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An overview of seismic base isolation for bridges and the current status in Vietnam

Tổng quan về giải pháp gối cách chấn cho cầu và thực tiễn áp dụng tại Việt Nam

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ABSTRACT

Bridges are essential components of transportation systems that are important to the smooth operation of socioeconomic activities. With particular structural characteristics, bridges are particularly vulnerable to earthquakes putting them at high risk of sustained damage or total collapse when subjected to strong earthquakes. Seismic base isolation (SBI) is a relatively new and advanced seismic design technique that can greatly reduce the impacts of earthquakes on structures, especially for bridges located in seismically active regions. This paper presents an overview of the seismic base isolation technique, with the fundamental characteristics of typical devices. An overview of recent studies and the application of these devices in Vietnam is also conducted. The seismic performance of isolators for bridges in a typical earthquake area in Vietnam is preliminarily investigated based on an analysis of a simplified isolated-base bridge model. The obtained results allow for providing fundamental research products and a more in-depth and comprehensive understanding of the base isolation application for bridges, toward practical application in Vietnam.

Keywords: Bridge; seismic base isolation; isolated bridge; isolator; seismic-resistant design.

1. INTRODUCTION

Earthquake is one of the natural disasters that cause heavy losses in the economy, society, and life. Throughout history, many earthquakes have seriously destroyed infrastructures. Therefore, research, calculation, and design of structures that can survive the seismic effects are always one of the top fields.

Bridges are expensive but essential structures for the functioning of socioeconomic activities. The bridge structures are particularly vulnerable to lateral impacts due to specific characteristics including long spans and its mass being mainly concentrated at the upper deck level. This characteristic put bridge structures at high risk of damage or total collapse when subjected to strong earthquakes [1, 2]. The seismic-resistant design of bridges to ensure safety in earthquake events is crucial for the smooth operation of the economy and society. The conventional methods of seismic-resistant design for bridges (i.e., capacity-based design, performance-based design) are based on the principle of dimensioning in capacity, which consists of designing the structures at resistance levels lower than the elastic demands imposed by the design earthquake. In addition, these methods use the structural capacity to dissipate seismic energy through inelastic deformations in expected critical locations, which are crucial to the performance and survival of the structure. Nevertheless, the presence of inelastic deformations in the structural elements implies high damage levels under the effect of design earthquakes. Consequently, significant earthquakes typically result in some level of structural-functional loss, requiring inspection, reinforcement, and restoration.

Over the past fifty years, advanced seismic technologies have grown considerably in popularity. These technologies often use mechanical equipment incorporated into bridge structures to improve their seismic performance. Each of these technologies has its concept, which involves modifying one or more structural parameters of the equation of motion of the dynamic structure to reduce the seismic demand and/or improve the structural capacity. For the bridge-bearing application, these technologies can be classified into three categories: seismic absorbers, seismic shock transmitters, and SBI.

Before the 1980s, the use of SBI to reduce the response of structures subjected to seismic impacts was not regarded as a realistic approach and was met with large skepticism by the engineering community. After a slow start, the concept is gaining widespread acceptance [3]. The extent of this acceptance can be gauged by the large number of journal articles, technical reports, workshops, and symposia devoted to the topic. Seismic isolation is at the present time in a very active state of development. Many new systems are being explored and upgraded to be more applicable, especially elastomeric-based bearings. More specifically, SBI is a common technique used in bridge design to protect them from earthquake impacts. It is increasingly used in the seismic-resistant design of new structures and also renovation of existing bridge structures. This technique has gradually established itself as one of the most attractive alternatives to counter the effect of earthquakes on bridges [4, 5], not only in high-seismic-areas but also in moderate-seismic-regions.

In Vietnam, the application of SBI for bridges has been carried out for about ten years. However, most practical applications are designed according to foreign standards proposed by device suppliers. In-depth research on techniques and applications of this solution still has many shortcomings.

This paper presents an overview of the SBI application for bridges, serving as an essential basis for further research on this technique to apply to Vietnam. The SBI's fundamental principles are first outlined. The most widely used seismic isolators are then detailed along with their specific characteristics. The approximate nonlinear behavior of the SBI, which is commonly used in numerical analysis, is also presented. A comprehensive review of the status of research and application in Vietnam is thoroughly investigated. Finally, a preliminary analysis of the SBI performance for a typical bridge structure is carried out to investigate its effects and potential application in Vietnam.

2. THE PRINCIPLE OF SEISMIC BASE ISOLATION

The SBI technique consists of lengthening the fundamental periods of structures to move them away from the range of the dominant periods of earthquakes and thus reduce the seismic energy transmitted to the structure. To achieve this, SBIs must have low lateral stiffness to increase the lateral flexibility of the structure. This feature is considered the most important of SBIs.

On the other hand, for an isolated-base bridge, corresponding to the fundamental vibration mode in horizontal directions, the lateral deformation primarily occurs at the level of the seismic isolators rather than substructures. The rest of the structure above the isolators essentially moves in the manner of a rigid body. The seismic isolators absorb the majority of the energy transmitted to the structure while the remaining energy is stored in the elastic form, thus protecting the structural components from inelastic deformations. The integration of high-damping components into the SBI is then necessary, allowing most of the induced seismic energy to be dissipated within the isolator bearings rather than in the structure. As a result, adding damping generally reduces both the seismic force and displacement demand [6]. Figure *1* illustrates the principle of SBI and its effect on the bridge structure's seismic demand.

