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Influence of seismic isolation system on bridge responses
Influencia del sistema de aislación sísmica en la respuesta de los puentes

Kaoutar Zellat[1]*, Tahar Kadri*

* University of Mostaganem, Mostaganem. ALGERIA

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Abstract

The purpose of an isolation system is to provide an additional means of energy dissipation, thereby reducing the transmitted acceleration into the superstructure. In order to demonstrate the effectiveness of seismic isolation and understand the behavior of seismically isolated bridges a three-span continuous deck bridge made of reinforced concrete is considered. The bridge is modeled as a discrete model and the relative displacements of the isolation bearing are crucial from the design point of view of isolation system and separation joints at the abutment level. The systems presented here are passive control systems and the results of some important experimental tests are also included. The results show that the base shear in the piers is significantly reduced for the isolated system as compared to the non isolated system in the both directions of the bridge. This indicates that the isolation systems are effective in reducing the earthquake response of the bridge.

Keywords: *Base isolation, bridge, seismic technologies*

Resumen

El objetivo de un sistema de aislación sísmica es proporcionar medios adicionales de disipación de la energía, reduciendo así la aceleración transmitida hacia una superestructura. Con la finalidad de demostrar la efectividad de la aislación sísmica y comprender el comportamiento de los puentes con aislación sísmica, se consideró un puente de tablero continuo de tres tramos construidos en hormigón armado. Se modeló el puente como un modelo discreto y los desplazamientos relativos del aislador sísmico son cruciales desde el punto de vista del sistema de aislación y juntas de separación a nivel del estribo. Aquí, se presentan los sistemas de control pasivo incluyendo los resultados de algunos importantes ensayos experimentales.

Palabras clave: *Aislación de base, puente, tecnologías sísmicas*

1. Introduction

Seismic isolation systems are used during the last two decades to improve the seismic performance of bridges and reduce the damages degree by absorbing a significant quantity of the energy induced by earthquake and transmitted to the structure. Figure 1 shows a typical isolated multi-span continuous deck bridge in which special isolation devices are used in place of conventional bridge bearings.

These bearings protect the substructure by restricting the transmission of horizontal acceleration and dissipating the seismic energy through damping. Considerable efforts have been made in the past two decades to develop improved seismic isolation design procedure for new bridges and retrofit guidelines for existing bridges. The suitability of a particular arrangement and type of isolation system will depend on many factors including the span, number of continuous spans, and seismicity of the region, frequencies of vibration of the relatively severe components of the earthquake, maintenance and replacement facilities.

A comparative study on seismically isolated bridges against earthquake excitation is presented herein. The study briefly covers the dynamic characteristics of base isolation devices as such, but puts most emphasis on the time variation of base shear and bearing displacement in order to understand the behavior of seismically isolated bridges with a comparison between isolated and non isolated bridges.

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[1] *Corresponding author:*

Doctorate Student, Materials and Construction Procedures Laboratory of Civil Engineering Department, Mostaganem, Algeria
E-mail: kouky88@hotmail.fr

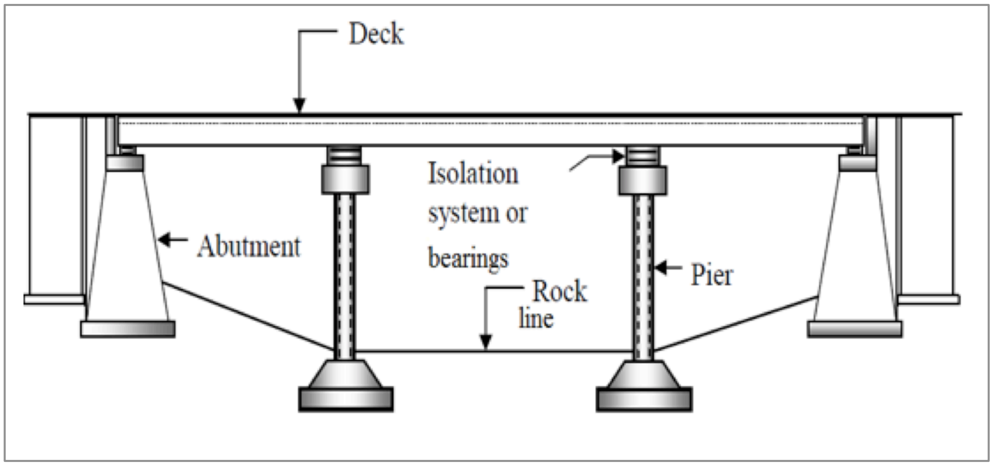


Figure 1. *Seismically isolated bridge*

2. Equation of motion in terms of energy

The equation of motion for an isolated structure in terms of displacements is given as in (1):

