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To cite this article: F Scheaua 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **591** 012029

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Modelling of the visco-elastic pendular hybrid system with dissipative rolling elements

F Scheaua

“Dunarea de Jos” University of Galati, Engineering and Agronomy Faculty of Braila,
Department Engineering Sciences and Management, MECMET Research Center, 29
Calarasilor Street, Braila, Romania

E-mail: fanel.scheaua@ugal.ro

Abstract: The construction industry has seen a remarkable development in recent decades, making it possible to build infrastructure elements capable of withstanding considerable demands on traffic, wind or seismic actions. These achievements have been made due to the solutions used for isolation against dynamic actions that may require the structure at a given time. In order to ensure the protection of construction structures against seismic actions, many constructive solutions have been developed which can be mounted inside the resistance structure. These are mechanical systems used for isolation and seismic energy dissipation, which by operation are able to modify structural behaviour at earthquake. A hybrid seismic isolation model is described which is classified under the building base isolation systems category. This system consists of concave roller elements in combination with elastomeric shock absorbing elements. An experimental model has been developed and analysed, and the results are presented in terms of accelerations in time and frequency at the level of the structural elements at which the recordings are made during excitation simulating the action of a seismic event. The isolation system is used on the low model of a bridge or viaduct structure. Analyses are made for different models of insulation system layout at the isolated structure and distinct cases regarding the construction of the component parts regarding the rolling elements in contact with the concave surface. The results are presented for each structural element in part describing the registered values of acceleration due to the excitation on the supporting pier and the superstructure over the three main directions of movement according to the constructive type of the rolling elements that are included in the isolating system. Experimental analysis was performed on a small-scale system under laboratory conditions, based on a set of simplified assumptions. The advantage of this approach is supported by multiple possibilities of simulation of real dynamic loading situations, static and dynamic loading states, structural and functional schemes and functional configurations of the supporting and isolation systems against dynamic actions. Thus, the transfer of experimental results from reduced models to real systems through mathematical and computer models associated with them is ensured by appropriate transfer functions.

1. Introduction

In addition to the classical methods of designing the construction structures represented by the dimensioning of the resistance structure basic elements, some protective elements were gradually implemented into the structural assembly in order to protect the buildings against structure degradation or collapse during earthquakes.

These protective elements are represented by isolation or energy dissipation systems which according to the constructive principle have the ability to interrupt the transmitting of the vertical



loads from the foundation ground to the superstructure which must remain stable during an earthquake or to consume a considerable energy amount induced into the structure by seismic motion.

Thus, various insulation systems are used which are positioned at the base of the structure (between the foundation and the superstructure) named base insulation systems, or dissipative systems that are typically positioned between two distinct structural frames in order to minimize relative displacements between them when the seismic motion occurs.

A hybrid isolation and dissipation system is presented which is intended for use in seismic isolation of bridges or viaducts against the effects of seismic action.

It represents a system that combines the isolation effect of the pendulum systems, that make use of the sliding horizontal and vertical movement, positioned on a set of elastomeric elements.

Additionally, viscous fluid anchor system may be used in order to achieve superstructure protection for dangerous displacements that would exceed the sliding bearings geometrically limit, endangering the superstructure stability.

It is a complex system that has to be properly dimensioned for each structure and an experimental assembly model has been tested under laboratory conditions on a small-scaled bridge structure. The experimental results obtained are presented in this paper, [1].

2. The hybrid isolation model assembly

In order to ensure an improved behavior of a bridge structure during seismic movements, it is necessary to consider the conditions in which the efforts at the foundation ground tend to be transmitted vertically to the superstructure in the event of a ground seismic movement. Thus, it is necessary to partially disconnect the superstructure from the foundation so that the foundation to be able to execute a relative free movement together with the ground and the superstructure can remain in a steady equilibrium position. In order to achieve this, a base insulation system is installed between the two structural elements (foundation and superstructure).

Due to the fact that the base insulation system introduces superstructure freedom of movement over many moving directions there is the danger that at a certain point in time when a high magnitude earthquake occurs, the superstructure tends to overcome the isolation system boundaries by forcing its destruction followed by structure damage or collapse.

In order to prevent this dangerous situation in completing of the base insulating system, the viscous fluid dissipative system can be mounted, which acts as an anchor system between the two bridge structural elements (foundation and superstructure).

As a result, the composition of the complete hybrid seismic protection system is made up of pendulum sliding bearings, elastomeric elements and viscous fluid dissipative systems used to limit some dangerous displacements on bearings made up to the breaking limit of the isolation system.