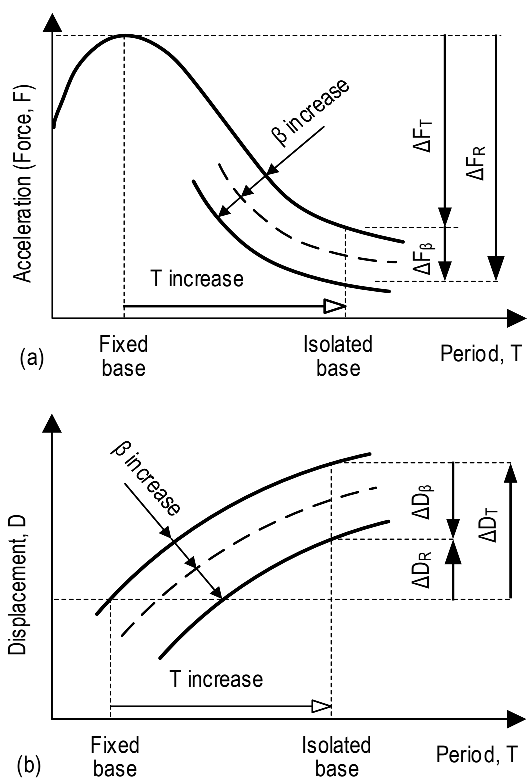


Figure 1. Effect of SBI on seismic response: (a) spectral acceleration; (b) lateral displacement [7]

Experience has shown that the forces induced by an earthquake in an isolated-base bridge can be reduced by a factor of five to twenty, even fifty times compared to those induced in the same fixed-base one [8]. This is attributed to its many undeniable advantages, including the significant reduction of seismic forces transmitted to the structure, making it possible to maintain an elastic behavior of the structural elements and minimize damage during earthquakes, preserve the functionality of the construction, and contribute to saving lives and to socio-economic resilience. In addition, it is possible to concentrate the demand for ductility and energy dissipation in the SBI, which is much easier to design and replace while maintaining the structural functions. By doing so, seismic damage to bridges can be reduced at relatively lower construction and maintenance costs. This constitutes a long-term advantage that consists in preserving the functionality of the structure during and immediately after an earthquake, etc., [4, 9, 10].

3. THE MAIN SYSTEMS AVAILABLE

Currently, there are several types of seismic isolators applied in the seismic-resistant design of bridges. The selection of the appropriate systems is critically based on characteristics of the structure, the seismic hazard, and the system's capacity to adapt to the specific requirements of each project. Most of the SBIs in use today can be classified into two main categories: elastomeric-based and friction-based systems.

3.1. Elastomeric-based seismic isolations

Among the common systems, elastomeric bearings are seen as a promising potential solution and are one of the most commonly used types of SBI.

In general, these systems are made up at the base of elastomer supports reinforced with steel plates and equipped with two steel plates allowing them to be anchored to the structure (see *Figure 2*). Steel plates and elastomer layers are manufactured with uniform thicknesses and bonded together (by vulcanization) so that the steel plates are fully bonded to the elastomer on all surfaces during molding.

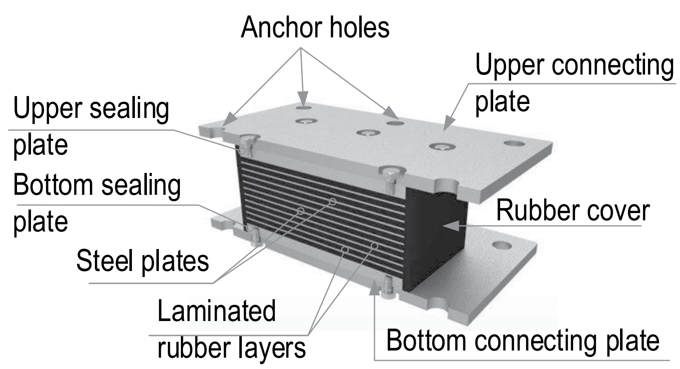


Figure 2. Typical elastomeric isolator [11]

The high lateral flexibility of the elastomer, working in shear, is the basis of the lateral displacement capacity of SBI. The presence of steel plates increases the lateral deformation capacity of the bearing without affecting its vertical load-bearing capacity.

Currently, there are two main categories of elastomeric-based isolators, distinguished by the presence or absence of the lead core inside the system and on the mechanical characteristics of the elastomer: i) rubber bearing, itself distinguishing into two sub-categories: i.1) low damping rubber bearing and; i.2) high damping rubber bearing and; ii) lead-plug rubber bearing. The most commonly used elastomer is natural rubber.

3.1.1. Low-damping rubber bearing

The behavior of elastomer in shear is viscous and linear up to strains above 100% with low damping (3% - 7%) [10, 12-14].

