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ON THE SELECTION OF FLUID VISCOUS DAMPERS FOR SEISMIC PROTECTION OF BRIDGES

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ABSTRACT

The seismic performance of bridges with fluid viscous dampers is determined using a parametric non-linear dynamic analysis of simplified bridge models, subjected to seismic ground motions recorded on the subduction zone of the Pacific Coast of Mexico. This paper presents charts that can be used by the practitioner engineers in order to find the best solution for the seismic design of bridges with this type of devices. The parametric study developed and the proposed methodology show to be a useful tool for the selection of the optimal dampers' characteristics as function of a target seismic deck displacement. The methodology proposed is explained with an example that describes the seismic design for an actual bridge. The results for real and simplified models of the structure are discussed.

Introduction

One of the major issues to be solved in the seismic design of bridges is the control of displacements. This control can be achieved by increasing the piers and abutments stiffness or increasing the energy dissipation capacity through the addition of damping devices. The second solution is appealing because it also decreases the substructure internal forces.

In bridge engineering practice, viscous dampers have been used either for upgrading existing structures or for protection of new bridges, e. g. the Vernègues (Boitel 1998) and the Saint-André (Datry 1998) viaducts in France, and the Cape Girardeu Bridge in the U.S.A. (Taylor 2002), among others. Moreover, these devices have been used in cable-stay bridges to reduce vibrations on the cables due to the simultaneously action of wind and rain (Main 2001). Two outstanding cases are the Golden Gate Bridge in the coast of California (Rodriguez 1996) and the Rion-Antirion Bridge over the Corinthian Gulf (Teyssandier 2000).

This paper presents a parametric non-linear dynamic analysis of bridge simplified models.

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The models are subjected to seismic ground motions recorded close to the subduction zone of the Pacific Coast of Mexico. The main objective of this work is to develop design aids (charts) presenting the most important results that can be used by the practitioner engineers for the selection of the most appropriate devices for the protection of bridges located on high seismic areas. In this way, the chosen device helps the designer to get the best solution for controlling the seismic displacements demands on the bridge. An application of this methodology is illustrated for an existent bridge.

Parametric Study

Fluid Viscous Dampers

The implementation of energy dissipation devices on bridges is an attractive alternative to reduce both seismic displacements and force on elements. Viscous dampers are able to dissipate seismic energy and, at the same time, to accommodate temperature and creep displacements without inducing forces on the devices, making this devices and appealing alternative for reducing seismic responses, especially in continuous long-span viaducts . Viscous dampers operate under the principle of flowing silicon fluid through orifices at high velocity; these devices provide a restoring force (*F*) which depends on the relative velocity (*V*). The constitutive law for fluid viscous dampers can be expressed as a fractional velocity power law:

$$F = C\,\mathrm{sgn}(V)\left|V\right|^{\alpha} \tag{1}$$

where *C* is the damping constant and the exponent α is defined by the type of device. These damping devices can be manufactured in a wide range of *C* and α values. A parametric study considering three values for the exponent α (1, 0.5 and 0.1) combined with several values of constant *C* in the range of 1 to10 kN/(m/s)$^{\alpha}$ was developed. The results were analyzed to identify the optimum damper parameters.

Analytical Model

The structural model used corresponds to a simplified single degree of freedom system (Jeronimo 2002), where the degree of freedom is the longitudinal displacement at the deck level. The piers and abutment stiffness were modeled by using a column with elastic behavior, and the deck mass was considered as a lumped unitary mass (Fig. 1). The column stiffness was calibrated in order to obtain period values in the range of 0.5 sec to 2.0 sec. The period values were assumed as representative solutions for bridges with dampers devices.

The nonlinear analyses were conducted using the commercial software SAP2000 V10. Link elements represent the nonlinear viscous dampers and frame elements were used for the structure components. The principal variables of interest are the maximum displacement, velocity, mass acceleration, and maximum forces on dampers and structure elements.

