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SEISMIC PROTECTION OF A REALISTIC BRIDGE STRUCTURE USING PASSIVE FRICTION DEVICES

BY

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Abstract. The application of passive control systems to bridge structures has been investigated in recent years to demonstrate the efficiency of these systems during exceptional natural events such as earthquakes. The paper proposes analytical models for the passive friction devices mounted between deck and piles in a realistic bridge structure subjected to severe earthquake motions. The models are analysed from numerical simulations point of view for seismic excitations. Comparison of the results from numerical simulations has been demonstrated the use efficiency of the friction devices to protect the bridge structure than in the case of unprotected structure.

Key words: structural control; earthquake engineering; seismic protection; passive control.

1. Introduction

Structural control has a long and successful history in civil engineering for mitigating dynamic hazards. The traditional approach to reduce vibrations due to the earthquake and wind loads is to design structures with sufficient strength and deformation capacity in a ductile manner. This approach, based on the ensuring of strength–ductility combination, provides the strong wind or

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*Corresponding author: *e-mail*: cristianpastia@yahoo.com seismic action as ultimate loads, accepting a certain number of structural or non-structural degradations.

In recent years it has been paid a considerable attention to new concepts of structural control including a large variety of techniques that can be defined in four classes: passive, active, hybrid and semi-active. From historical point of view, passive control techniques, such that base isolation and passive control devices, are the first of them implemented. A lot of researches have studied structures equipped with these passive devices and a lot of practical realizations have already implemented in many countries (Budescu *et al*., 2001; Housner *et al*., 2007; Luca & Pastia, 2009; Pastia, 2004).

From energetical point of view the passive control systems are divided into two classes:

a) *Base isolation*. Isolation dampers, such as elastomeric bearings or sliders (metal blocks), as well as isolation layers as fine sand or graphite material are introduced between the foundation and superstructure. Consequently, the *reducing of the input energy* of an earthquake in superstructure as well as the increasing of displacements across the isolation level is achieved due to the flexible decoupling between superstructure and foundation (Budescu *et al*., 2001). The most common adopted technique is the laminated rubber bearing with alternating layers of rubber and steel. The stiff steel plates provide lateral constrain of each rubber layer when the bearing is subjected to vertical load, but does not constrain the horizontal shearing deformation of the rubber layers. This produces a bearing that is very stiff in the vertical direction and very flexible in the horizontal direction. A base isolation system depends of natural frequencies of a structure in its design.

b) *Passive control devices*. The passive control devices generally *dissipate or absorb energy inputed to a structure*. The motion of the structure is utilized to produce a relative motion within the passive control devices, thereby the energy is dissipated. They may be also divided in two classes: energy dissipating devices, which are independent with respect to the natural frequencies of a structure for their design, and tuned or resonant devices, which are dependent of the natural frequencies. Most of dissipating devices known as friction damper, hysteretic damper, visco-elastic damper or fluid viscous damper operate on principles such as frictional sliding, phase transformation in metals, deformation of visco-elastic solids or fluid orificing. An exception of frequency-independent devices is the visco-elastic and fluid viscous dampers.

The second class includes tuned mass damper (TMD), tuned liquid damper (TLD), tuned liquid columns damper (TLCD), suspended pendulum mass damper, mass pump, and so on. TMD and TLD systems have been extensively studied from point of theoretical, numerical and experimental view to control mostly wind input vibrations. Generally, inertial mass is attached near the top, through a spring and a viscous damping mechanism (*e.g.* fluid damper or visco-elastic damper).

In what follows the seismic response of a bridge structure with passive friction devices is evaluated numerically. The analytical models used in the numerical study are based on an experimental test set-up that has been performed at ELSA (European Laboratory for Structural Assessment) (Pastia, 2004). The numerical simulation results show that the performance of passive friction device is quite effective.

2. Analytical Models

The bridge is a reinforced concrete structure and was designed for a realistic case (Fig. 1). The bridge structure consists of a 150 m three-span bridge modeled numerically with finite elements (Dorka *et al.*, 1998). In this case, the piles, the deck as well the elastomeric bearings were modeled with finite elements, working in elastic domain. Taking advantage of symmetry, only half of the bridge was simulated. Finally, the model is condensed to ten master nodes (black points shown in Fig.2), with twenty-degrees of freedom.