The advantages of the low-damping rubber bearing are: easy to manufacture, easy to model, and their mechanical response is unaffected by speed, temperature, history, or aging. In addition, according to Naeim and M. Kelly [10], the elastomer is not very sensitive to creep when sheared at strain levels below 150%. On the other hand, it has good long-term stability of its compressibility and shear modulus. *Figure 3* shows a prototype natural rubber isolator and the hysteresis curves obtained during laboratory tests.

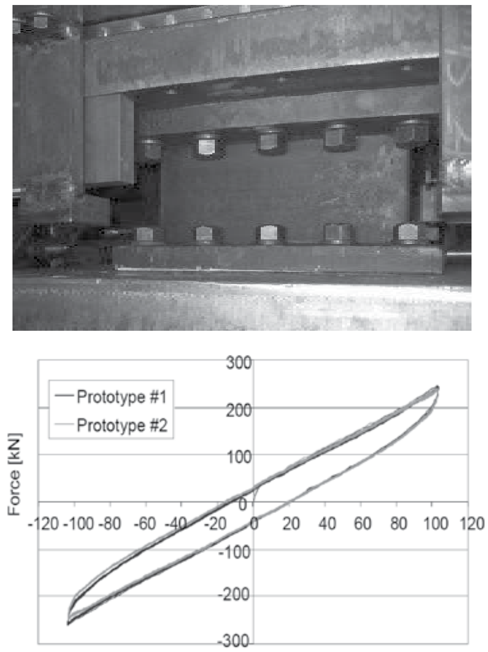


Figure 3. Natural rubber bearing and the hysteresis behavior at ambient temperature [15]

The main limitation of these bearings for more widespread application is their low damping capacity - an essential feature to limit seismic displacement, especially in seismic zones with rich low-frequency signals [16, 17]. Attempts to improve these bearings have led to the development of high-damping rubber bearings (HDRB).

3.1.2. High Damping Rubber Bearing

The development of a natural rubber compound with enough inherent damping to eliminate the need for supplementary damping elements was achieved in 1982 by the Malaysian Rubber Producer's Research Association of the United Kingdom [10]. The elastomer used is obtained using a special formulation to have a higher energy dissipation capacity than the standard one, through its hysteretic properties. The damping ratio is increased to levels between 10% to 20% at 100% shear strains [10, 14, 18]. During the earthquake, the HDRB will have an excellent seismic effect by producing large deformation and small rigidity.

The material behavior is nonlinear at shear strains around 15% and is characterized by higher stiffness and damping, which tends to minimize response under low-level seismic load. Over the range of 20% - 120% shear strain, the modulus is low and constant. At larger strains, the modulus increases due to a strain crystallization process in the rubber that is accompanied by an increase in energy dissipation. This increase in stiffness and damping at large strains can be exploited to produce a system that is stiff for small input, is fairly linear and flexible at design level input, and can limit displacements under unanticipated input levels that exceed design levels. The HDRB utilizing this principle generates excellent seismic isolation function.

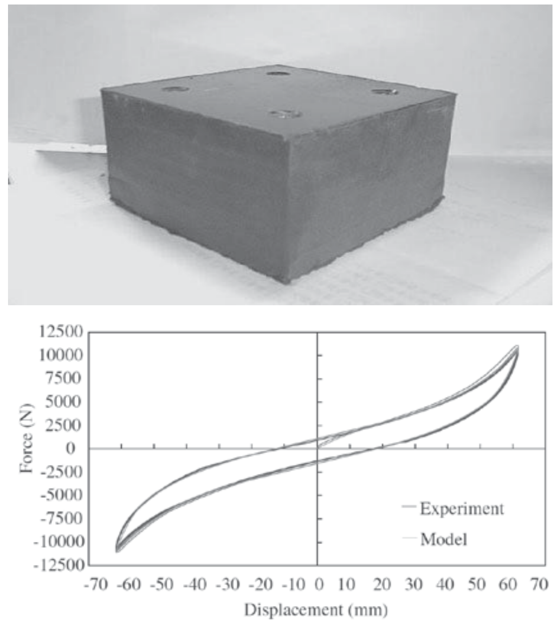


Figure 4. High-damping rubber bearing and hysteresis behavior [18]

Nevertheless, this type of bearing is very sensitive to low temperatures and is subjected to the scragging, which considerably reduces its effectiveness, especially in cold regions. Therefore, the development of other options and alternatives for improving the performance of ordinary natural rubber strapped bearings for use as simple seismic isolators in cold regions is still very timely.

3.1.3. Lead-plug rubber bearing

The lead-plug rubber bearing (LRB) was invented in New Zealand and has been used extensively worldwide. It is a laminated rubber bearing similar to the low-damping rubber bearing but contains one or more lead plugs that are inserted into pre-formed holes. In addition, these plugs are sized so that they are an interference fit after installation.

