieve some mechanical devices that can act as energy absorbers or isolators [1], [2], [17]. This isolators have a favorably influence about the dynamic response of the structures subjected to random actions.

In the engineering computations must take into account the dynamic response of the buildings when the disturbing factor is a result of dynamic random actions induced by the environment- earthquakes, traffic, technological shocks and vibrations.

In terms of capacity of resilience and stability, the structures must withstand, corresponding to a safe level, according to the current technical regulations, to a limit load corresponding to the most unfavorable load combinations (such as seismic loads acting in the center of gravity of the structures). A good resilience capacity of a structure avoids the loss of stability or the destruction of the components or of the entire structure [3], [4], [5], [18].

At this moment are known and widely used two methods for anti seismic isolation and protection against vibrations [6], [7], [8]:

- the base isolation using elastic and dissipative elements between the structure and the foundation such that the movement components, which can be vibrations or seismic waves, to be transmitted to a lower extent from the foundation to the insulated structure. This method is generally used for rigid structures (monobloc structures, rigid constructions) or compact structures that no allow additions of structural elements;
- the change of the dynamic characteristics of the isolated structure when acts disruptive actions such as dynamic vibrations or seismic waves, through the installation of additional dissipative elastic structural elements - process used mainly for elastic structures that allow the installation of additional structural elements.

In this work is considered and analyzed a system which falls into the category of base isolation systems through the use of some elements with a predominant elastic feature.

2. THEORETICAL APPROACHES

The performance level which characterizes the anti-seismic elastic devices is highlighted through the vibration parameters there are transmitted. These parameters are amplitude, frequency, transmissibility and to determine their values it is analysed a practical situation of use the elastic systems, namely the vibration and seismic waves isolation for buildings or parts thereof. For this purpose it was considered a building P+7, insulated on special elastic systems [13], [14], [15], [16]. We mention that for the analyzed case it was adopted the rigid solid hypothesis. The isolated structure is considered a concentrated mass elastic orthogonal insulated on terrain.

The analysis was made for the situation of an anti-seismic isolation to a P+7 building, insulated on elastic special systems. The characteristic parameters for the building are:

- the number of levels = 8
- the built area = 20 x 20 = 400 m^2
- the total building height = 24 m
- the total mass of the construction = 2912 tons

The physical adopted model is shown in figure 1 and is characterized by the motion equations system (1). For the adopted version, characterized by a single concentrated mass (the rigid solid model), elastic orthogonal insulated to the extremities, are available the following hypothesis:

- the performance level regarding the vibration and seismic waves isolation is based on the evaluation of the values of the specific parameters for the transmitted vibrations to the foundation;
- the installing of an additional elastic element offers to the isolated structure a very low value of the fundamental frequency, compared with the situation in which the structure is rigid mounted on the foundation and, also, compared with the frequencies domain specify for the foundation movement. The first dynamic mode of the isolated structure involves deformations only in the isolated system. The superior dynamic modes don't participate to the movement and although is a higher energy contribution on these high frequencies, this energy is not transmitted to the isolated structure.

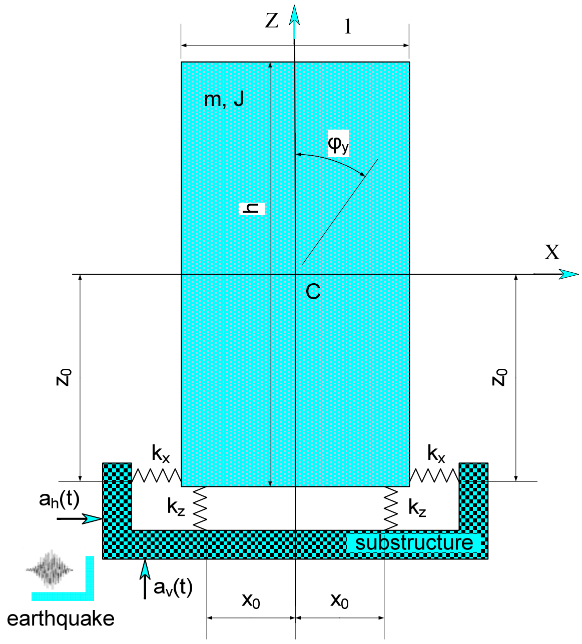


Figure 1. The physical model for a P+7 structure subjected to seismic actions

We consider that the seismic excitation is an acceleration and is acting by the two orthogonal directions X and Z. The system of differential equations of motion, corresponding to the schematized model from Figure 1, is the following:

$$\begin{cases} \ddot{x} + 4\dfrac{k_x x}{m} + 4\dfrac{z_0 k_x \varphi_y}{m} = 4a_h \\ \ddot{\varphi}_y + 4\dfrac{\varphi_y\left(k_z x_0^2 + k_x z_0^2\right)}{J_y} + 4\dfrac{z_0 k_x x}{J_y} = 4\dfrac{m z_0 a_h}{J_y} \\ \ddot{z} + 4\dfrac{k_z z}{m} = 4a_v \end{cases} \tag{1}$$

where a_h, a_v are the seismic waves accelerations measured on the two orthogonal directions. For a_h is chosen the horizontal NS or EV direction, depending on the placement mode of the building and on the prevailing direction of the seismic motion.

$$A_x = \frac{m a_h}{4k_z}\frac{\sqrt{\left[\left(\dfrac{x_0}{\rho_y}\right)^2 - \left(\dfrac{\omega}{\omega_z}\right)^2\right]^2 + \left[\dfrac{k_x}{k_z}\dfrac{x_o}{\rho_y}\dfrac{z_0}{\rho_y}\right]^2}}{\left(\dfrac{\omega}{\omega_z}\right)^4 - \left[\dfrac{k_x}{k_z} + \dfrac{k_x}{k_z}\left(\dfrac{z_0}{\rho_y}\right)^2 + \left(\dfrac{x_0}{\rho_y}\right)^2\right]\left(\dfrac{\omega}{\omega_z}\right)^2 + \dfrac{k_x}{k_z}\left(\dfrac{x_0}{\rho_y}\right)^2} \tag{2}$$

$$A_{\varphi} = \frac{m a_h}{4 k_z \rho_y} \frac{\sqrt{\left[\frac{z_o}{\rho_y}\left(\frac{\omega}{\omega_z}\right)^2\right]^2 + \left[\frac{x_o}{\rho_y}\left(\frac{k_x}{k_z} - \frac{\omega^2}{\omega_z^2}\right)\right]^2}}{\left(\frac{\omega}{\omega_z}\right)^4 - \left[\frac{k_x}{k_z} + \frac{k_x}{k_z}\left(\frac{z_0}{\rho_y}\right)^2 + \left(\frac{x_0}{\rho_y}\right)^2\right]\left(\frac{\omega}{\omega_z}\right)^2 + \frac{k_x}{k_z}\left(\frac{x_0}{\rho_y}\right)^2} \quad (3)$$

$$A_z = \frac{m a_h}{4 k_z} \frac{1}{1 - \left(\frac{\omega}{\omega_z}\right)^2} \quad (4)$$

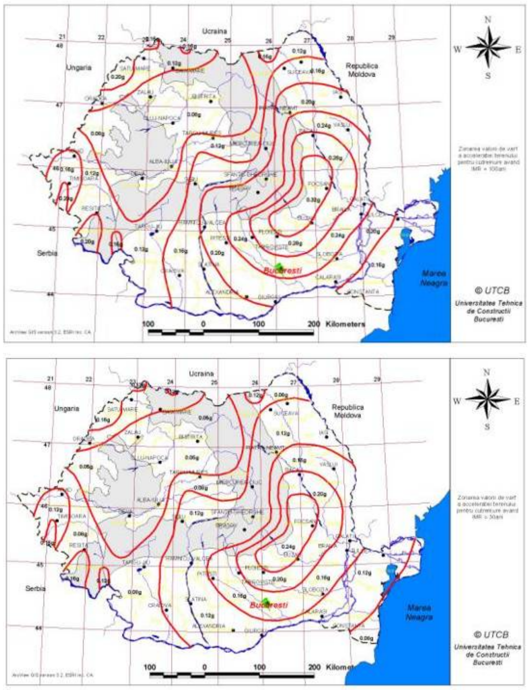
It was made a comparative analysis between the three obtained amplitudes and this study goes to the following issues:

- for the vertical displacement Z, we can see that the maximum level of the signal decreases once with the improvement of the insulation-solution.
- for the direct insulation solution on elastic elements, the system response on vertical direction is about two times lower versus the response to the horizontal direction.
- on the NS direction, the system response analysis should take into account the corresponding values of the equivalent rigidities of the special insulating systems. Thus, for any insulating solutions that were analyzed, the maximum amplitude of the system response is lower than that of the excitation on the same direction (NS).
- regarding the rotation motion around the Y axis, it has very low values (less than 0.008 degrees), therefore his influence on the system motion can be neglected.

3. SEISMIC ACTIONS ON STRUCTURES

Regarding the building design in Romania, considering the zonal seismic activity, The Romanian Seismic Design Code P100 establishes some important aspects and from these, significant for this paper are the following [9]:

- For the earthquake design of the buildings, in Romania the territory is divided into seismic hazard zones. The level of seismic hazard in each area is considered, simplified, to be constant. For major urban centers and for the constructions with a special importance it is recommended a local assessment of the seismic hazard based on instrumental seismic data and on specific studies for the considered structure.
- The intensity for the seismic hazard design is described by the peak value of the terrain acceleration, a_g, determined for the average recurrence interval of reference (IMR), a value named herein "the design terrain acceleration".
- The design terrain acceleration for each seismic zone corresponds to an average recurrence interval of 100 years reference. The zone division of the terrain acceleration for earthquake design with an average recurrence interval IMR = 100 years is shown in the Figure 2, a. The zone division of the terrain acceleration for earthquake design with an average recurrence interval IMR = 30 years is shown in the Figure 2, b.



(a)

(b)

Figure 2. The peak value of the terrain acceleration for design a_g, for earthquakes with average recurrence interval IMR = 100 years (a) and IMR = 30 years (b)

- The seismic movement in a point on the terrain surface is described by the elastic response spectrum for accelerations.
- The horizontal seismic action on constructions is described by two orthogonal components considered independent each other and represented by the same response spectrum.
- The normalized elastic response spectra for accelerations are obtained from the response spectra for accelerations through the division to the value a_g.

4. RESULTS AND DISCUSSIONS

Based on the transmissibility and on the vibration isolation can be done an assessment for the isolation degree. For this, is analyzed the significant spectral component of the earthquake complex signal as an excitation factor defined through the terrain motion acceleration. The case used for analysis is the Vrancea earthquake of 1977 [10], [11], [12]. The earthquake had as a distinct characteristic a multishock behaviour and the movement propagation was made on NESV direction. According to INCERC recordings, the peak acceleration of the terrain on NS direction had the value $194{,}93 cm/s^2$, the peak speed had the value $71{,}94 cm/s$ and the peak displacement of the terrain had the value $16{,}31 cm$.

I have presented in the Table 1 some reference parameters for 1977 Vrancea earthquake. We can observe that on the NS direction in the horizontal plane the acceleration has the maximum value and the domain of the dominant frequencies has significant values [9].

Table 1

Reference parameters for 1977 Vrancea earthquake

1977 Vrancea earthquake	Maximum accelera-tion [m/s^2]	Dominant frequen-cies [Hz]	Significant freq. for the power distribu-tion [Hz]
EW	1,62	0,3-3	0,4-0,31
NS	1,94	0,65-3,12	0,65-3,12
Vertical	1,05	0,51-5,64	0,51-5,64

Considering at reference the parameter values from the table corresponding to the NS direction in the horizontal plane, I wanted to analyze the eigen frequencies values of the structure relative to the pre- and post-resonance, so as to avoid the resonance danger. It must be also satisfied the essential structural and functional requirements for static and dynamic solicitations. The calculation showed that, for small values of the eigen frequencies, are obtained unacceptable results regarding the large static deformations of the insulating system. In these circumstances the positioning in the post-resonance area of the working feature is not feasible. For high values of the eigen frequencies, which corresponds to an operating mode in the pre-resonance area, are obtained high stiffness coefficients, respectively static small deformations, acceptable, of the insulating systems.