The schematic representation of the hybrid isolation system assembly model on a bridge structure type having in composition pendulum rolling bearings and elastomeric elements is shown in figure 1, [2, 3].

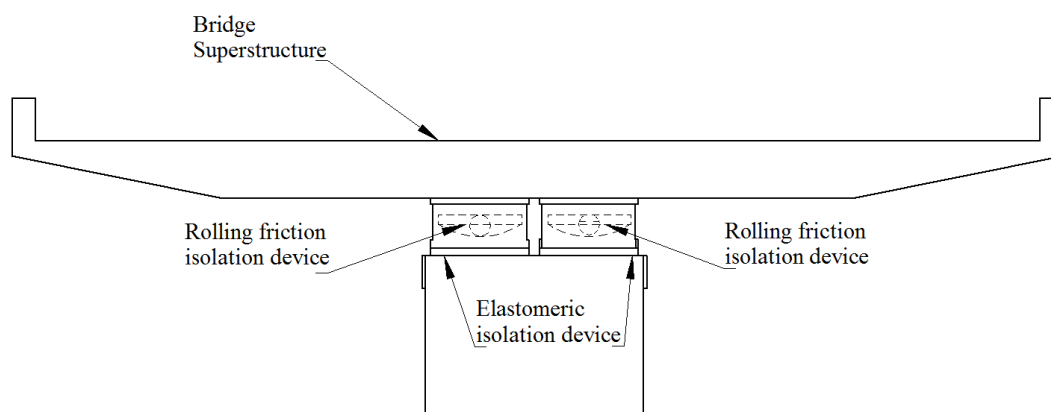


Figure 1. Schematically representation of hybrid isolation system model on a bridge structure.

An earthquake action produces a forced ground displacement that drives the foundation of the bridge structure in motion.

A high earthquake magnitude has the potential to overturn the bridge's structure.

To prevent the structure collapse, the base isolation and dissipation system is used, which by its components acts to mitigate the effects of seismic action on the bridge structure.

Due to the disconnection made by the isolation system at the base positioned between the support leg and the superstructure, the foundation can move with the ground and the superstructure has a different vibration period that protects it from the ground acceleration amplitudes.

The insulator system allows movement up to the limit of the sliding bearing and the elastic limit of the elastomeric system.

The displacements above this value are limited by the fluid viscous dissipative system which acts as an anchor and limitation system for the relative displacements between the structural frames between which it is positioned.

3. Experimental work on isolation of a bridge deck by means of a hybrid base isolation system

Under laboratory conditions, a small-scaled model of a bridge was constructed which is insulated by means of hybrid base isolation system comprising roller pivot systems and elastomeric elements positioned between bridge pier and superstructure.

The isolation device assembly contain a set of elements consisting of two main plates, one with a flat surface placed at the top and the other with the concave geometry placed at the bottom representing the rolling bearing being positioned on top of elastomeric elements. Between the two plates of rolling bearing is placed the central piece represented by a steel sphere, which has the possibility of rolling on the two main surfaces.

The pieces are simply leaned so that a relative displacement between the two main plates of the insulating system, which are connected to the model foundation (the bottom plate) and to the superstructure (the upper plate), can be achieved.

Thus, the disconnection between the bridge pier and superstructure is made, which theoretically receives freedom of movement in the horizontal plane but also in the vertical plane (lift) due to the concave geometry of the main rolling surface at which the relative displacement of the two structural elements occur, displacement allowed by the insulating system.

Experimental tests were carried out by dynamically stressing the structure with the help of an excitatory force-adjusting device applied directly to the foundation and the support pier of the experimental stand, mainly following the acceleration values in the three orthogonal directions, the acceleration amplitudes according to the excitation frequency recorded at the pier level as well as at the superstructure level, where tri-axial accelerometers were mounted.

Experimental stand model with rolling isolation system mounted is presented in figure 2.



Figure 2. Experimental stand model with rolling isolation system mounted.

The main spherical surface of the pendulum support has the geometry shown in figure 3, the material being 3 mm thick steel and a friction coefficient of 0.15 ... 0.18 for steel-steel (free dry friction) and in the case of contact between the rubber-coated steel spheres and the main steel-rolling surface the coefficient of friction-free rubber-free rubber is 0.8, [2].