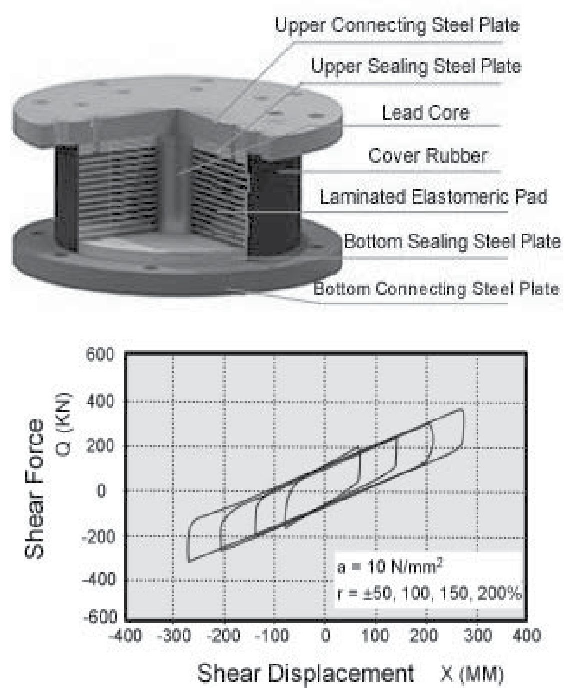


Figure 5. Hysteresis behavior of a lead-plug rubber bearing [19]

The steel reinforcing plates provide confinement to the lead cores, vertical stiffness, and load capacity. The lead cores provide resistance to wind induces and vehicle braking forces to minimize the movement of the structure under service loads and also provide yield and energy dissipation under earthquakes. The steel plates in the process of being subjected to earthquakes lead to the shear deformation of the plugs. The lead core, which is well confined by the elastomers, deforms in shear according to an almost perfectly elastoplastic behavior [20]. Its seismic energy dissipation efficiency is considered the most significant contribution of the lead core, greatly increasing the damping ratio. These devices can easily achieve damping ratios of up to 30% [4, 10, 17]. Further, creep in the lead plug permits slowly applied environmental movements to be accommodated with minimal effect on the substructures. Figure 5 shows prototype elastomer isolators with a lead plug and the hysteresis curves [21].

In general, elastomer-based isolation systems have many advantages, in particular their economic advantages due to the ease of their manufacture, installation, and maintenance. They allow both to control two main characteristics of a seismic isolation system, namely: energy dissipation and lateral flexibility. Nevertheless, these systems have some disadvantages, including: their sensitivity to low temperatures, aging, loading history, and their large dimensions in the presence of high vertical loads [4, 12, 22]. Another disadvantage that can be cited for the lead core system is its potential for environmental lead pollution. Finally, the stability under vertical loads and lateral deformations of these systems is a concern since the vertical capacity of the bearing decreases when it deforms laterally.

3.2. Friction-based isolations

These systems use a sliding interface to allow lateral movements. Materials used for the sliding interface are typically austenitic stainless steel in contact with unfilled or filled Polytetrafluoroethylene (PTFE or Teflon). Contemporary sliding seismic isolations may take a variety of forms. Generally, the frictional characteristics of this system are dependent on temperature, velocity, degree of wear, and cleanliness of the surface.

3.2.1. Friction Pendulum System

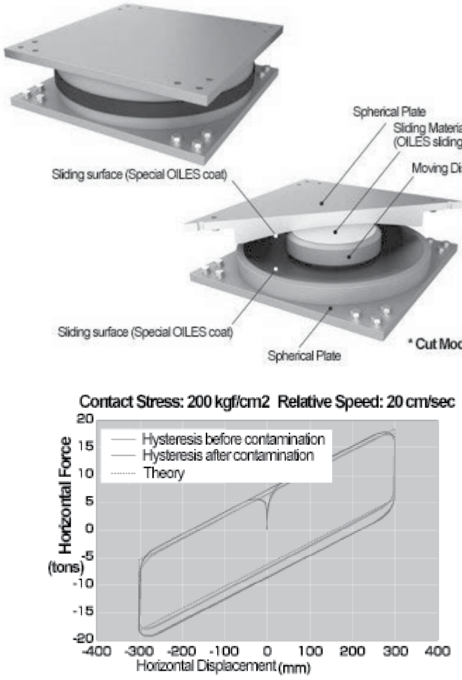


Figure 6. Typical device and hysteresis behavior of FPS [23]

One of the most widely used friction-based isolators is the friction pendulum system (FPS). The FPS is made up of two plates, facing each other, undergoing a normal controlled confinement force. They make it possible to decouple the movements of the superstructure from the foundation unit using a sliding interface articulated between them as illustrated in *Figure 6*. In the FPS, the contact surface is spherical and concave, allowing the centering of the support, and the system works like a pendulum. The radius of curvature of the surface controls the period of the pendulum while the coefficient of friction of the sliding interface controls the damping of the system.

3.2.2. System based on confined-elastomer

There are other SBIs using the principle of sliding along an interface like the Izolatech system (ZTS). This system is illustrated in *Figure 7*, which was developed by Goodco_Z-Tech (2017). It is composed of a confined-elastomer support fitted with a sliding interface and steel coil springs for restoring. With a confined-elastomer disc, this system can withstand higher vertical loads in a more compact space than elastomer-based systems.

Springs provide elastic behavior and control the post-elastic stiffness. The sliding interface is made of stainless steel – Teflon and controls the energy dissipated [24]. Slide-based systems exhibit good stability under vertical loads since there is a decoupling between the horizontal movement and the vertical bearing capacity. In other words, the vertical capacity is not affected by the lateral deformation of the bearing. They are also relatively easy to manufacture, install, and maintain. However, their characteristics are more difficult to vary over a wide range and are affected by several factors such as temperature, speed, contamination, wear, etc.