Based on this first phase of the study was made the diagram from Figure 3. In that diagram was marked the restricted area, corresponding to the spectral domain of the excitation signal, in the analysed case of the seismic wave. Analysing the dependence of the movement in respect with the frequency, it is observed that the optimal working area of the elastic insulating systems is in the right part of the dominant excitation frequencies area, with other words, in pre-resonance.

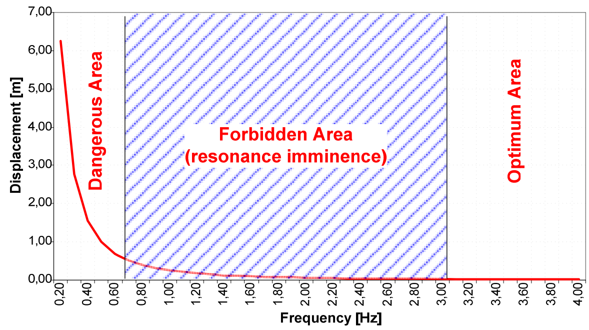


Figure 3. The static displacement versus frequency dependence

On the vertical direction there is a static load given from the weight of the considered structure, and a dynamic overload, which is the seismic excitation on this direction. Thus, the total arrow of the insulating devices has on this direction a static component and a dynamic one. On the vertical direction the elements must have high rigidity because, in these conditions, is ensured the working condition in pre-resonance regime. In the same time the high rigidity increase the bearing capacity of the insulating elements, so that there is a reserve for static and dynamic loads to take over.

On the horizontal direction the insulating elements take over only a dynamic load. According to the classical theory of the vibration isolation, the dimensioning of the elements it will be make to ensure a working regime in post-resonance regime, so the rigidity of these elements must be small.

In this paper, for the functional reasons in static regime, will be considered as known the stiffness coefficient on the vertical direction k_v, as a reference value.

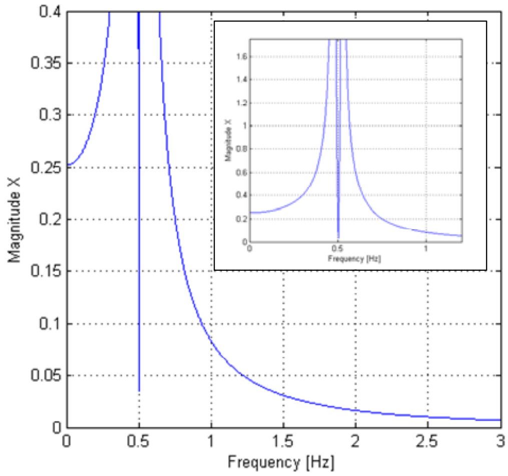


Figure 4.1. The dependence between x magnitude and frequency for $k_v / k_h = 100$

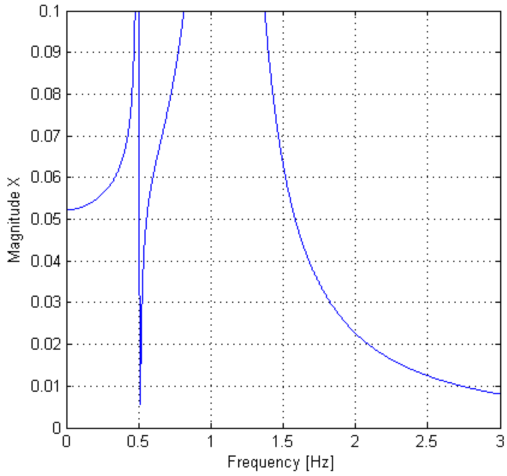


Figure 4.3. The dependence between x magnitude and frequency for $k_v / k_h = 20$