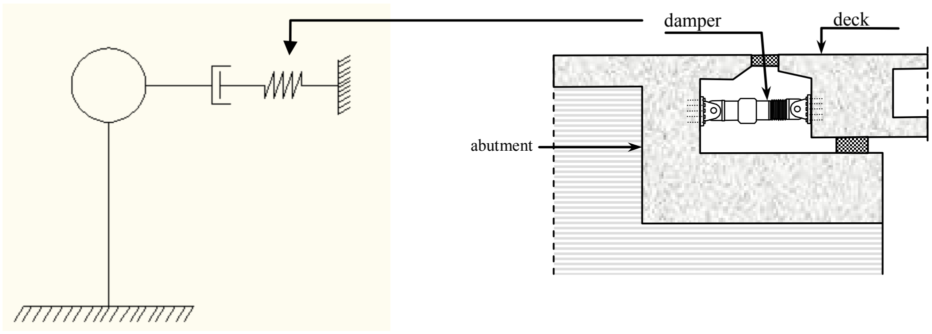

Figure 1. Simplified analytical model.

Seismic Ground Motions

A suite of 20 seismic ground motions from the Mexican Strong Motion Database recorded in hard soils close to the subduction zone of the Pacific Coast of Mexico were selected as input records. Table 1 presents some characteristics of the time history accelerations. In order to have similar amplitudes of the records, all accelerograms were scaled to a peak ground acceleration (PGA) equal to 0.75g; this value was selected considering the PGA of the design spectra proposed on the CFE Specifications (1993) for hard soil at the central-west zone of the country.

Table 1. Characteristics of the seismic records.

ID	Date	M_W	Direction	PGA (gal)
APAT7903	04/03/1998	7	N 90 E	-62.217
APAT8509	15/03/1998	6.8	N 90 E	81.282
AZIH8509	02/03/1998	6.8	S 90 W	-153.93
CALE8509	02/03/1998	6.8	S 90 E	-140.68
CALE9701	16/01/1997	6.5	S 90 E	396.21
CHI18501	06/05/1998	6.8	N 00 E	-194.0
CHIl9509	14/09/1995	6.4	N 00 E	-26.31
COPL9310	09/04/1996	6.2	N 90 E	-274.03
LZ019510	15/03/1996	7.3	N 45 W	13.29
LZ019701	20/03/1998	6.9	N 90 E	196.74
MZ019510	15/03/1996	6.5	N 00 E	387.62
OCTT8904	23/03/1998	6.3	N 90 E	-201.16
PAPN8509	02/03/1998	6.3	S 00 W	242.69
PARS8509	01/04/1998	6.3	S 00 E	-625.78
PETA9607	28/10/1996	5.7	S 00 E	-183.45
PTSU9701	20/01/1997	6.5	N 00 E	-311.04
RIML9701	01/01/1997	6.9	N 90 E	6.37
SICC7903	04/03/1998	7	N 90 W	307.21
SMR28904	25/03/1998	6.3	S 00 E	-175.14
SUCH8509	12/03/1998	6.8	S 00 W	-103.12

Parametric Analysis

The main results are focused on the deck maximum displacement (relevant for the evaluation of the seismic displacement control), the deck maximum acceleration (important for assessing the maximum force in the structure), and the damper force and velocity (essential values for the damper´s design).

Figure A3 shows the results for a system period of 1.5 sec. The first two graphics (a) and (b), represent on the vertical axis the displacement and acceleration of the deck, as a function of the parameters C and α that characterized the dampers. The value of C=0 represents the model without damper. As expected, deck displacements decrease as C increases and α decreases.

The variation of forces and velocity on the damper are displayed on graphics (c) and (d) of the same figure respectively. The response in terms of the damper velocity follows a similar trend of the one obtained for deck displacements. In contrast, the maximum damper force is inversely proportional to displacements, i.e. lower displacements lead to higher forces. Low acceleration levels were presented for all the C values with an optimum force reduction for $C = 2$ $kN/(m/s)^{\alpha}$.

