Coupling methods and optimal use of modern anti-seismic insulation systems at building and bridge construction structures

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Abstract: The construction industry has recorded an unprecedented advance in recent years, especially in the world recent developed countries and this involves the increasing development of insulation techniques against the effects of seismic actions that can threaten the structure integrity at a certain time. Most recent achievements in terms of structure insulation systems are successfully used within building and bridge structures in order to ensure the optimal stability level during a potential earthquake, which allows ensuring a proper safety level both for operation and in terms of investments protection. The protection methods of the structures are directed in two directions, namely in achieving the insulation at the base of the structure by strategically positioning the systems at the base of the structure while the second direction is directed at seismic energy consumption or energy dissipation by using dissipative systems mounted on frames the resistance structure of the building. By combining the action of the two types of mechanical systems, good results can be obtained regarding the behaviour of the structure isolated by the earthquake. The paper presents constructive aspects of the mechanical systems used for the seismic insulation of both building and bridge structures and their functional role in the whole structure to which they are mounted. Through the experimental tests made are highlighted the better results in terms of acceleration for the structure isolated with the composed system. Are emphasized in this manner the protective system role in ensuring an improved behaviour for the structure where is mounted at seismic dynamic motions that can occur in time.

1. Introduction

Multiple construction solutions for insulation systems are currently used all over the world to ensure stability conditions of structures against seismic actions.

They are built to protect the structure against the destructive earthquake effects, especially if it is positioned in an area with intense seismic activity and by earthquake operating is ensured an energy dissipation of the total energy amount that appears during the ground movement dictated by the seismic wave.

Depending on the earthquake type that can affect the structural system, the effects can be described as follows:

- rapid dynamic action corresponding to surface earthquakes can cause the deformations increase inside the structural system, increase the structure flexibility and avoid the transient resonance zone.
slow dynamic action corresponding to intermediate earthquakes can act in the sense of structure flexibility increase until the resonance limit with seismic movement is reached having the effect of structure seismic stresses increasing on the above the load limit, which can cause destruction.

Increasing the safety level of construction structures to dynamic seismic action consists in designing systems so that, when a certain level of structure response intensity become dangerous, changes in its dynamic characteristics are made accompanied by significant energy dissipation amounts.

Conceptually, the methods of protection of structures against dynamic actions were based on the ductility of the structural elements, so that a system could have its own capacity to dissipate the energy received from a certain dynamic action [1-8].

Over time, however, multiple ideas have been developed for the isolation of construction structures which, by introducing special devices inside the resistance structure, manage to change the structure's response during dynamic actions.

These special devices can be insulating systems that use either dry friction force (Coulomb) for energy consumption or plastic deformation of some metals (steel, lead) to achieve the proposed insulation objectives.

The essential role in the application of the insulating method is based on the use of insulators coupled with energy dissipating devices for taking over and consuming the energy induced by the earthquake inside the structure, ensuring the hysteretic damping for the structural system.

2. The isolation systems used for structures

In order to ensure the necessary conditions for achieving optimal insulation of structures against seismic actions, we can start from the change of the structure behaviour during the earthquakes action in the sense of displacements limiting and going further speeds and accelerations of structural elements.

By introducing isolation systems into the composition of a structural system, contributions to the structural rigidity change are made and further the change of its dynamic behaviour.

An increase in the strength rigidity of the structural system may mean placing the system in another spectral zone that may not always be beneficial (figure 1) [9-22].

Most isolation devices used at structures are considered as passive control systems when operating independently and do not include any other control apparatus.

When a certain structure is equipped with such devices, an improvement of the structural system behavior can be observed in certain ground movements resulting from dynamic actions.

The category of passive insulation systems includes the base insulation systems that can be installed between the foundation and the superstructure of a building.

These protection systems use the dry friction force (Coulomb friction) between two surfaces in permanent contact, while ensuring the possibility of the isolated structure to move freely in the plane of the sliding surface during seismic actions (figure 2).
The main sliding surface can be flat or concave, so that the displacement of the superstructure imposed by the insulating system can have both horizontal plane components \( u \) for the flat surface and the vertical component \( h \) imposed by the concave or spherical sliding surface [9-22].

![Schematic representation of base isolation system of friction pendulum type](image)

**Figure 2.** Schematically representation of base isolation system of friction pendulum type [9-22].

At the beginning of the ground seismic movement, the insulating system has the ability to come into action only when the friction force value \( F_f \) is exceeded by the lateral force \( F \), until this moment there is an increase in the rigidity of the isolated structure.

The geometric shape of the sliding surface dictates the possible occurrence of the remaining displacements of the superstructure if a flat sliding surface were used, while the spherical sliding surface ensures the superstructure return to the initial position due to the gravitational forces action [20-23].