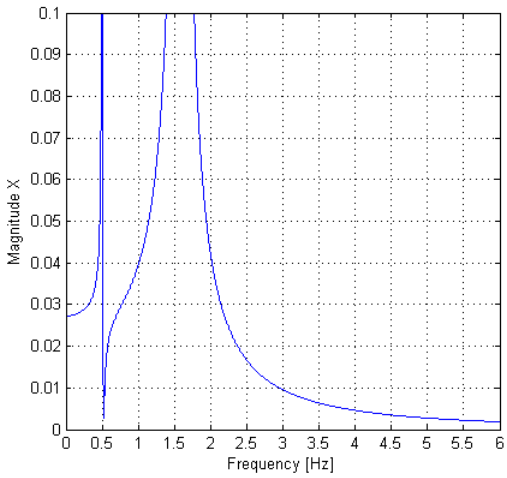


Figure 4.5. The dependence between x magnitude and frequency for $k_v / k_h = 10$

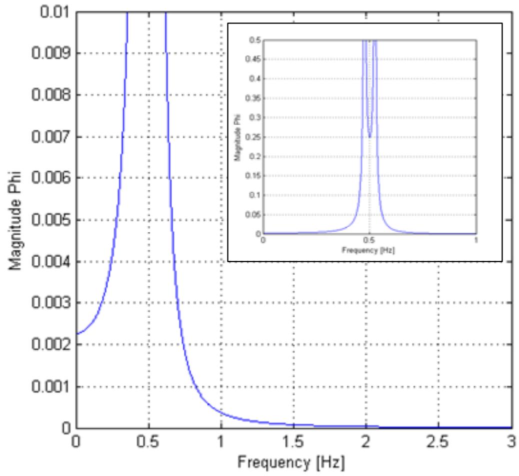


Figure 4.2. The dependence between φ magnitude and frequency for $k_v / k_h = 100$

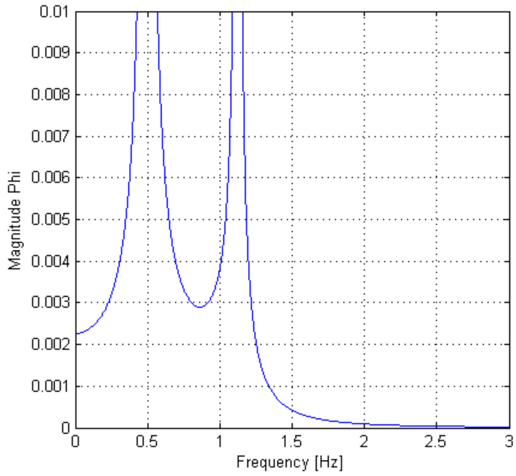


Figure 4.4. The dependence between φ magnitude and frequency for $k_v / k_h = 20$

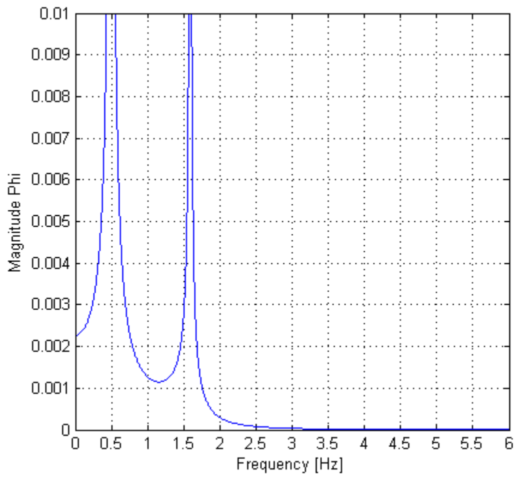


Figure 4.6. The dependence between φ magnitude and frequency for $k_v / k_h = 10$