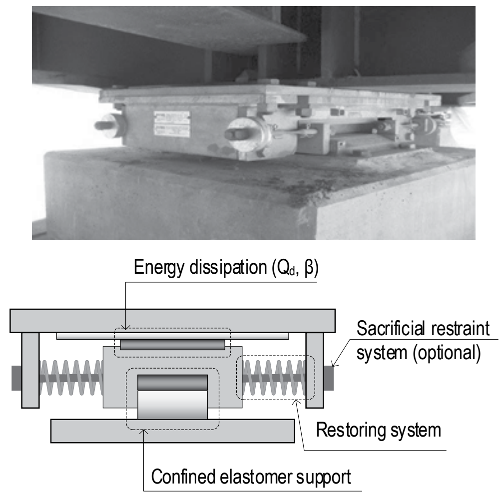


Figure 7. Confined-elastomer friction isolator system – Izolatech [24, 25]

3.2.3. Roll-N-Cage (RNC) Isolation System

The RNC (Roll-N-Cage) isolation system, as illustrated in *Figure 8*, is a system combining certain components specific to elastomer-based systems with others specific to sliding systems. It was first presented by Ismail, Rodellar [26] as a new system allowing isolation in three directions, incorporating all the necessary functions (resistance to non-seismic loads, horizontal flexibility with increased stability, good dissipation capacity of energy, a re-centering mechanism based on inherent gravity, fairly rigid vertical support).

The main mechanism of the RNC is a hollow elastomer cylinder with suitably designed thickness, around the rolling body. Based on its particular structure, the superstructure – substructure decoupling of the structure is achieved thanks to the rolling body (rolling/sliding interface). The vertical rigidity is assumed by the elastomer cylinder. The energy dissipation is achieved through elastomer components with additional necessary features such as metal rods (having a U-like shape) or lead bars incorporated into the cylinder. These metal rod dampers are designed and arranged around the rolling body to provide the damping and horizontal stiffness to withstand the minor vibrations desired. The re-centering mechanism is provided by the rolling body, analogous to the friction pendulum [26, 27].

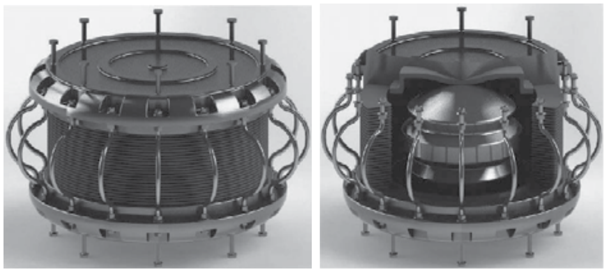


Figure 8. Roll-N-Cage (RNC) isolation system [27]

4. MODELING OF SEISMIC BASE ISOLATION

The main characteristics of SBI are the energy dissipation to control its lateral displacements and reduce the seismic force, the lateral flexibility under the earthquake impacts but the lateral rigidity under low load levels, and the resistance to vertical support under the gravity or live loads. These have to be considered along with the total structural mass, and with some relatively simple and common calculations for SDOF vibrations, the designer determines the constitutive parameters of the isolators and the new dynamic characteristics of the structure, to achieve the required increase in the period of vibration and the consequent reduction of the applied inertia force. Usually, a fundamental period of 2.0 sec or longer is expected in both horizontal directions, so that the system is most effective.

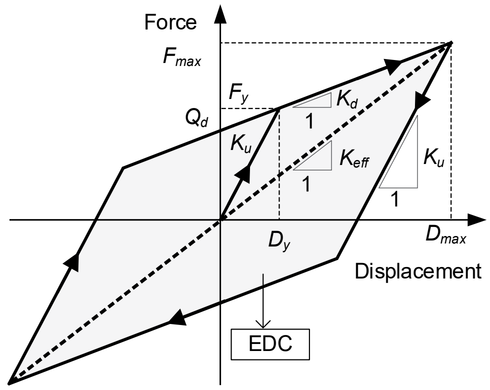
Considering that the isolation systems are almost nonlinear, an equivalent linear static analysis is commonly utilized in the preliminary design phase employing effective bearing properties, whilst the final design is usually performed with nonlinear time-history analysis using the exact dynamic and hysteretic characteristics of the isolators and the structural components [9, 28].

The force-displacement relationship of isolators is interdependent on several parameters and conditions, in particular the architecture and nature of the components of the system, the rate deformation, temperature conditions, level of internal loads/stresses, instantaneous velocity, loading history, the interaction of mechanical properties with increase in internal temperature, contamination and/or aging of components, etc., [4, 10, 12, 14, 18].

Several hysteretic models can represent the force-displacement relationship of SBIs with varying degrees of sophistication and complexity [4, 10, 29]. These models are selected based on the complexity of the structural analysis required, the level of precision desired, and the specific mechanical behavior. Among these, the nonlinear hysteretic models are the most complex but are also the ones that can the best and most faithfully represent the real behavior of certain systems, such as elastomer-based isolators with a stiffening of the material under large deformations [30]. However, such models are rarely used in practice due to the complexity of the calculations, not justified by the desired precision.

