ENERGY DISSIPATION DEVICES IN BRIDGES USING HYDRAULIC DAMPERS

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ABSTRACT

Specially designed energy dissipation systems are well known for improving seismic performance of structures by absorbing earthquake induced energy. In this paper, the use of linear and nonlinear hydraulic dampers is investigated in a bridge application. A two-span, skewed, cast-in-place prestressed concrete bridge with an outrigger bent is examined. The bridge is located in a highly seismic area of Southern California. It is observed that dampers alleviate the torsional movement and reduce the transverse and longitudinal movements of the superstructure.

INTRODUCTION

It is common practice today that structural engineers do not design their structures to remain fully elastic during a seismic event as in the past. Instead, they allow structures to experience plastic hinging in certain areas that are carefully detailed for this particular reason. Thereby, energy dissipation is achieved through hysteretic damping. This concept of ductile design leads in general to more economical designs provided that a certain level of safety is still maintained.

Another approach to enhance seismic performance is to increase system damping by introducing energy dissipation devices in certain areas within the structure. The objective here is to have structures meet code strength requirements without the devices and reduce displacement demands through increased damping by utilizing energy dissipation devices and thus, improve seismic performance. This in turn results in safer and more cost effective structures in the long run.

Several types of energy dissipation devices (passive, active, or semi-active) have been proposed or applied to various structures throughout the world during the past three decades. In this study, the use and effects of fluid viscous (hydraulic) dampers are investigated in a bridge application by performing nonlinear time history analysis.

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Various applications of passive viscous dampers in bridges have been reported in the past. The first use of viscous damper stoppers in bridge application was performed on the Tokyo Metropolitan Expressway, Tokyo, Japan in 1962 (Kawashima 1992). It was a five span, 116.9 m long, 16.7 m wide, four-cell box girder structure. The dampers were installed between the superstructure and substructure at both abutments and at the top of the piers at bents three and four. Yamadera and Uyemae (1979) also reported the use of viscous damper stoppers in at least ten bridges in Japan after the Tokyo Metropolitan Expressway including the Kaihoku Bridge, a five span 285 m long one-cell box girder bridge that suffered no damage during the strong earthquake of Miyagi-ken-Oki in June of 1978.

As another bridge application of dampers in the United States, Brown (1995) referred to a retrofit project on Pennsylvania S.R. 29 over the Schuylkill River in Montgomery County. The bridge, which is a five span, four girder structure with a central fixed pier at the center, is upgraded to sustain earthquake forces by placing dampers that work as lock-up devices on two of the four girders at the three expansion joints.

HYDRAULIC DAMPERS

Hydraulic dampers are introduced in the early 1960's in industrial applications and function on the principle of fluid flow through orifices (Figure 2). They are designed to operate over a wide temperature range, typically between –40 degrees C to 70 degrees C. They consist of a stainless steel piston with bronze orifice head and an accumulator. The fluid is silicon oil. The damping force that the devices produce is the result of the different pressure across the piston head and is given by the equation F=C*V exp(n), where, F is the damping force, C is a constant, V is the piston rod velocity, and n is a predefined coefficient in the range of 0.4 to 2.0. When n=1, the damper is linear. This behavior primarily affects the frequencies of motion below a predetermined frequency level that is related to the characteristics of the accumulator valves. Above this cutoff frequency the higher modes of vibration are both damped and stiffened so that their contribution is drastically reduced, while below this frequency the lower modes are only damped.

NONLINEAR DYNAMIC ANALYSIS

A very efficient method suitable for static and dynamic analyses with linear and nonlinear elements with limited number of predefined nonlinear elements was used. The method, which was first proposed by Wilson in 1982, in order to minimize the size of the nonlinear system, employs stiffness and mass orthogonal load dependent Ritz Vectors. The general dynamic equilibrium equations of the elastic system with nonlinear elements at a given time t is given as:

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) + f(t) = F(t)$$

where, m is the mass, c is the proportional damping, and k is the stiffness matrices; $x(t), \dot{x}(t), \ddot{x}(t),$ and $F(t)$ are node displacement, velocity, acceleration and externally applied loads, respectively.