3. Dissipation systems used for structures

The energy dissipating systems introduced inside a structural system make possible the response reducing during a seismic action, in terms of displacements, speeds and accelerations, due to the increased possibility of the system to dissipate seismic energy.

Figure 3 shows the modification of the structural system response to seismic action by placing on other curves corresponding to the spectral values obtained by using seismic energy dissipators, which increase the possibility of the structure to dissipate the received energy by increasing the fraction of critical damping, \( \zeta \). The specific values for the spectral acceleration \( a_s \) depending on the structure vibration period \( T \) are presented. It can be observed that by using the protection systems it is obtained the structural system placement on other spectral curves of lower acceleration values correlated with modified vibration period values [10].

![Spectral values mitigation in case of energy dissipators mounted at structures](image)

**Figure 3.** Spectral values mitigation in case of energy dissipators mounted at structures [10].

A constructive solution for dissipative systems is the use of viscous elastic devices that once introduced into a structural system can change the structure response to possible dynamic actions by
increasing the system total rigidity.

The principal diagram for a viscous elastic device is shown in figure 4, such a system can achieve a significant energy consumption from the total amount induced by earthquake in the structure.

![Figure 4. Structural system model equipped with viscous elastic dissipating device [10].](image)

Figure 5 shows the mounting solution of a fluid viscous device at a structural system. Viscous fluid dissipation devices, unlike other systems, do not change the rigidity of the structural system as a whole, they are a viable solution to consider for displacements limitation between the structural frames where they are mounted and dissipate a large amount of earthquake energy by taking it and transformation into caloric energy.

Energy dissipative devices with viscous fluid can also be used in combination with other types of insulating systems to complement their action and obtain a higher stability level for the insulated structure during high intensity seismic actions.

4. Mounting solutions for protective systems at structures

Solutions for coupling to the bridge-type structure of some constructive variants of elastomeric protective systems are presented.

The system allows a specific movement limited by the composite material elastic properties, necessary in the event of an earthquake that could request the structure in a dynamic regime.

The separation between the superstructure and the foundation allows a minimum free movement of the foundation in case of a seismic event, without involving the superstructure that must remain stable, thus aiming to change the structural response to lateral forces that may occur.

The appearance of the seismic movement entrains the foundation ground which registers an acceleration which is transmitted further to the insulating system at the same time.

The structural system seismic response reduction to lateral forces can be obtained by increasing the fundamental period of the structure, by changing the shape of the fundamental vibration mode, by increasing the damping or by combining these effects.

Figure 6 schematically shows the insulation system with elastomeric supports as a solution for the rehabilitation and seismic insulation of a bridge structure [10].

![Figure 6. Schematic representation of bridge isolated structure with elastomeric supports [10].](image)
The coupling method of the insulating system with elastomeric supports on the three-dimensional model of the bridge between the superstructure and the support pier transverse beam is presented in figure 7.

The insulating system can take over the vertical loads resulting from the traffic and the efforts coming from the foundation ground as a result of the seismic actions, ensuring horizontal displacements limited by the elastic properties of the composite materials.

![Seismic insulated bridge structure configuration using elastomeric supports](image)

**Figure 7.** Seismic insulated bridge structure configuration using elastomeric supports [10].

The structure lateral flexibility is modified by placing the insulation system between the structural components and is practically negligible in relation to that of the insulation system.

It can be said that a complete isolation of the structural system is achieved when the bridge superstructure behaves elastically, otherwise it is considered that the structural system is only partially isolated.

A hybrid constructive variant of the isolation system is represented by the use of sliding insulating devices in combination with elastomeric elements. The coupling method is enhancing the use of both dry friction and elastic forces in order to acquire displacements limitation and to shock damping coming as a result of the dynamic actions on a bridge structure.

The resulting assembly has the ability to combine the insulating and dissipating properties of sliding and elastomeric systems, resulting in a composite system that can provide improved damping to stresses acting directly on the structural system, preventing displacement due to inertia of structural components thus ensuring bridge stability.

By using these isolating systems working in tandem is ensured the lowest possible transmission of seismic stresses in the vertical direction from the ground through the foundation to the superstructure avoiding the structure placing in the transient resonance zone for the received stress level.

In figure 8 is presented the constructive solution for the insulating system composed of elastomers and sliding supports on concave surface [10].

![Schematically representation of the insulating system](image)

**Figure 8.** Schematically representation of the insulating system composed of elastomers with sliding supports [10].

By using a composed seismic energy insulating and dissipative system introduced inside the resistance structure of a bridge structure, the assembly rigidity decrease is pursued at the same time with damping increase at small and medium deformations and the efforts vertical transmission from
the foundation is accomplished with diminished force values, in the end the seismic movement being
damped.

The structure rigidity and the damping possibility gradually increase proportional to the
deformations, increasing the resistance capacity of the entire structural assembly to the seismic action.