$$M\ddot{x}(t)+C\dot{x}(t)+Kx(t)=-Mr\ddot{x}_g(t) \qquad (1)$$

Where M is the mass matrix, C is the matrix of the damping constant and K is the stiffness matrix. Integration with regard to the movement of Equation (1) which represents the motion in terms of strength, gives us the equation of dynamic equilibrium in terms of energy given as follows:

$$\int_0^t [dx(t)]^T M\ddot{x}(t)+\int_0^t [dx(t)]^T C\dot{x}(t)+\int_0^t [dx(t)]^T Kx(t)=-\int_0^t [dx(t)]^T Mr\ddot{x}_g(t)$$
$$E_K(t)+E_D(t)+E_S(t)+E_H(t)=E_I(t) \qquad (2)$$

With:
$E_I(t)$ = input energy of seism.
$E_K(t)$ = kinetic energy.
$E_D(t)$ = energy dissipated by structural damping.
$E_S(t)$ = stored potential energy.
$E_H(t)$ = energy dissipated by the hysteretic behavior of the damping of the isolation

3 The LRB isolation system behavior

The isolation system LRB lead rubber bearing is composed of alternate layers of rubber and steel related the ones to the others around a pure lead core, inserted into the center of these layers of steel and rubber. The lead cylinder controls the lateral displacements of the structure and absorbs a part of the seismic energy. The plastic of the lead core confers to this device an important hysteretic behavior. This hysteretic behavior can be represented by the bilinear approximation illustrated in the Figure 2.

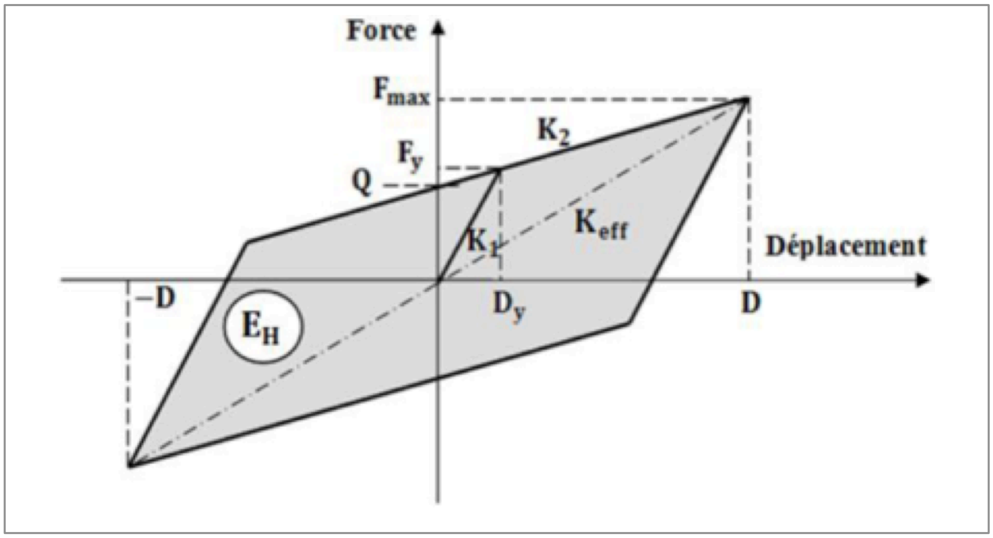


Figure 2. *Bilinear approximation of a hysteretic law behavior expressed in force-displacement*

The parameters of the bilinear approximation expressing the law of hysteretic behavior are the following:
D_y: the yield displacement with:

$$D_y = Q/(K_1 - K_2) \tag{3}$$

D: The design displacement of lead rubber bearing LRB
E_H: Energy dissipated by cycle corresponding to the design displacement, equal to the total area of hysteresis loop, it is given by the following formula:

$$E_H = 4Q(D - K_y) \tag{4}$$

F_y: The yield force in a monotonous loading
Q: The force, corresponding to null displacement during a cyclic loading, represents also the characteristic strength and the yield force of lead bar for the LRB,

$$Q = F_y - K_2 D_y \tag{5}$$

F_{max}: The maximum shear force corresponding to the design displacement D
K_1: Elastic stiffness for a monotonous loading also equals to the stiffness of unloading in cyclic loading, with:

$$K_1 = F_y / - D_y \tag{6}$$

K_2: The post elastic stiffness, with:

$$K_2 = (F_{max} - F_y)/(D - D_y) \tag{7}$$

K_{eff}: The effective stiffness of the LRB, it is given by the following formula:

$$K_{eff} = K_2 + \frac{Q}{D} \qquad D \geq D_y \tag{8}$$

B_{ef}: The effective damping factor of the seismic base isolation system, it is expressed as follows:

$$\beta_{eff} = \frac{4Q\ (D - D_y)}{2\pi K_{eff} D^2} \tag{9}$$

4. Description of the isolated bridge and the seismic excitation

In order to demonstrate the effectiveness of seismic isolation a three-span continuous deck bridge made of reinforced concrete is considered. The properties of the bridge deck and piers are given in Table 1.