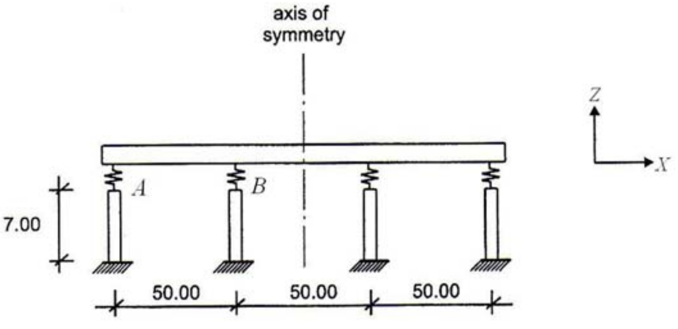

Fig. 1 – Real bridge structure.

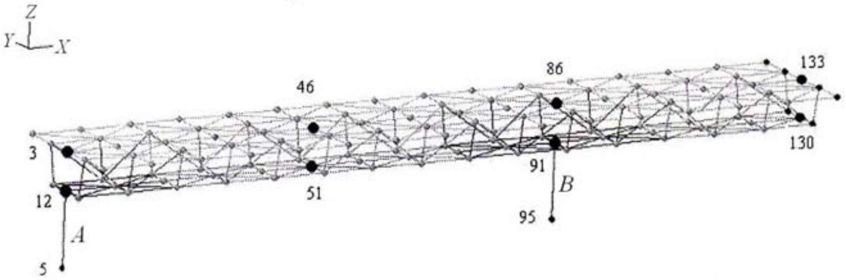

Fig. 2 – Model of the bridge structure with finite elements.

The passive friction device has been considered mounted between deck and piles.

The response of the structure will be analysed only for degrees-of-freedom in *Y*-direction because the system response in the other directions is insignificant.

Two configurations have been investigated (Fig. 3) as follows:

1. Configuration *A*. The device located between master nod 5 (DoF4) and master nod 12 (DoF6).

2. Configuration *B*. The device located between master nod 95 (DoF16) and master nod 91 (DoF14).

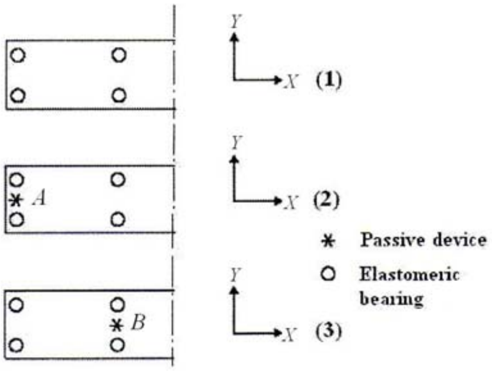

Fig. 3 – Location of passive friction device.

The behavior of the friction damper has been considered at the same with a controllable friction device that has tested at ELSA.

The controllable friction device utilizes the force generated by surface friction to dissipate energy. The friction system is made up of two steel plates and bronze inserts. The lower steel plate serves as guidance for the bronze inserts, while the top plate has a sand-blasted surface, which is in contact with the inserts and forms the sliding surface.

A pneumatic system with electronic control varies the pressure in order to change the friction force at the sliding surface. A control algorithm manipulates the air pressure of the gasket through a power source with a maximum voltage $U_{\max} = 8$ V. Under these conditions the interface exhibits essentially Coulomb type friction with a variable friction coefficient, μ, in the range of 0 to 0.45 at variable pressure of 0 to 8 bar.

The testing machine is composed by a hydraulic actuator with maximum force 150 kN and maximum stroke 10 cm that can be controlled either by force or displacement. The reference signal was the displacement and the corresponding force was measured at the same time. The imposed displacement consisted in any type of curves with maximum amplitude of ±10 cm. The actuator is directly connected to the controllable device. The second end of the device is situated on a plate. A very accurate load cell is mounted between the controllable device and the head of testing actuator in order to measure the evolution of the forces. The displacement is measured either by Temposonic transducer (magnetic) and a Heidenhein one (optical), which provide a digital output of very high precision.

In practical configuration of test the device is introduced between two iron plates (Fig. 4). A thin teflon plate is fixed by the lower iron plate to accomplish a sliding surface between the device and lower iron plate with low values of the friction force ($F_{\text{frict.(2)}}$). This reason is because the actuator must impose the shear displacement of the device and in this case restoring force represents the friction force ($F_{\text{frict.(1)}}$). The upper iron plate has very rigid connections at its corners with the lower plate.