Insulating systems that use the composition of dissipative and insulating actions can be used
successfully to ensure earthquake protection for different structures types, rigid or flexible and for any
type of earthquake action (surface, intermediate or deep), using appropriate methods to each case.

It can be achieved the proposed objective, namely isolation from seismic motion for all stress
states, or seismic energy dissipation and obtaining finally the structural system response limitation to
seismic actions.

Figure 9. Schematically representation of a seismic insulated bridge structure with composed insulating system.

In figure 9 and 10 are presented the schematically and three-dimensional model of bridge structure
endowed with hybrid seismic insulation system composed of elastomers and sliding supports.

Figure 10. Composed insulating system mounted at bridge structure (3D model) [10].

The sliding isolation system works on the simple pendulum operation principle. When the seismic
motion occurs, the spherical articulated part moves along the concave surface and the structure
performs a simple harmonic motion.

Similar to the simple pendulum, the supports can increase the structure vibration natural period,
allowing the structure to slide along the concave support surface.

The sliding joint surface in contact with the spherical surface is lined with a composite material
with a low friction coefficient (usually Teflon) used in combination with steel. The supports are closed
and sealed to avoid contamination of the sliding surface.
Figure 11. Sliding support on the concave surface.

The elastomeric system acts in addition to the sliding bearing action, providing an additional movement reserve, which may be required for seismic actions of higher intensity.

The composite system acts as a safety system, activated only if the shear force appearing on the sliding surface is greater than the static friction force.

Once in motion, the sliding joint moves on the spherical surface, resulting in a mass lifting, combined with a horizontal displacement (figure 11), a pendulum similar movement.

The kinematic movement and operation mode of the support are identical, regardless of whether the main sliding surface is positioned face down or upwards.

The characteristics of sliding bearings combined with those of elastomeric systems, consisting of durability under severe environmental conditions, low weight and sensitivity to the earth frequency movements, make them a viable solution for the formation of a composite system that can provide better seismic insulation of bridge type structures, but also for not very tall buildings.

5. Experimental results for seismic motion on bridge structure

Experimental tests were performed using a scaled OSB bridge structure with dimensions \((L \times l \times h) = (2 \times 0.36 \times 0.017)\) m, insulated with elastomeric elements and friction pendulum bearings which use rolling spherical steel parts on the steel surface, where the coefficient of friction is 0.8, Coulomb friction without lubrication.

The bridge structure was loaded with a concentrated load (uniformly distributed) of 30 kgf, the seismic shock was modeled using a pendulum system with a constant mass of 1.135 kg and the possibility of adjusting the angle of fall and an excitation force of 400 N was applied to the structure.

The behavior of the insulating system is analyzed in terms of acceleration in time, acceleration amplitude function of frequency values and frequency in time with eigenvalues for the pier and superstructure for two main directions of movement longitudinal and transversal. The results are presented in figures 12 and 14 for the bridge pier and figures 13 and 15 for the bridge superstructure for both transversal and longitudinal main directions of movement.

The improved values obtained at the level of the superstructure as a result of the action of the composite insulating system are followed [9-22].
Figure 12. Pier longitudinal direction of movement
(a) acceleration–time; (b) acceleration amplitude-frequency.

Figure 13. Superstructure longitudinal direction
(a) acceleration–time; (b) acceleration amplitude-frequency.
Figure 14. Pier transversal direction of movement
(a) acceleration–time; (b) acceleration amplitude-frequency.

Figure 15. Superstructure transversal direction
(a) acceleration–time; (b) acceleration amplitude-frequency.
Based on the obtained results from experimental tests, the improved values for acceleration at the level of the insulated superstructure can be observed compared to the values obtained at the level of the support pier being emphasized the insulating and dissipative character of the composite protective system which is interposed between the two structural elements.

6. Conclusions
Theoretical aspects regarding the use of energy isolation and dissipation systems for installation in construction structures are presented in order to reduce the effects of seismic actions on construction structures.

In addition to the structure resistance structure that has the ability to preserve the integrity of the structural system to the arising demands base insulation systems are also used, but also energy dissipation systems to meet and avoid the destructive effects of seismic actions on bridge structures types.

The constructive solution for coupling the insulating system with sliding friction with the elastomeric type system is presented as the optimal solution to be applied to the bridge structures type.

By combining the effects of the two systems in the ensemble, an improved freedom of movement is provided for the foundations that act together with the ground, while the superstructure tends to remain as long as possible in the state of relative equilibrium, so that field efforts are no longer transmitted entirely in the vertical direction at the superstructure.

It represents an innovative method of coupling two isolation systems that can also ensure seismic energy dissipation at the same time, at the level of the isolation system.

The structural and functional analysis of the insulation systems against seismic actions, taking into account the isolation and energy dissipation effect is highlighting the range of specific advantages to each major category of insulator system.