The bilinear model is nevertheless the simplest non-linear model and also the most widely used for the analysis of isolated bridges, making it possible to capture the essence of the behavior of the most common isolators. The viscoelastic model is an equivalent linear model, based on the bilinear model, used in linear analyses, such as spectral analyses [4, 10, 13, 24, 31]. These two models are also adopted as base design codes and implicitly recognized as being sufficiently reliable and accurate for seismic base isolation systems [9, 28, 32].

The bilinear model of the force-displacement relationship is considered an idealized general theoretical behavior for typical SBIs. This behavior model with main parameters and characteristics are defined in *Figure 9*. It is the simplest model used for nonlinear temporal analyzes where the level of deformations is very variable [4, 9, 10, 28, 32].



The constitutive parameters

- Characteristic strength, Q_d
- Initial elastic stiffness, K_u
- Post-elastic stiffness, K_d
- Elastic limit, $F_y = Q_d.K_u / (K_u - K_d)$
- Force maximum:
  $F_{max} = Q_d + K_d.D_{max} = K_{eff}.D_{max}$
- Energy dissipated per circle:
  $EDC = 4Q_d.[D_{max} - Q_d / (K_u - K_d)]$
- Equivalent damping ratio:
  $\beta_{eff} = EDC/(2p.K_{eff}.D^2_{max})$

Figure 9. Bilinear hysteresis model applied for isolators

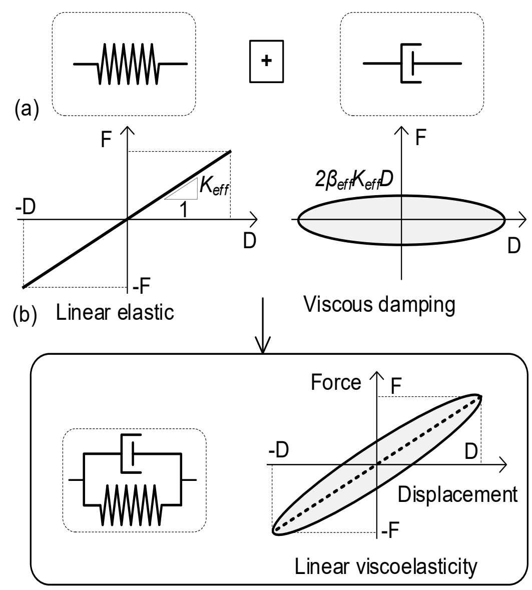


Figure 10. Linear viscoelastic model: (a) diagrams; (b) component behavior

For this model, the initial elastic stiffness, K_u, is typically a very high value, as the displacement at the yield point, D_y, is typically 0 to a few millimeters. This characteristic has a secondary importance on the system's behavior in earthquakes and its main role consists in ensuring the initial rigidity of the system, under the non-seismic loads. The initial characteristic strength, Q_d, and the post-elastic stiffness, K_d, are the most important system characteristics affecting its efficiencies as well as the performance of structures under large earthquakes [4, 10, 32].

For the needs of elastic seismic analyses, such as unimodal or multi-modal spectral analysis, this behavior can approximately be represented by an equivalent linear viscoelastic model. Specifically, the linear viscoelastic model is a combination of an elastic spring and a viscous damper, mounted in parallel, and is illustrated in *Figure 10*. It is defined by the effective stiffness, K_{eff}, (of the linear spring), and the equivalent viscous damping ratio, β_{eff}, (of the damper), evaluated at the design displacement.

Generally, effective parameters are approximately determined at the expected peak responses and the constitutive parameters of the bilinear model, as follows:

$$K_{eff} = \frac{F_{\max}}{D_{\max}} = \frac{Q_d}{D_{\max}} + K_d \quad (1)$$

$$\beta_{eff} = \frac{4Q_d\left(D_{\max} - D_y\right)}{2\pi K_{eff} D_{\max}^2} \quad (2)$$

Accordingly, the energy dissipated per circle is dependent on the maximum displacement, while the expected displacement is unknown and shall be matched the design spectrum, damping ratio, and the bilinear behavior. Therefore, an iterative procedure is usually employed to estimate these effective parameters and the seismic demands of isolated bridges [4, 33].

5.CURRENT STATUS IN VIETNAM

Vietnam situates in a region with significant earthquake risk and many active faults [34, 35]. Large-magnitude earthquakes have occurred in northern Vietnam in the past and will inevitably occur in the future, along with seismic activities in neighboring countries that significantly affect the infrastructures in general and the bridge structures in particular.

Research on SBIs has been mentioned, conducted, and promoted over the past twenty years. Many publications have mentioned seismic isolation as an effective solution for seismic-resistant design of constructions [36].

Recently, some authors have strongly promoted research on SBI. Le Xuan Tung [37] established differential equations of motion to investigate the behavior of SBI subjected to earthquakes in the vertical and horizontal directions. In this paper, the author focuses on studying the FPSs, the results showed that the devices offer a great seismic performance that significantly reduces the shear force in the structure. However, the influence of seismic properties and the optimal characteristics of SBI have not been mentioned.

Nguyen Anh Dung et al. focused on the application of HDRB for highway bridges and buildings [29, 38, 39]. In these publications, the authors studied the nonlinear behavior of HDRBs applied to structures located in strong earthquake regions. The authors also proposed using the rheology model for modeling the high damping rubber bearing [29, 38]. The effects of different temperature conditions on behavior and efficiency of the device were conducted [29].