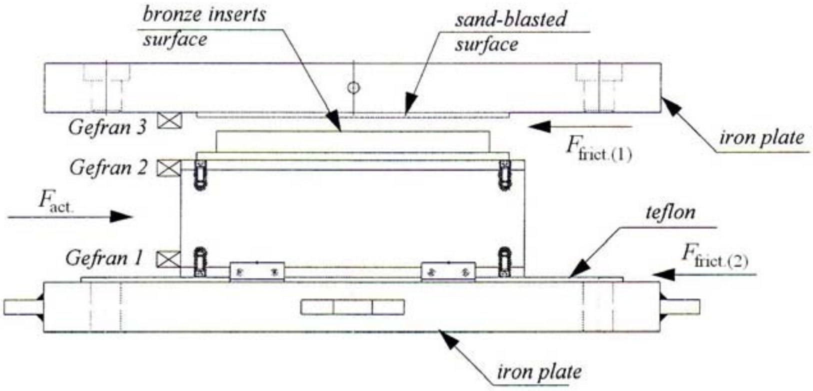

Fig. 4 – Experimental test set-up.

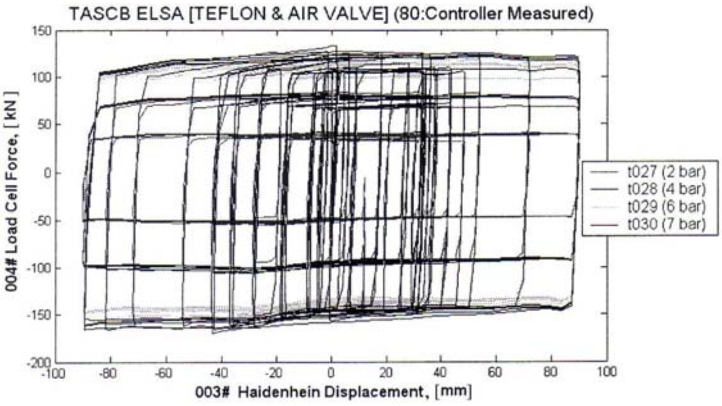

Fig. 5 – Hysteretic characteristics of controllable device.

Several cyclic tests were conducted at different pressure levels: 2 bars, 4 bars, 6 bars and 7 bars. The imposed displacement consisted in a sinusoidal curve with constant frequency (1 Hz) and initial maximum amplitude of ±10 mm, then slowly decreasing to zero value for the first part of the signal. The second part is a random signal. Fig. 5 shows the dissipative characteristics of the device. It’s clearly that the device has an elasto-perfectly plastic behaviour at different constant air pressures.

The hysteretic device is characterized by two elements in order to obtain an appropriate analytical model, as follows:

a) a constant elastic stiffness element, *k*, for all pressures;

b) a maximum elastic displacement, *u*, (*i.e.* yield displacement in case of steel material) corresponding to maximum friction force, $F_{\text{frict.}}$, at a constant air pressure.

3. Numerical Simulations

The bridge structure was excited with a synthetic acceleration time history (Fig. 6) compatible with Eurocode 8 for stiff soils with a maximum peak ground acceleration of 0.35g, scaled to 20%.

The characteristic values, which modelled the behaviour of the device for a pressure of 6 bars, are

$$F = \pm 100 \text{ kN}, \; k = 100{,}000 \text{ kN/m}.$$

The eqs. of motion have been solved using an appropriate time-integration algorithm (central difference method). The piles are very stiff and for this reason only the displacement responses of the DoF6, the DoF14 and the device are plotted. In the analysed cases, a small substantial difference is gained by the configuration *B* instead of the configuration *A*.

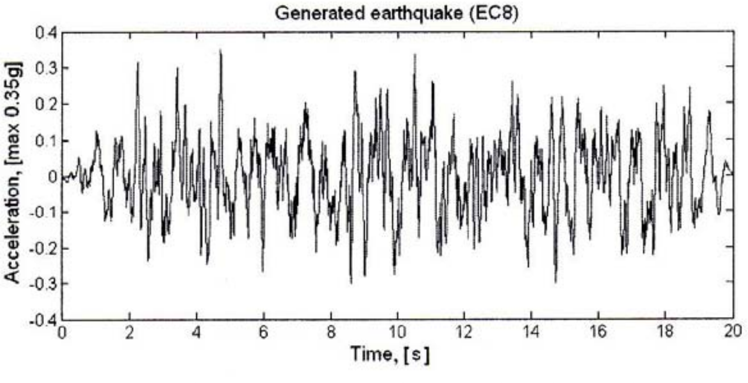

Fig. 6 – Time history of EC8 synthetic earthquake acceleration.