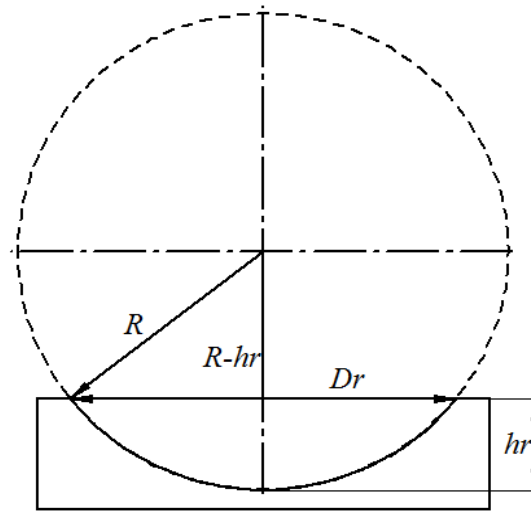


Figure 3. The main rolling spherical surface geometry.

The relationship between the geometrical dimensions of the support relative to the radius of the concave rolling surface, height and bearing diameter is described by means of the equations (1)-(3), [2]:

$$R^2 = \left(\frac{D_r}{2}\right)^2 + (R - h_r)^2 \quad (1)$$

$$R^2 = \frac{D_r^2}{4} + R^2 - 2Rh_r + h_r^2 \quad (2)$$

$$R = \frac{\frac{D_r^2}{4} + h_r^2}{2h_r} \quad (3)$$

where:

R – the radius of the main spherical rolling surface;

D_r - the diameter in the horizontal direction of the support;

h_r - the height of the support surface;

For the rolling spherical bearings used for the experimental determinations we have the following values, [2]:

$$D_r = 62mm; h_r = 14mm$$

The structure was requested by the shock produced by an excitatory system, following the time dependent beam behavior, which represents the model superstructure, but also of the pier, which receives the excitation force in dynamically regime.

The occurrence of relative displacements between the two structural elements is followed and recorded, which means relative accelerations, highlighted in the results obtained on the basis of the recordings made using beam and support pier mounted tri-axial accelerometers.

The differences between the acceleration values in identical directions between the beam and the supporting pier highlight the insulating and dissipating role of the rolling friction pendulum system with and without built-in elastomeric elements are highlighted.

The experimental results obtained for the analyzed cases with excitation on the isolated structural system are presented, representing the time accelerations and the acceleration amplitudes according to the excitation frequency recorded on the three acquisition channels corresponding to the three main orthogonal directions both for the model superstructure and for the support pier, [4].

4. The experimental results obtained

Successive experimental tests were carried out using possible combinations between the components of the hybrid isolator system to highlight the possible differences that may occur in system operation and the behavior of the structure insulated with these types of systems.

Initially, the pendulum steel spherical roller was used, and then the elastomeric system was added to work in tandem.

The cases presented are instances of isolation systems whose assembly contains:

- Elastomeric outer spherical steel parts rubber coated, used in rolling pendulum bearings, without elastomeric support system;
- Elastomeric outer spherical steel parts rubber coated, used in rolling pendulum bearings, with elastomeric support system represented by three elastic elements mounted in linear configuration on the base plate of the pendulum bearing;

The obtained results show the values for the acceleration amplitude in time and the excitation frequency recorded at the model support pier and superstructure.

Due to the action of the insulator system, lower values are recorded at the level of the superstructure relative to the supporting pier, which demonstrates the insulating and dissipative character of the system mounted to the insulated structure.