It is worthwhile that several combinations of C and α values lead to similar displacement reductions for almost the same force on the dampers (Fig. A.3). The great number of combinations for the same displacement reduction allows the designer to adopt a solution over a wide range of possible combinations, making easier the device parameter selection from the available commercial solutions.

Similar trends are obtained for other system periods as it can be seen in figures A1, A2 and A4.

Analysis of an Existent Bridge

The proposed methodology for the selection of a viscous fluid damper is based on the previous results and it is applied to an existent bridge. As it will be shown, the results of the parametric study can be extended for the analysis of more complex structures.

La Chuta Bridge is an important structure located along the Playa Azul-Manzanillo Highway (18°03’03’’N 102°33’27’’W). Fig. 2 shows a panoramic view of the structure and Fig. 3 displays a lateral scheme of the bridge.

The bridge superstructure consists of a continuous deck supported on six vertical piers and two abutments. The seven-span bridge has a prestressed concrete box deck with a total length of 227.53 m. The dampers were considered at both ends of the bridge connected to the abutments in the longitudinal direction for controlling longitudinal deck displacements.

Figure 2. La Chuta Bridge.

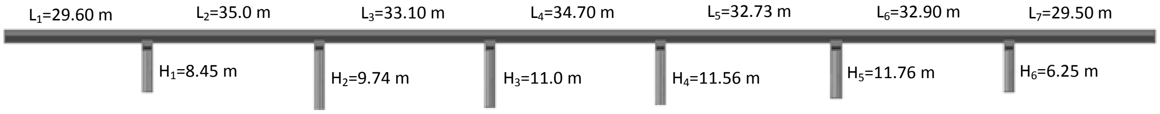

Figure 3. Lateral view of the bridge.

Table 2. Dynamic characteristics of the bridge.

Mode	**Period (sec)**	**Modal participating mass ratios**		
		Longitudinal	**Transverse**	**Vertical**
1	1.6577	0.0000	0.7920	0.0000
2	**1.5059**	**0.8750**	**0.0000**	**0.0000**
3	1.3433	0.0000	0.0002	0.0000
4	1.0518	0.0000	0.0860	0.0000
5	0.6656	0.0000	0.0000	0.0000
6	0.4042	0.0000	0.0003	0.0000
7	0.2983	0.0000	0.0013	0.0000
8	0.2955	0.0190	0.0000	0.0000
9	0.2883	0.0210	0.0000	0.0000
10	0.2881	0.0000	0.0210	0.0000

Table 2 summarizes the dynamic characteristics of the bridge. According to the mass participating factors presented in Table 2, the second mode is the most important for the longitudinal response of the bridge. The 3D bridge model was constructed using the SAP2000 program. Frame elements with six degrees-of-freedom at each node were used for piers and deck. The bridge model was subjected to the same 20 records presented in Table 1.

To select the characteristics of the dampers a target displacement of 26 mm is considered. This displacement assures a total protection of the piers, meaning not expected damage (Medina 2009). Using Fig. A.3 for a structure with a fundamental period of 1.5 sec (the bridge has a longitudinal period of 1.506 sec), two solutions are possible to fulfill defined target: (1) $\alpha = 0.10$ and $C = 3.87$, and (2) $\alpha = 0.50$ and $C = 8.0$. The C value obtained in this way is associated to a unitary mass model, for that reason C must be multiplied by the mass associated to the longitudinal movement of the deck. The linear dynamic analysis of the bridge shows a mass value (M_x) of 3,862.77 kN in longitudinal direction. If an exponent α=0.10 was used (solution 1), then,

$$C' = M_x \cdot C = 3{,}862.77 \text{x} 3.87 = 14{,}956.7 \text{ kN/(m/s)}^{0.10} \tag{2}$$

where C' is the damper characteristic and C is the damping constant defined for a unitary mass adopted in the parametric study. If the solution (2) is preferred the parameters that characterize the damper are α=0.50 and C=30,902.7 kN/(m/s)$^{0.50}$.