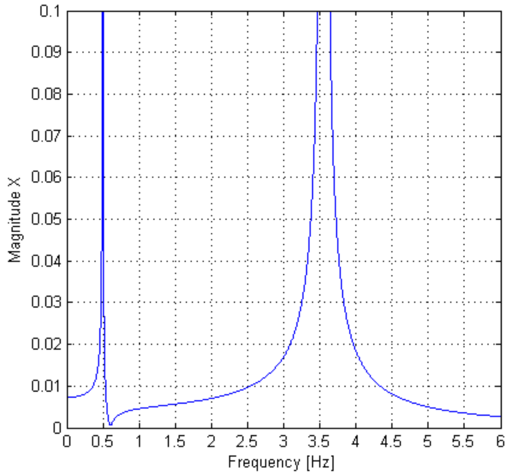


Figure 4.7. The dependence between x magnitude and frequency for $k_v/k_h = 2$

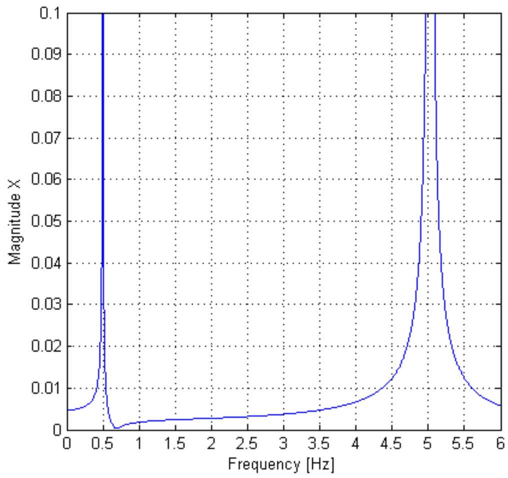


Figure 4.9. The dependence between x magnitude and frequency for $k_v/k_h = 1$

Considering k_v at reference, it will be examined the influence of the stiffness coefficient in the horizontal direction k_h on the global isolation characteristic of the structure-insulator-terrain system. Thus, we will consider a set of 5 values of the k_v/k_h ratio. According to this ratio was realized a qualitative study regarding the spectrum amplitudes for the two coupled degrees of freedom of the structure-insulator-terrain system (x and φ). From many results obtained during the analysis were selected for the presentation in this paper five sets of diagrams, considered to be representative for the initially proposed analysis. Thus, the figures beside show the pairs of diagrams corresponding to the coupled degrees of freedom x and φ, for the following k_v/k_h ratio values: 1, 2, 10, 20, 100.

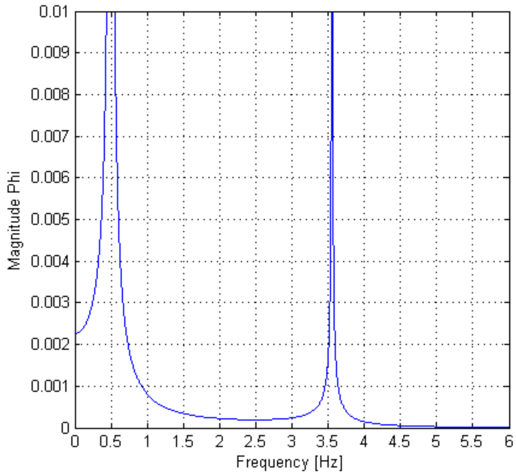


Figure 4.8. The dependence between φ magnitude and frequency for $k_v/k_h = 2$

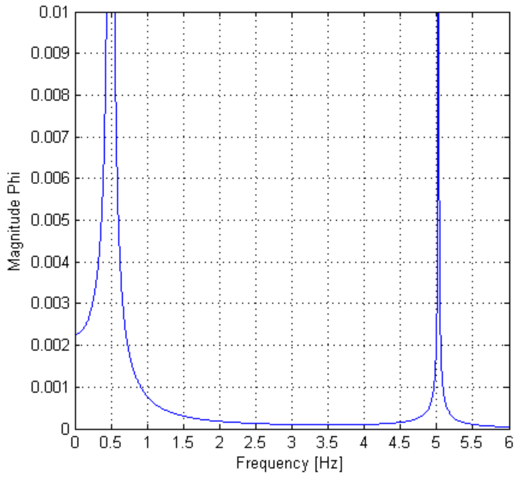


Figure 4.10. The dependence between φ magnitude and frequency for $k_v/k_h = 1$

The influence of the rigidities ratio on the frequencies corresponding to the coupled modes can be evaluated from the comparative analysis of the spectral characteristics presented in Fig. 4 and results the diagram from Fig. 5. This diagram shows the dependence between the stiffness ratio and the natural frequencies ratio for the coupled modes, ratios considered for the five analysed cases.