These properties correspond to the bridge studied by Wang et al. (1998) using a sliding isolation system. The bridge is modeled as shown in Figure 3 as a discrete model. The fundamental time period of the piers is about 0.1 sec and the corresponding time period of the non-isolated bridge works out to be 0.5 sec in both longitudinal and transverse directions. The damping in the deck and piers is taken as 5% of the critical in all modes of vibration. In addition, the number of elements considered in the bridge deck and piers are 10 and 5, respectively. Response quantities of interest for the bridge system under consideration (in both longitudinal and transverse directions) are the base shear in the piers and the relative displacement of the elastomeric bearings at the abutment. The pier base shear is directly proportional to the forces exerted in the bridge system due to earthquake ground motion. On the other hand, the relative displacements of the isolation bearing are crucial from the design point of view of isolation system and separation joints at the abutment level.

Table 1. *Properties of the bridge deck and piers*

Properties	**Deck**	**Piers**
Cross-sectional area (*m²*)	3.57	4.09
Moment of inertia as (*m⁴*)	2.08	0.64
Young's modules of elasticity (*m²*)	20.67×109	20.67×109
Mass density (*kg/m³*)	2.4×103	2.4×103
Length/height (*m*)	3×30 = 90	8

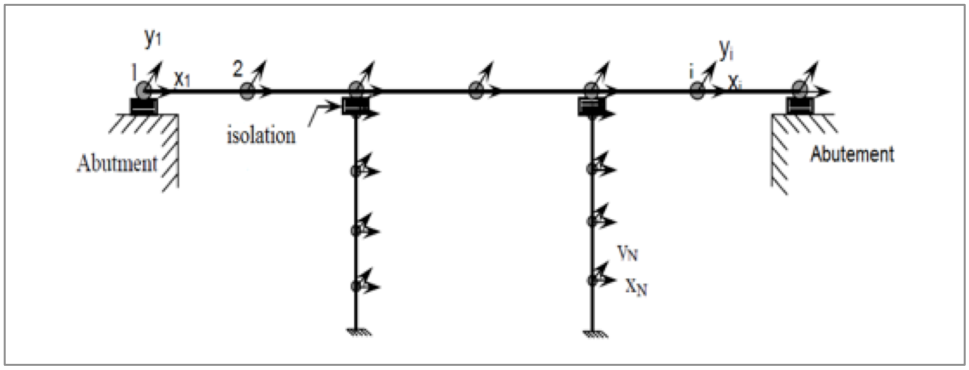
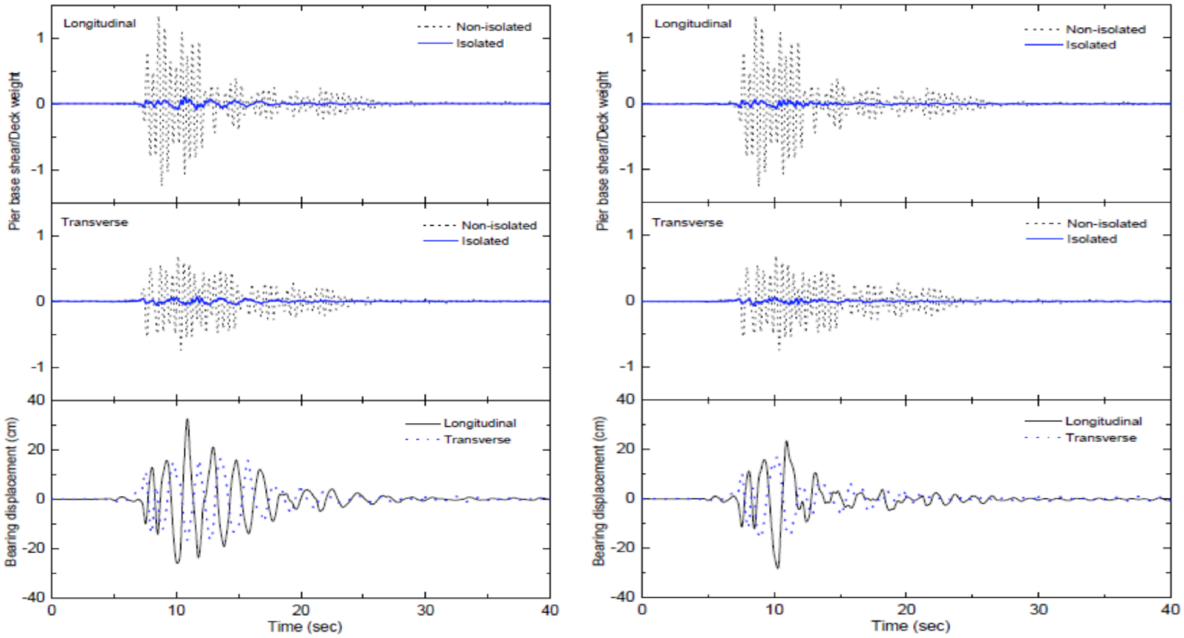