As the bridge has two dampers, one at each end, dampers with $C'/2$ value were considered at both ends of the structure.

Table 3 shows the bridge seismic responses and the results of the simplified model for solution (1). The values in Table 3 are the average of the maximum response obtained for each of the 20 seismic records considered in the study. A good agreement of the results obtained for the 3D and the simplified models is observed on Table 3. Similar errors are obtained on the analysis of the models for solution (2).

Table 3. Results of the analysis for α=0.10 and C'=14,956.7 kN/(m/s)$^{0.10}$.

	Displacement (mm)	**Velocity (m/s)**	**F_{damper} (kN)**
3D Model	25.4	2.116	8060.39
Parametric study	26.0	2.250	8110.04
Error (%)	+2.4%	+6.3%	+0.6%

Conclusions

The use of fluid viscous dampers is a relatively novel concept in seismic design in Latin America. One of the more representative examples is the Torre Mayor building, located in Mexico City; it has 98 dampers distributed in 59 stories (Reichmann 2009). There is, however, a lack of a consistent methodology that helps the designer to select an appropriate device for its application to bridge enginnering.

The parametric study developed and the proposed methodology presented in this study

(Jeronimo 2002), show to be a useful tool to obtain a set of designing charts compatible with a specific seismic area. The methodology proposed is a simple approach to select the optimal characteristics of dampers as function of a target deck seismic displacement. The use of a simplified model in the dynamic analysis showed to be a good alternative to get accurate values of the solution.

Low values of α exponent are the most efficient way to control displacements but lead to high forces in the damper and, as a consequence, in the substructure. Nevertheless, from the charts presented in the Appendix, it can be concluded that several combinations of *C* and α values conduct to similar results in terms of the displacements and the damper forces. This result shows the possibility of selecting a solution over a wide range of possible combinations, with obvious benefits on the device parameter selection from available commercial solutions.