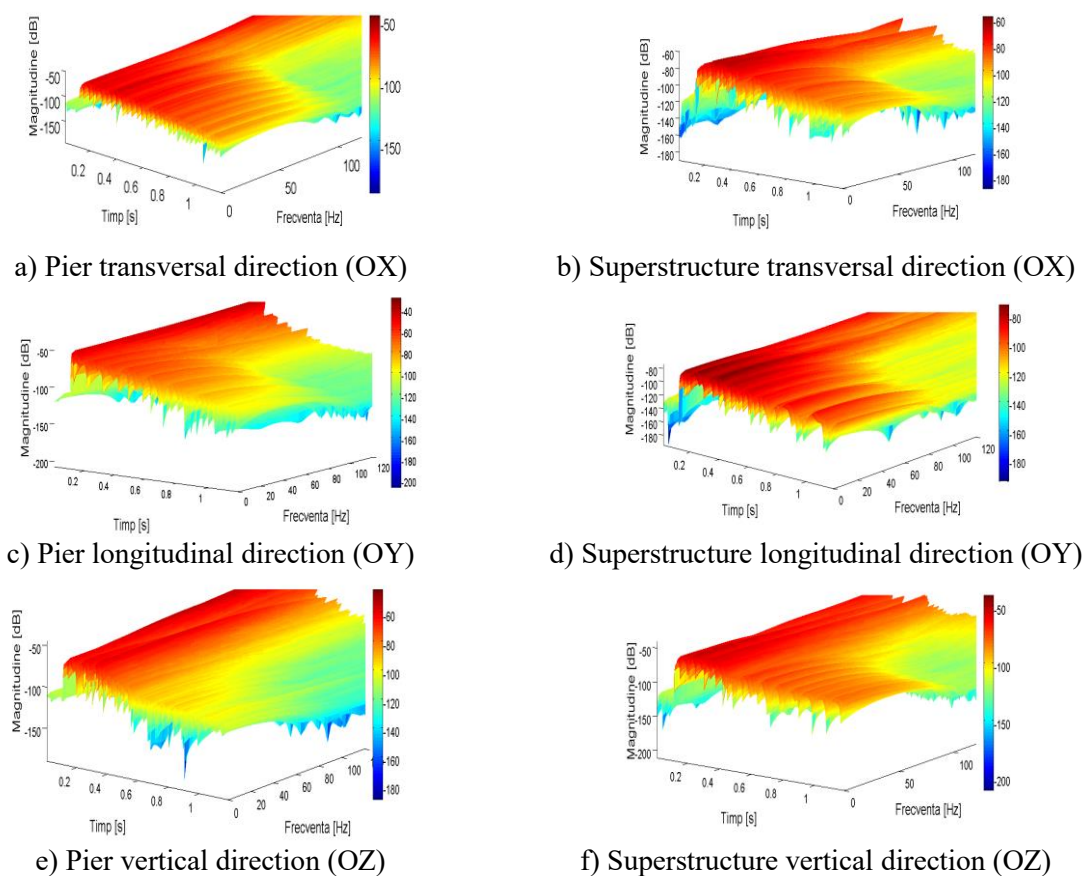


Figure 4. The results obtained for Case 1 rolling pendulum isolation system without elastomeric bearing – excitation value of 400 J, [2].

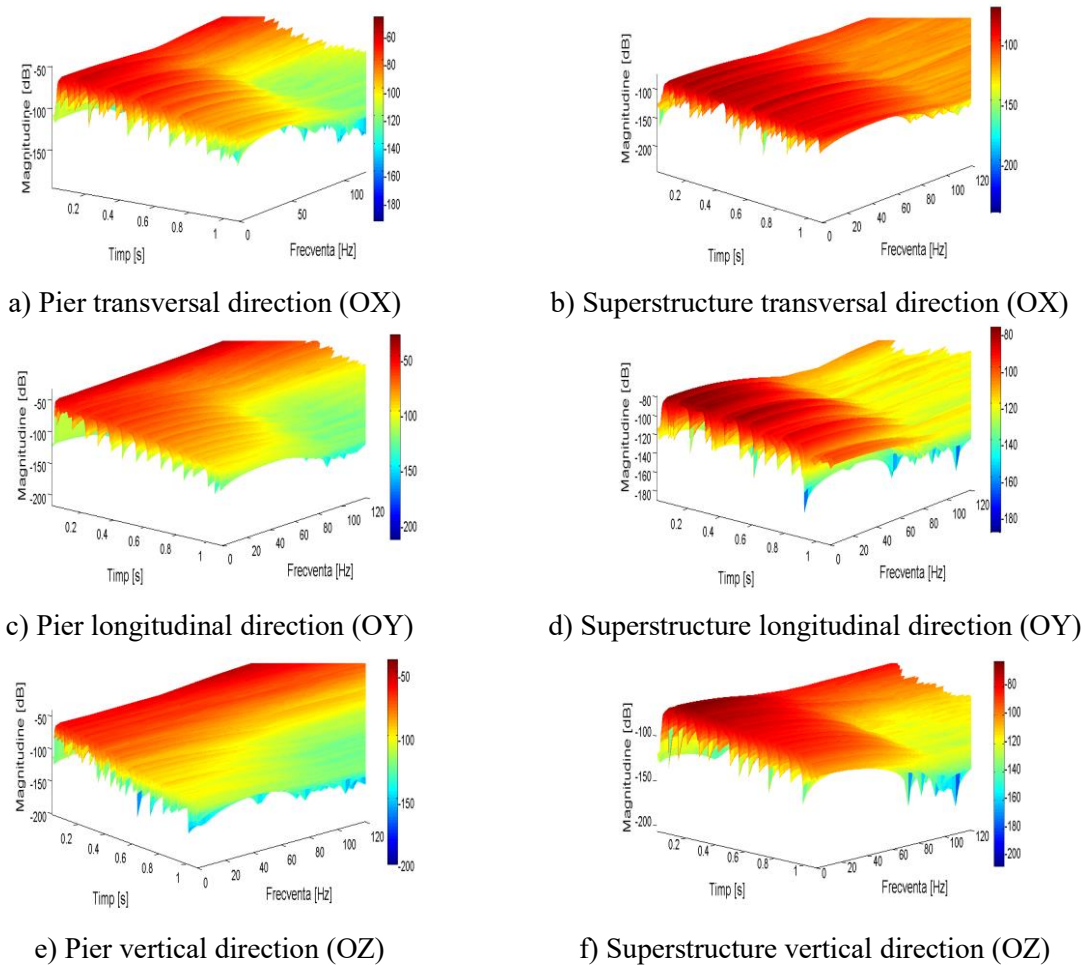


Figure 5. The results obtained for Case 2 - Rolling pendulum isolation system with elastomeric bearing – excitation value of 400 J, [2].