The term f(t) represents the global vector due to the sum of the forces in the nonlinear elements and is calculated through iteration within each time step. The nonlinear elements used in this application are the damper element and the abutment crush element shown in Figures 5 and 6.

BRIDGE APPLICATION

Hydraulic dampers are utilized in the design of the 91/5 HOV Connector Separation bridge in Orange County, CA (Figure 1). The bridge consists of a two span cast-in-place prestressed concrete box girder with 3 cells. It is a 117 m long, 12.95 m wide structure with a 31.4 m prestressed outrigger bent and 30 degrees skewed abutments. The bridge sits on a alluvium soil layer which is at least 50 m thick. The site specific ground acceleration is estimated as 0.6 g.

A plan view of the computer model is shown in Figure 3 where 8 dampers are placed at an angle, 4 at each abutment. For higher efficiency, they are placed perpendicular to each other. One end is connected to the abutment and the other is connected to the superstructure at the soffit (Figure 4). The force-displacement behavior of the dampers is shown in Figure 5. Additionally, 6 crush elements (3 per abutment: 2 transversely and 1 longitudinally with respect to the abutment axis) are employed in the computer model to simulate the effects of the abutment fill and those of the wingwalls. These abutment elements engage after closing an initial gap of 100 mm. They can take only compression forces and yield at a certain displacement which results in a permanent displacement (Figure 6).

The analysis was performed in two stages. In the first stage, only the dampers engage while in the second stage, both abutment crush elements and dampers engage. A Loma Prieta 3-D time history record was used during stage 1 (Figure 7 shows the strong ground motion in the transverse direction only). Figure 8 shows the displacement response of the left abutment node in the longitudinal direction without dampers with peak value of 257 mm. It also shows the response of the same node when nonlinear dampers (n=0.75) and linear dampers (n=1) are used. In the latter case, the node moves 41 mm and 42 mm longitudinally, a displacement reduction of 84% and 83%, respectively. Similarly, in the transverse direction the node moves 66 mm without the dampers (Figure 9), 31 mm with the nonlinear dampers, and 32 mm with the linear ones, a displacement reduction of 53% and 51%, respectively. Figure 10 depicts the strain energy of the elastic system as well as those of the nonlinear and linear damped systems with maximum value reductions of 58% and 57%, respectively. Figure 11 shows the force deformation curve of the nonlinear damper (n=0.75) at the obtuse corner of the left abutment, while Figure 12 shows the same when a linear damper (n=1) is used instead.

In the second stage, the time history record is multiplied by a factor of 5 in order to simulate a very strong ground excitation. Figure 13 shows the displacement response of the left abutment node in the longitudinal direction when crush elements are used. Its peak response is 750 mm. It also shows the same node response with the addition of the nonlinear damping elements. The peak response is reduced by 70% to 227 mm. In the transverse direction, Figure 14 indicates maximum values of 314 mm and 180 mm or a reduction of 42% in displacement. Finally, Figure 15 shows the response of a crush element in the longitudinal direction with and without the use of nonlinear dampers.

CONCLUSIONS

Fluid viscous dampers are effective in improving bridge performance under dynamic conditions by dissipating energy. They introduce damping into the system and, consequently, reduce force and displacement demands. This could result in simpler connections and lower construction cost. Moreover, reduction or even elimination of structural damage as well as traffic loss could be achieved after a seismic event, yielding substantial economic benefits. Nonlinear dampers with n less than one are more effective than linear ones since they dissipate more energy; as n decreases, the efficiency of the dampers increases. Nonlinear dampers also engage at lower velocities. As the velocity increases, the damping force increases at a lower rate, and thus protecting the device from excessive force.