Appendix

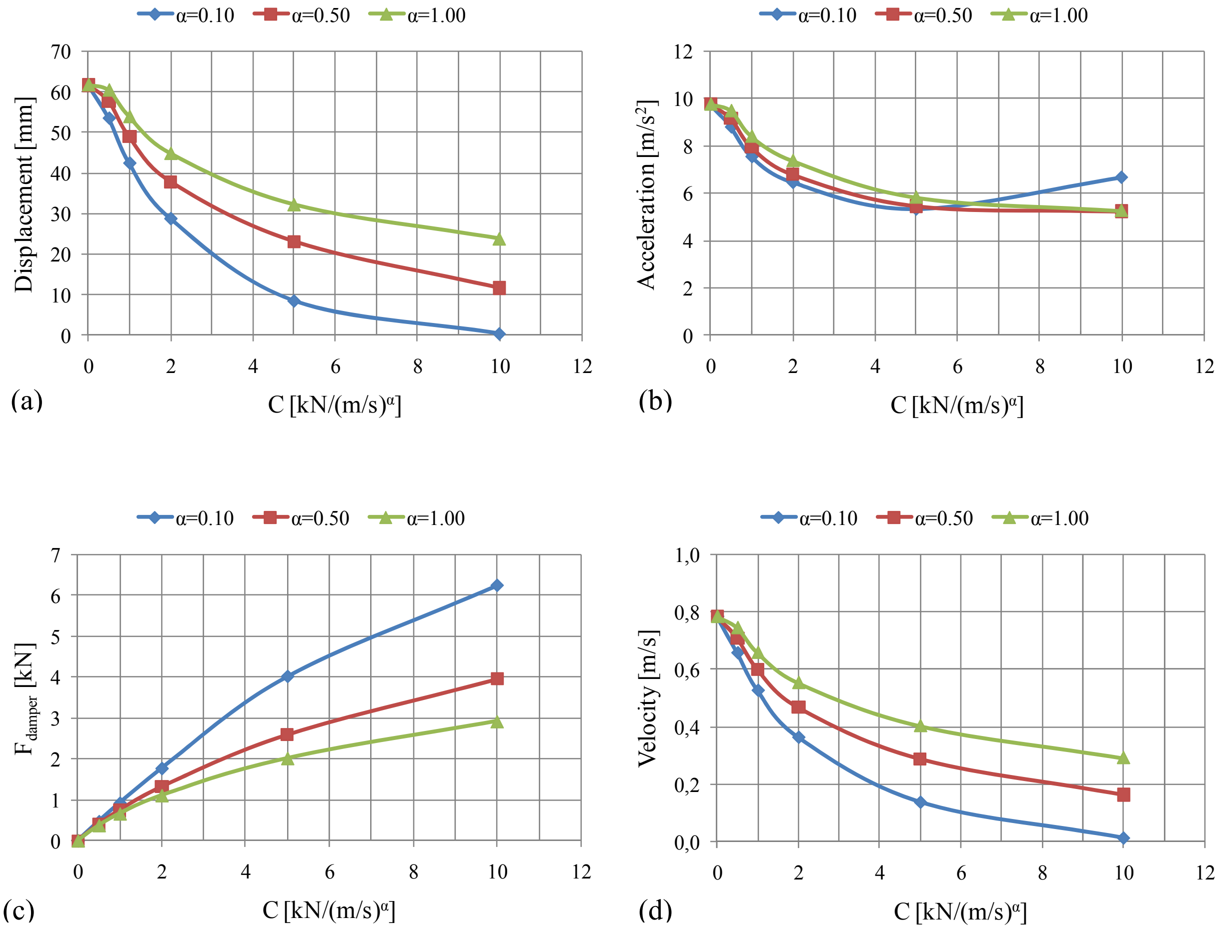

Figure A.1. Charts for bridges with a fundamental period of 0.50 sec.