Behavioural modelling and analysis in an intense and varied dynamic regime performed for each of the above-mentioned categories will highlight the specificity of the corresponding dissipative characteristics.

The results obtained from testing in this research stage provide the informational support necessary for the configuration and implementation of combined isolation system that present a series of advantages taken from each constituent element.

7. References

[1] Lupasteanu V, Soveja L, Lupasteanu R and Chingalata C 2019 Installation of a base isolation system made of friction pendulum sliding isolators in a historic masonry orthodox church
Engineering Structures 188 369-381.

[2] Avossa A M, Di Giacinto D, Malangone P and Rizzo F 2018 Seismic retrofit of a multi-span pre-stressed concrete girder bridge with friction pendulum devices
Shock and Vibration.

[3] Hong X, Guo W and Wang Z 2020 Seismic analysis of coupled high-speed train-bridge with the isolation of friction pendulum bearing
Advances in Civil Engineering.

[4] Cho C B, Kim Y J, Chin W J and Lee J Y 2020 Comparing rubber bearings and eradi-quake system for seismic isolation of bridges
Materials 13(22) 5247.

[5] Hassan A L and Billah A M 2020 Influence of ground motion duration and isolation bearings on the seismic response of base-isolated bridges
Engineering Structures 222 111129.

[6] Haeri A H, Badamchi K and Tajmir R H 2019 Proposing a new hybrid friction–yielding–elastomeric bearing
Journal of Vibration and Control 25(9) 1558-1571.

[7] Nuraini S, Tambusay A and Suprobo P 2018 A comparative study of base isolation devices in light rail transit structure featured with lead rubber bearing and friction pendulum system
In MATEC Web of Conferences 195, p. 02013 EDP Sciences.

[8] Narhare M M and Kasnale A 2017 A review of behaviour of building under earthquake with or without base isolation
Technology 5.
[9] Scheaua F D 2015 Description of a Composed Seismic Isolation System for Bridge Structures *Analele Universitatii “Eftimie Murgu” Resita** XXII**(2) ISSN 1453 – 7397.

[10] Scheaua F D 2013 Analiza comportarii sistemelor de disipare cu frecare uscata la actiuni dinamice PhD Thesis Dunarea de Jos University of Galati.

[11] Axinti G and Axinti A S 2009 *Actionari hidraulice si pneumatice* Vol III Editura Tehnica-Info, Chisinau.

[12] Scheaua F 2019 Modelling of the visco-elastic pendular hybrid system with dissipative rolling elements In *IOP Conference Series: Materials Science and Engineering* 591**(1)** p. 012029 IOP Publishing.

[13] Scheaua F 2020 Improvement of structures seismic response based on pendulum systems with double sliding surface In *IOP Conference Series: Materials Science and Engineering* 916**(1)** p 012102 IOP Publishing.

[14] Scheaua F D 2017 Special pattern of hydraulic dissipation system used for isolation of bridges against earthquakes *Analele Universitatii “Eftimie Murgu” Resita* 24**(1)**.

[15] Scheaua F 2014 Considerations on functional parameters of dry friction seismic isolation systems *Annals of “Dunarea de Jos” University of Galati* Fascicle XIV Mechanical Engineering 21**(1)** 67-70.

[16] Scheaua F 2011 Seismic base isolation of structures using friction pendulum bearings *Annals of “Dunarea de Jos” University of Galati* Fascicle XIV Mechanical Engineering 18**(1)** 61-64.

[17] Scheaua F 2021 Composed Isolation System Concept for Vibration Effects Mitigation on Bridge Structures. *In Acoustics and Vibration of Mechanical Structures AVMS* pp. 473-483 Springer, Cham.

[18] Scheaua F 2014 Functional aspects for antiseismic double sliding isolation systems *Annals of “Dunarea de Jos” University of Galati* Fascicle XIV Mechanical Engineering 21**(2)** 45-48.

[19] Scheaua F 2015 Results obtained from testing a hybrid model of vibration isolation system *Annals of “Dunarea de Jos” University of Galati* Fascicle XIV Mechanical Engineering 22**(2)** 41-44.

[20] Goanta A M and Haraga G 2017 Aspects of modelling classical or synchronous modelling with Solid Edge ST 9 In *MATEC Web of Conferences* 112 p. 06024 EDP Sciences.

[21] Goanta A M 2019 Modern annotate and export instruments in 3D pdf files *Journal of Industrial Design and Engineering Graphics* 14**(1)** 119-122.

[22] Goanta A M 2017 Aspects of obtaining orthogonal projections and intelligent indicators by inventor 2016 *Journal of Industrial Design & Engineering Graphics* 12**(1)**.

[23] Sanchez J, Masroor A, Mosqueda G and Ryan K 2013 Static and dynamic stability of elastomeric bearings for seismic protection of structures *Journal of structural engineering* 139**(7)** 1149-1159.