The results from the numerical simulations show that the peak displacements of protected bridge with supplementary passive friction device were reduced with about 40% in comparison with unprotected structure.

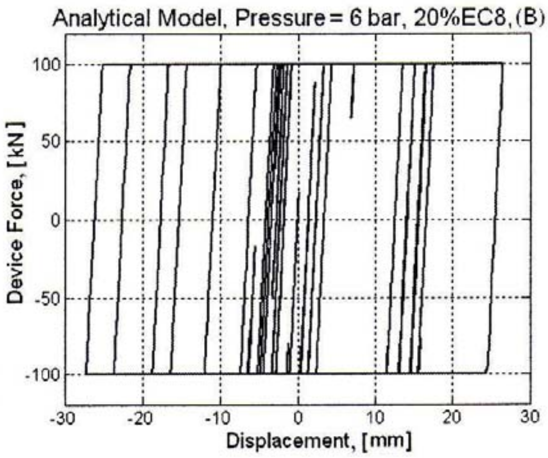

Fig.7 – Hysteretic loops of the passive device.

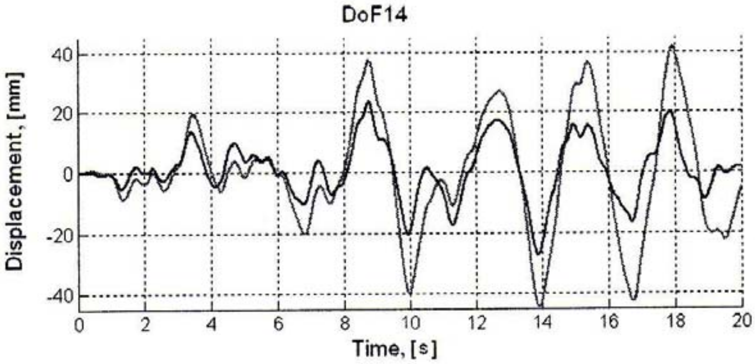

Fig.8 – Comparison of displacement responses between protected structure case and unprotected structure case.

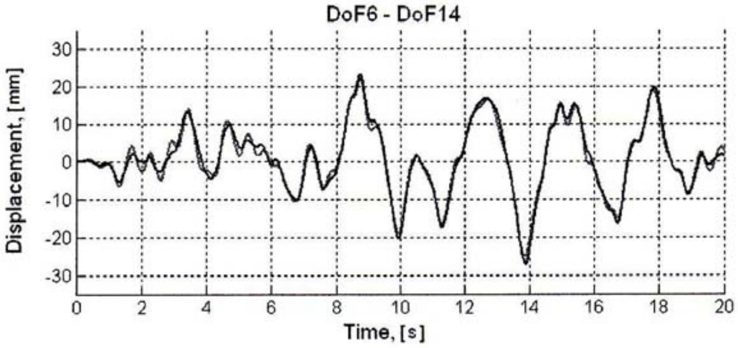

Fig. 9 – Displacement responses of DoF14 and DoF6.

4. Conclusions

The main scope of this paper is the investigation of the passive friction dampers applied to a realistic bridge structure in order to mitigate the vibrations produced by strong earthquake. The performance of passive device is compared with uncontrolled case. The numerical simulation results demonstrate that the performance of the proposed passive friction device is quite effective, the maximum displacements response decreasing with 40% in comparison with unprotected structure one.

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PROTECŢIA SEISMICĂ A UNEI STRUCTURI DE POD REALE FOLOSIND DISPOZITIVE CU FRICŢIUNE PASIVE

(Rezumat)

Aplicarea sistemelor de control pasiv la structurile de poduri a fost investigată în ultimii ani pentru a demonstra eficacitatea acestor sisteme în timpul evenimentelor naturale excepţionale, cum ar fi cutremurele. Se propun modele analitice pentru dispozitivele cu fricţiune pasive montate între tablier şi pile într-o structura de pod reală supusă la mişcări seismice severe. Modelele sunt analizate din punct de vedere al simulărilor numerice pentru excitaţii seismice. Comparaţia rezultatelor simulărilor numerice a demonstrat eficienţa folosirii dispozitivelor de frecare pentru a proteja structura de pod în raport cu cazul structurii neprotejate.