Ngo Van Thuyet et al. studied the application of SBI in the seismic-resistant design of buildings, focusing on non-bonded fiber-reinforced elastomeric bearings [40-42]. In these studies, the authors are mainly interested in the detailed structure of the bearing and the determination of constitutive parameters of the device for numerical modeling.

Some research on SBI was also conducted by other authors such as Hoang Phuong Hoa [43, 44], Nguyen Hoang Quoc [45], etc. Most of them focus only on considering the principle of operation and the efficiency of the devices as seismic-resistant design solutions for structure.

Always within the framework of SBI studies, the results on the application of these devices for building structures have been carried out in some typical publications of Nguyen Xuan Dai et al. [7, 46]. Accordingly, in isolated building structures, the deformation due to the effect of ground motions occurs mainly in the SBI instead of structural components, resulting in a significant reduction of the force and displacement of the structural responses. Therefore, the seismic resistance of the structures is greatly improved.

In addition, Nguyen Xuan Dai et al. [47] have evaluated the applicability of SBI for bridges located in specific seismic regions of Northern Vietnam through numerical analyses of simplified models of a single-degree-of-freedom system. The findings showed that the efficiency of the SBI application depends on the flexibility of the bridge substructure and this technique should not be applied to non-isolated bridges with a long fundamental vibration period (longer than 1 s) in earthquake regions of Vietnam. The post-elastic stiffness K_d of SBI is considered a key factor in preventing the residual displacement of isolated bridges, while the other seismic responses may be controlled by appropriate values of SBI characteristic strength Q_d. In addition, the obtained results also suggested that the SBI with the ratio of $K_d/K_u > 0.05$ and $Q_d/W \le 0.05$ will be more suitable for bridges located in seismic regions of Northern Vietnam. These preliminary favorable findings create a great drive for research to further investigate and improve the results achieved, towards practical application for bridge in Vietnam.

Despite that, bridge structures in Vietnam are still commonly designed to resist earthquakes according to structural solutions. Although there are a number of companies in Vietnam that have the capacity to manufacture seismic bearings, such as: Vinh Hung JSC (https://vinhhungjsc.com/), Kawakin Core – Tech (https://kawakinct.co.jp/en/), etc. However, the number of bridges applying the SBI technique is quite limited. Some typical recent projects have used seismic bearings for bridges such as Cam Lo – La Son expressway (150 elastomeric bearings), the My Thuan 2 bridge (12 elastomeric bearings), the Bach Dang bridge (04 friction pendulum bearings, 12 elastomeric bearings). However, most of these devices are designed employed foreign design standards. Therefore, the research on SBI is always topical to provide fundamental research products and a more in-depth and comprehensive understanding of the SBI application for bridges, contributing to the implementation of the construction and sustainable development plan.

6.PRELIMINARY INVESTIGATION OF THE SBI PERFORMANCE FOR BRIDGES IN VIETNAM

Based on the above overview and discussion, in this section, the authors conduct a simple parametric study to investigate the performance of SBI for bridges in a typical earthquake region in Vietnam allows providing a scientific basis to evaluate the potential application to bridges in Vietnam.

It allows to approximate that the bridge superstructure is a horizontal rigid diaphragm, all the isolators therefore experience the same displacement. Their properties can be lumped into a unique equivalent isolator. A lumped mass represents the mass of the superstructure. Accordingly, a typical simplified model of isolated bridge is performed as illustrated in *Figure 11*. In fact, this simplified model was specified in many seismic-resistant design standards. Further, studies have shown that the simplified model ensures the necessary reliability [31, 33, 46], especially in the framework of the preliminary investigation.

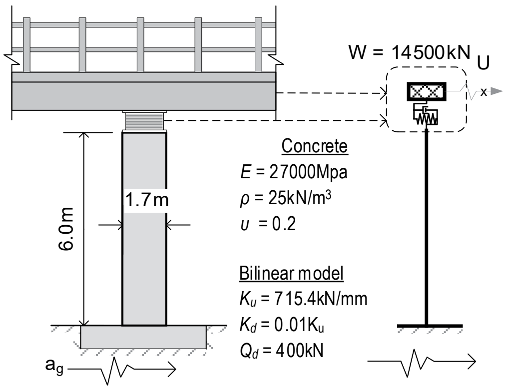


Figure 11. Typical model of isolated-bridge

The bridge is located in Son La, supported on soil class II (according to TCVN 11823:2017) and 5% damping. To perform nonlinear time-history analysis, the ground motion record of the Kobe earthquake is selected and scaled by the linear scaling method [48] to match the target spectrum. The time-history acceleration, the spectral ground motion, and the elastic response spectrum of location are plotted in Figure 12.

Figure 13 shows the history responses of bridge with and without SBI. As shown, even the use of SBI increases the drift of the superstructure, the base shear force and the displacement in the pier are significantly reduced when compared to the fixed-base structures. Namely, for fixed-base bridge, the peak responses of displacement and shear force of the pier structure is D_{max_p} = 59mm, F_{max} = 31296kN, respectively. Meanwhile, for the isolated-base bridge, the responses are D_{max_p} = 3.6mm (93.89% reduction), F_{max} = 1893kN (93.95% reduction). The maximum displacement of superstructure of the isolated bridge: D_{max_sup} = 206.15mm.