The results obtained from the numeric analysis are presented as spectrograms based on structure experimental model containing two distinct cases, namely a case when using a pendulum rolling system (case 1) attached to the structure model in figure 4 and the second considered isolation method when a combination of rolling pendulum system is positioned on elastomeric support base, (case 2) results presented in figure 5.

The spectrograms recorded for each main direction of movement both for the support pier and the superstructure can emphasize the specific acceleration magnitude values function of time and frequency excitation when the structure model is required by excitation at 400 J applied at the structure base simulating an earthquake action in reality.

The elevated values are recorded for the support pier level and attenuated values are recorded at the superstructure level due to the action of the base insulating system.

The analysis of the results obtained and presented by means of spectrograms recorded on the main directions of movement confirms the action of the isolation system at the base of the structure by more attenuated values in terms of acceleration magnitudes in time and frequency for the insulated superstructure with the pendulum system used in simple configuration and also in the elastomeric base version.

The movement attenuation is explicable by the fact that the insulating system introduces flexibility within the structural system allowing the movement support without superstructure.

In this way the efforts are no longer fully transmitted to the superstructure due to the disconnection made through the insulating system.

Table 1 shows the actual values recorded for both cases at the support pier and superstructure level for maximum acceleration amplitude, vibration time, acceleration and excitation frequency for the three main motion directions.

Table 1. The result values obtained from experimental work for the two cases, [2].

Case	Motion direction	Pier		Superstructure	
		a_{max} [m/s ²]	$t[s]$	a_{max} [m/s ²]	$t[s]$
1	x	0.11	14.43	0.03	14.43
	y	0.19	14.43	0.19	14.43
	z	0.47	14.42	0.03	14.43
2	x	0.11	13.94	0.05	13.95
	y	0.36	13.94	0.01	13.95
	z	0.48	13.94	$10.45 \cdot 10^{-4}$	13.95

From the result values presented in table 1, the acceleration amplitude values recorded at the superstructure level are lower than those recorded at the support pier, which means visible motion attenuation for the superstructure model relative to the support pier for both analyzed cases and all three main directions of movement.

Lower values are recorded for the use of the elastomeric support to complement the pendulum system action.

Based on the experimental results obtained, a system consisting of a rolling pendulum bearing in combination with elastomeric support can be considered as the optimal version for the insulation of the bridge structure model.

5. Conclusions

The issue of the construction structures isolation against the effects of seismic actions is currently topical at the moment.

In order to solve this problem various isolation methods have been designed which, through time use, have yielded beneficial results in increasing the structures stability degree.

Over time, many systems have been developed that are capable of providing seismic isolation and energy dissipation during an earthquake occurrence time.

Such insulating systems are pendulum-type systems that act for vibration isolation by mounting at the structure base.

This paper presents a complex isolation solution consisting of a pendulum system in combination with an elastomeric system.

In this configuration the insulating system was made on a small scale and tested on a bridge structure model under laboratory conditions.

The structure was requested with the help of an excitatory system, with an excitation of 400 J applied to the structure support base.

The insulating system was positioned between two structural elements of the bridge model, namely between the support pier and superstructure.

By means of tri-axial accelerometers mounted on the two structural elements (pier and superstructure) it was possible to record the acceleration values during the experiment.

Due to the position and action of the insulator system, specific values were obtained for the two structural elements, demonstrating the insulating and dissipative character of the system used.

The results are presented by means of the spectrograms recorded for each main direction of movement for both the support pier and the superstructure.

Visible differences were recorded for the two experimental cases for the exclusive use of pendulum system (case 1) and the hybrid system consisting of the pendulum system in tandem with elastomeric supports (case 2).

Based on the acceleration amplitude values obtained over time and frequency, it is admitted that the superstructure benefits from attenuated acceleration values transmitted by the excitation system due to the insulating and dissipating action of the pendulum and elastomeric system.

The optimum solution to be used is the constructive solution comprises both the pendulum and elastomeric systems.

6. References

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