From Fig. 5 results that the increase of the stiffness ratio (which means the increasingly lower values of the stiffness in the horizontal direction compared with the reference value of the stiffness in the vertical direction), involves the reducing of the value of the eigen frequencies ratio (for x and for φ).

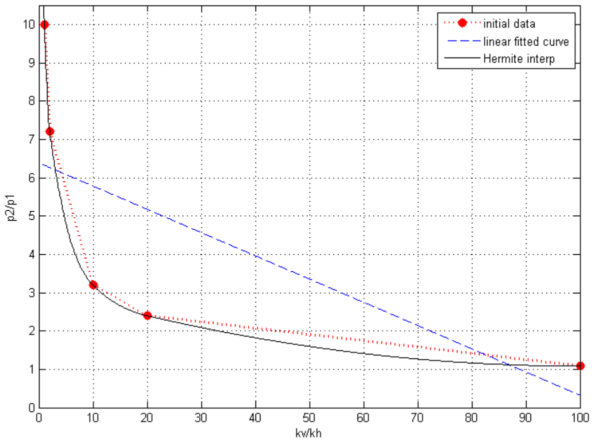


Figure 5. The stiffness ratio and the natural frequencies ratio dependence

Making a comparative analysis between the spectral diagrams from Fig. 4 and the graphic from Fig. 5, we can observe that the reducing of the eigen frequencies domain come together with the maintaining of a constant lower limit and with the shifting of the upper limit to the low frequency values. This is based on the initial hypothesis, according to all structural and functional parameters of the system structure-insulator-terrain which don't covered by this analysis are constant. The reduction of the eigen frequency domain together with its shifting to low values of the spectrum is particularly beneficial because it reduces or even eliminates the risk that the dominant seismic action spectrum to interfere with the eigen frequencies domain of the analysed system, thus avoiding the resonance.

5. CONCLUSIONS

According to the presented analysis, for the functional and static/dynamic stability considerations, the working regime in the vertical direction must be in the pre-resonance. On the other side, in the horizontal direction is assured the functioning in post-resonance regime with major advantages regarding the isolation degree to dynamic disturbing actions, which can be intense and varied, such as seismic waves.

The analysis shows the need to identify and evaluate the functional correlations between the reference parameters of the structure and the characteristics of the isolating and insulating devices. With these correlations known, can be avoided the resonance phenomena, which occur due to the overlap of the two essential spectra - the excitation signal one and the perturbed system one.

One future research direction is to identify an additional set of essential parameters which can be able to provide the shifting of the lower limit of the dominant eigen frequencies spectrum, corresponding to the two coupled modes of the structure-insulator-terrain system to low values. In this way it will be possible to grant very precise the working regime in the post-resonance with the reference spectrum of the disturbing dynamic action of seismic wave type.

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Corelații funcționale privind izolarea pasivă a sistemelor simetrice

Rezumat: *Lucrarea se ocupă de izolarea pasivă pentru o structură rigidă rezemată pe dispozitive antiseismice elastice. Ipoteza de bază este aceea conform căreia structura prezintă simetrii geometrice şi de rezemares. Aceasta asigură decuplarea modurilor proprii şi astfel sunt mai uşor de evaluat forțele transmisestructurii de către teren în timpul cutremurului. Teoria clasică a izolării vibrațiilor este folosită pentru a evalua gradul de izolare pentru structura considerată. Ca factor de excitație a fost considerat semnalul complex al unui cutremur definit prin acceleratia de mişcare a solului. Analiza din lucrare evidențiază nevoia unor cerințe de identificare şi evaluare a unor corelații funcționale între parametrii de referință ai structurii şi caracteristicile dispozitivelor de izolare.*

Aurora POTÎRNICHE, Assist. Drd. Eng., “Dunărea de Jos” University of Galați, Engineering Faculty in Brăila, Research Center for Mechanics of Machines and Technological Equipments, E-mail: roselady24ro@yahoo.com, Office Phone: 0239/612572.

Silviu NĂSTAC, Lect. Dr. Eng., “Dunărea de Jos” University of Galați, Engineering Faculty in Brăila, Research Center for Mechanics of Machines and Technological Equipments, E-mail: snastac@ugal.ro, Office Phone: 0239/612572.