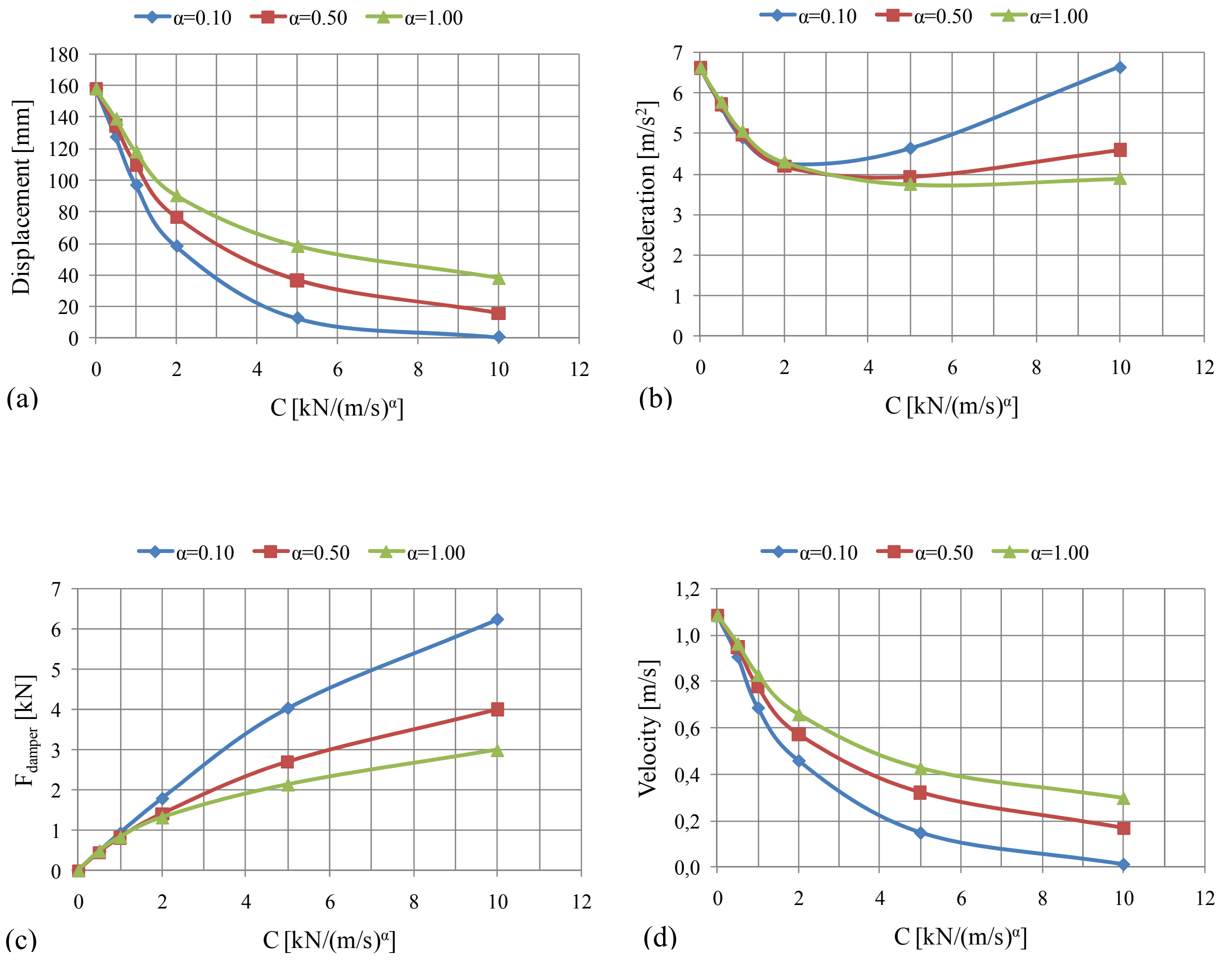

Figure A.2. Charts for bridges with a fundamental period of 1.0 sec).

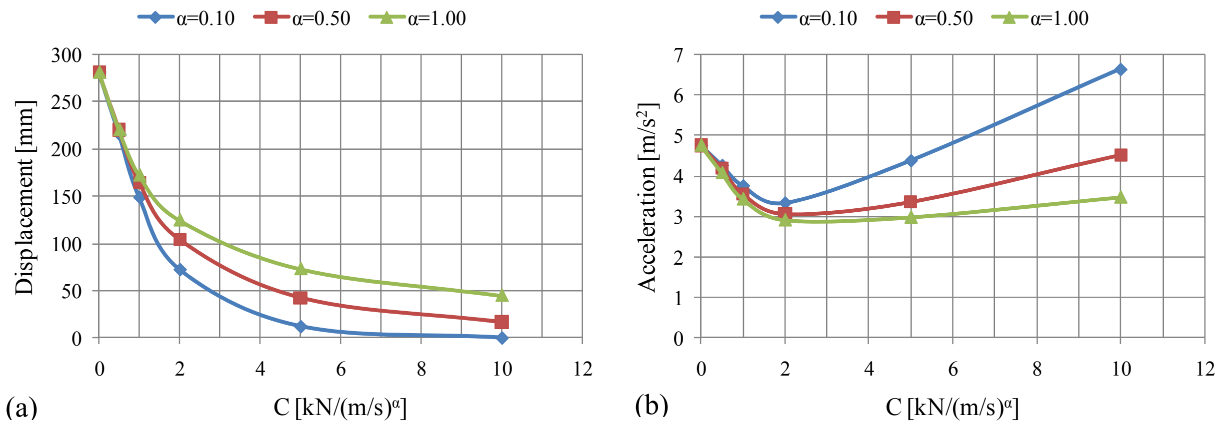

Figure A.3. Charts for bridges with a fundamental period of 1.5 sec.