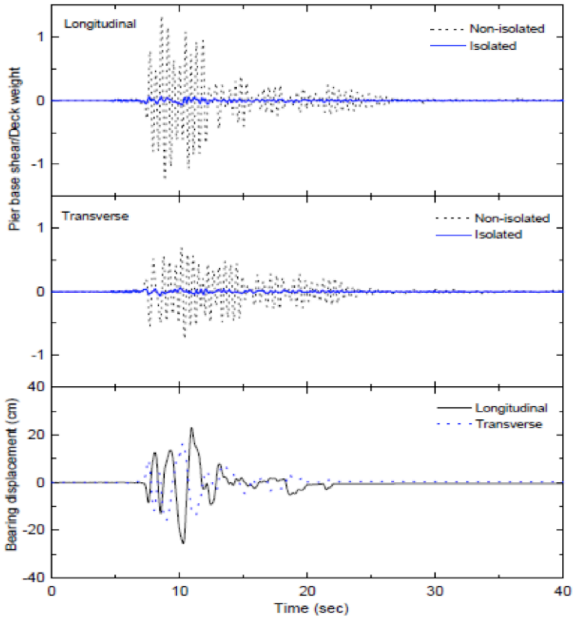
Figure 3. *Mathematical modeling of isolated bridges*

5 Results and discussion

Figures 4a, 4b and 4c, the time variation of the base shear in the pier and relative displacement of the bearings of the bridge isolated by the LRB, N-Z and FPS is shown. The LRB system is designed to provide isolation period of 2 sec (based on rigid deck and pier condition) and 10 percent damping ratio. The isolation period for the N-Z and the FPS system is taken as 2.5 sec. The yield strength of the N-Z system is taken as 5 percent of deck weight and the friction coefficient of FPS system is considered as 0.05. The system is subjected to Kobe, 1995 earthquake ground motion in the longitudinal and transverse directions. The base shear in the piers is significantly reduced (about 80 to 90%) for the isolated system as compared to the non isolated system in the both directions of the bridge. This indicates that the isolation systems are quite effective in reducing the earthquake response of the bridge system. The maximum peak displacement of the bearing is 32.87, 27.65 and 31.50 for LRB, N-Z and FPS system, respectively in the longitudinal direction of the bridge.



(a) LRB isolation system -(b) Z isolation system



(c) FPS isolation system

Figure 4. *Time variation of base shear and bearing displacement of the bridge isolated by FPS system under Kobe 1995 earthquake motion*

6. Conclusions

This study shed light on recent and economical technique for bridge protection against several damages and collapse due to earthquake forces and the effectiveness evaluation of the seismic isolation in bridges construction which has led to the following conclusions:

- *Bridges damages during large earthquakes helped engineers to understand their seismic behavior and identify different pathologies and their causes.*
- *The designer needs to understand how different structural forms will behave in real earthquakes and detail the structure to account for this.*
- *New technologies particularly seismic isolation of bridges offer attractive alternative which allows economy realization at short and long extent. This discipline is further more supervised by codes and norms.*
- *The seismic protection is particularly complex: a large number of factors must be taken into account and their treatment must be highly accurate, but still changes as it tries to be even more efficient in preserving human life.*
- *Investigations of effectiveness of seismic isolation for skew bridges and bridges curved in plan and elevation.*
- *In spite of favorable conditions and research progress carried out during last years the number of new aseismic technologies in bridges domain is still restraint.*
- *Finally, random nature factors still existent so, it is impossible to achieve total security.*

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