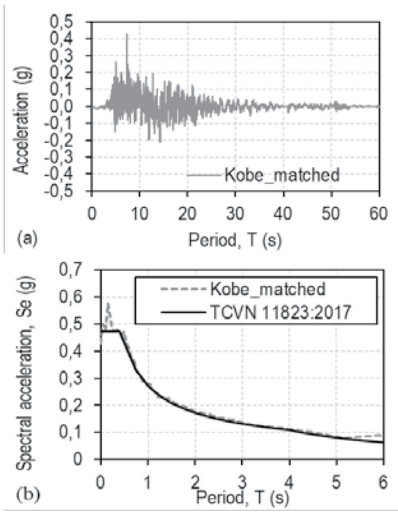


Figure 12. The ground motion used for analysis

In the case that the linear viscoelastic model is employed, the iterative procedure is performed on a simplified model using a response spectrum determined according to TCVN 11823:2017. The predicted responses of isolated-bridge and effective parameters of isolator are obtained as follows:

D_{max_sup} = 198.57mm, K_{eff} = 9.5624 kN/mm, β_{eff} = 13.37%

The history responses of the nonlinear and linear analysis are presented in Figure 14. Accordingly, the difference in peak value responses between the two models is not significant. Specifically, the results predicted by the viscoelastic model are slightly larger than those of the bilinear model, but at an acceptable level in calculations.

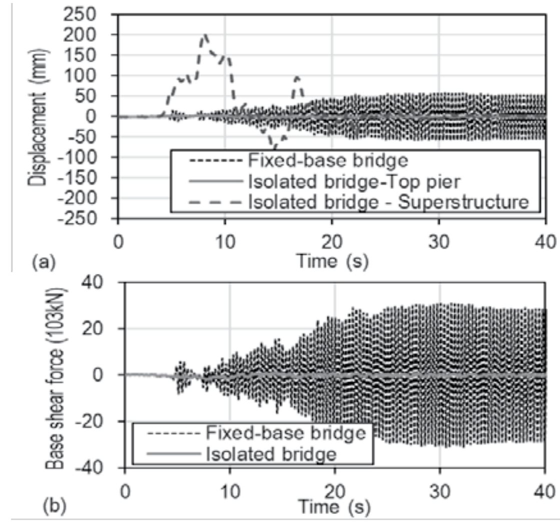


Figure 13. Time-history response of bridges subjected to scaled Kobe earthquake

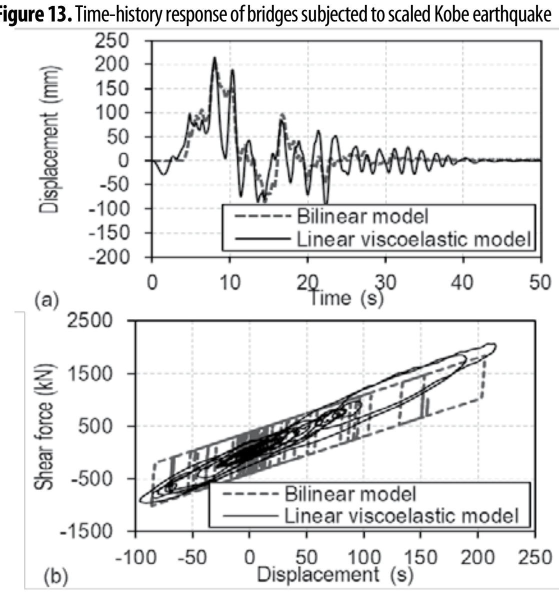


Figure 14. Nonlinear behavior of the isolator

7.CONCLUSION AND PERSPECTIVES

Although the concepts were created relatively early, SBIs have recently been the focus of extensive research and widespread implementation over the past few decades. Numerous investigations and research projects have been conducted, leading to the development of numerous methodologies for SBIs. A summary of significant features of SBI for bridges is offered in this paper, along with a discussion of current isolation approaches. A preliminary study investigating the current status and potential application of SBI for bridges in Vietnam was also carried out. The following is a summary of the study's major findings:

- The isolation techniques are increasingly used and high effective in controlling earthquake effects, mitigating the transmitted energy, and controlling the relative displacement in acceptable ranges.
- There are many different types of SBI that have been developed and applied in practice. The most important features of these devices include high lateral stiffness under low-level impacts to ensure the stability of the structure; low lateral stiffness under the strong earthquake to ensure the essential high flexibility; great energy dissipation capacity to control the lateral displacement and to reduce lateral force.

- The seismic behavior of isolators is generally nonlinear which can be approximated as a bilinear model. The hysteresis loop's area represents the energy dissipated per circle of vibration of the structure.

- The application of SBI for bridges helps to effectively reduce the internal force and displacement of the substructure, but the drift of the superstructure needs to be carefully controlled.

- The majority of SBI were developed primarily for high-seismic-areas, where high seismic performance devices are frequently required. For bridges in moderate-seismic-areas (such as Vietnam), the SBI approach is still necessary and deserves due attention.

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