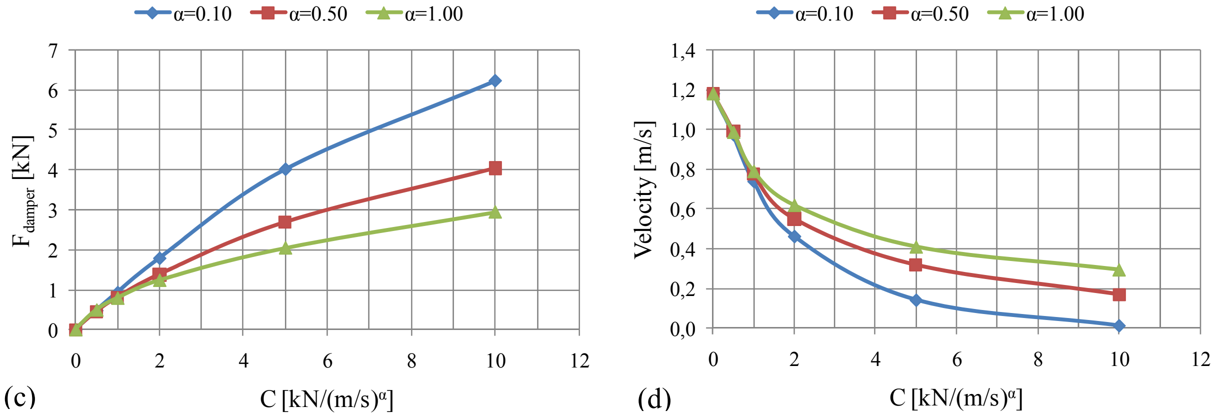

Figure A.3. Charts for bridges with a fundamental period of 1.5 sec. (cont.)

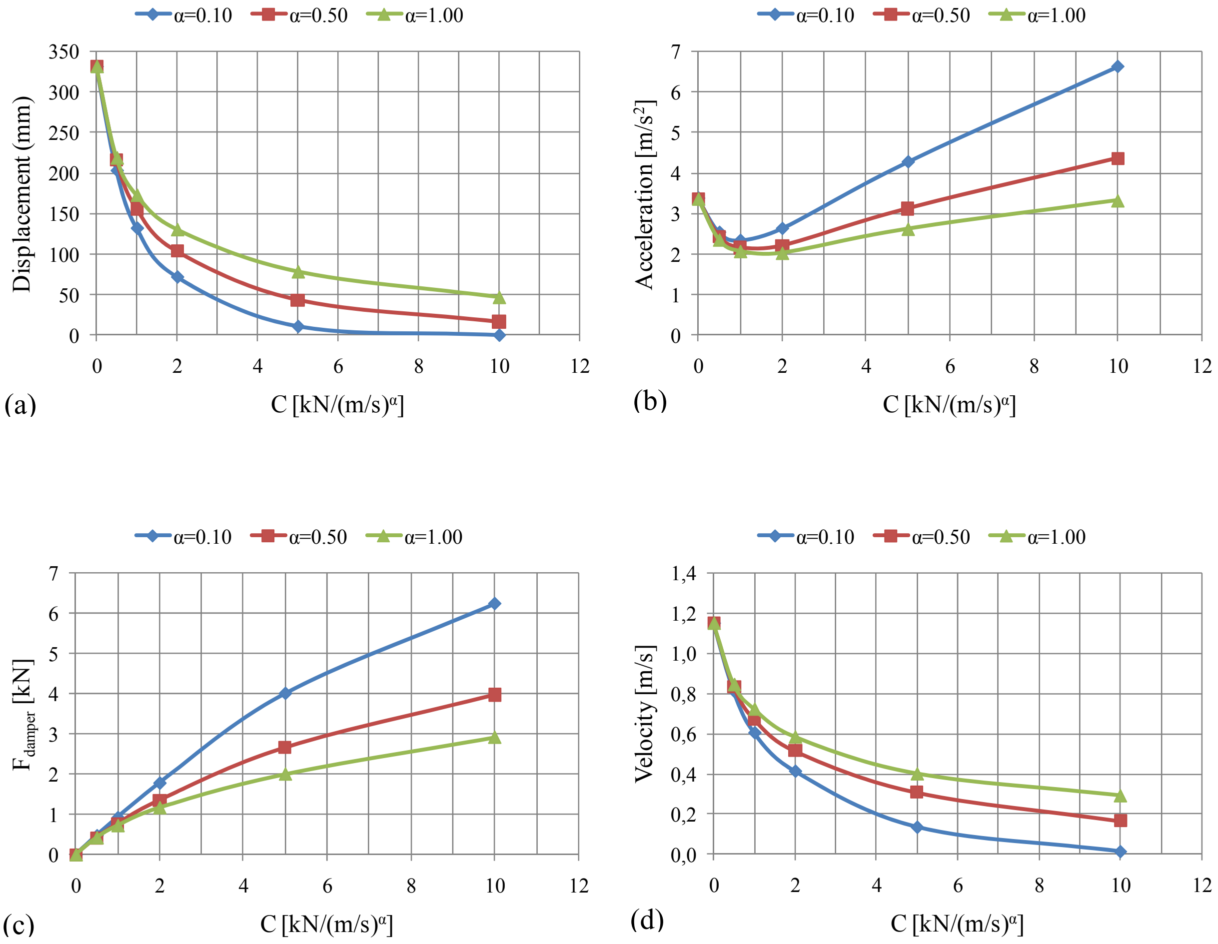

Figure A.4. Charts for bridges with a fundamental period of 2.0 sec.

References

Boitel, P., and C. De La Fuente, 1998. Aseismic devices for bridges, *Proceedings of the 13th FIP Congress*, Amsterdam, Netherlands, 105-109.

Campos, S., 2009. Evaluacion sismica de puentes con amortiguadores, *MSc Thesis*, Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico (in Spanish).

Comision Federal de Electricidad (CFE), 1993. *Manual de Diseño por Sismo,* Mexico (in Spansh).

Datry J.-B., L. Marracci, A. Krief and C. Neant, 1998. Para-seismic protection using visco-elastic damping devices. The Saint André Viaduct (A43 highway), *Proceedings of the 13th FIP Congress*, Amsterdam, Netherlands, 153-161.

Jeronimo, E., and L. Guerreiro, 2002. Seismic displacement analysis of bridges with viscous dampers, *Proceedings of the 12th European Conference on Earthquake Engineering*, London, UK, Paper No. 373 (CD-ROM).

Main, J. A., and N. P. Jones, 2001. Evaluation of viscous dampers for stay – cable vibration mitigation, *Journal of Bridge Engineering* 6 (6), 385-397.

Medina, S. I., 2009. Estimacion del nivel de daño en pilas de concreto de puentes con distintas condiciones de apoyo, *MSc Thesis*, Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico (in Spanish).

Reichmann, I., 2009. Torre Mayor, *URL: [http://www.torremayor.com.mx]* (in Spanish).

Rodriguez, S., and T. J. Ingham, 1996. Seismic protective systems for the stiffening truss of the Golden Gate Bridge, *Proceedings of the 11th World Conference on Earthquake Engineering*, Acapulco, Mexico, Paper No. 1333 (CD-ROM).

Taylor devices inc., 2002. Taylor devices seismic dampers and seismic protection products, *URL: [http://www.taylordevices.com/3seismic.htm]*.

Teyssandier J.-P., J. Combault and P. Morand, 2000. The Rion Antirion Bridge design and construction, *Proceedings of the 12th World Conference on Earthquake Engineering*, Auckland, New Zealand, Paper No. 1115.