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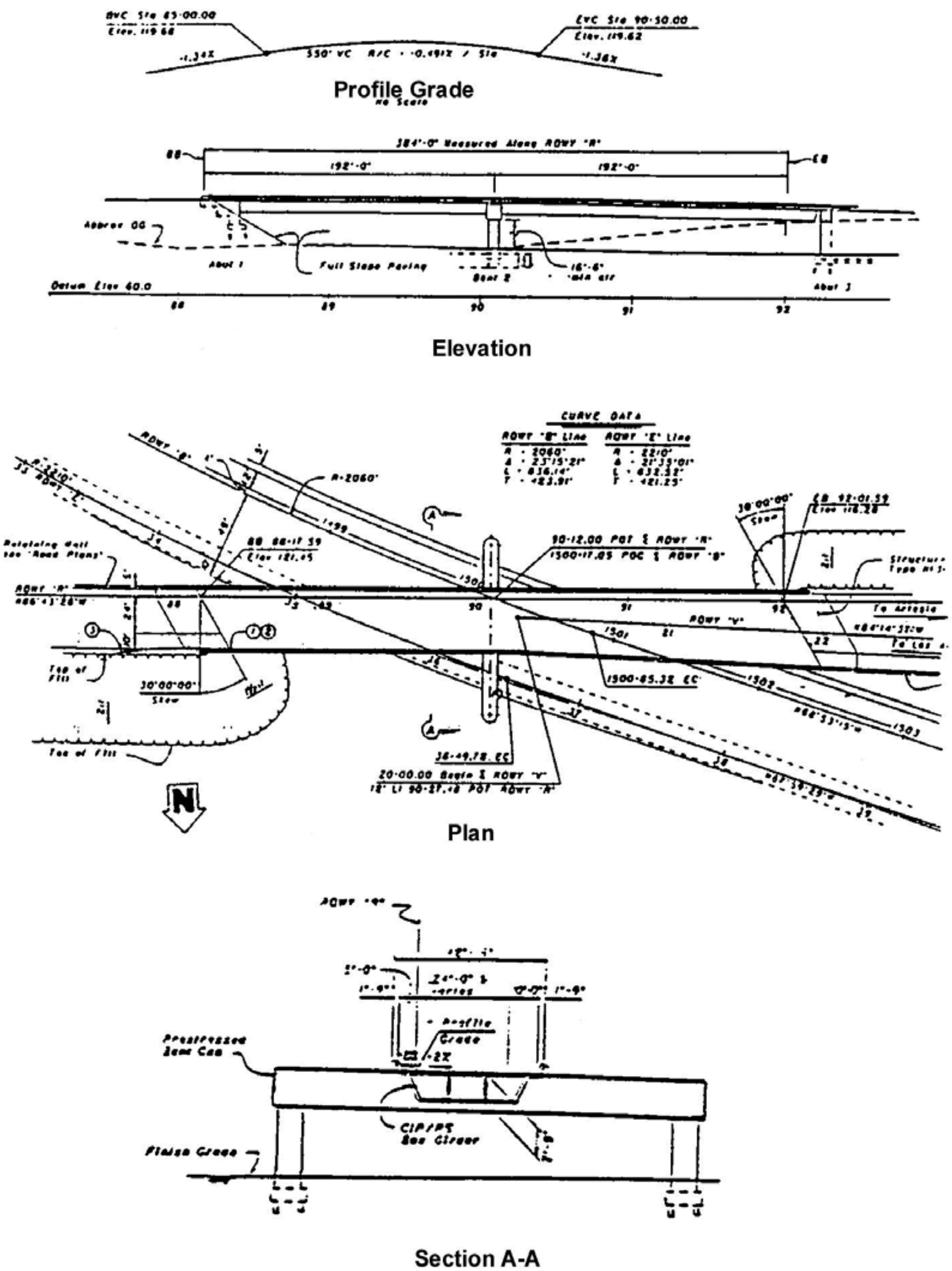

FIGURE 1
91/5 HOV CONNECTOR SEPARATION BRIDGE

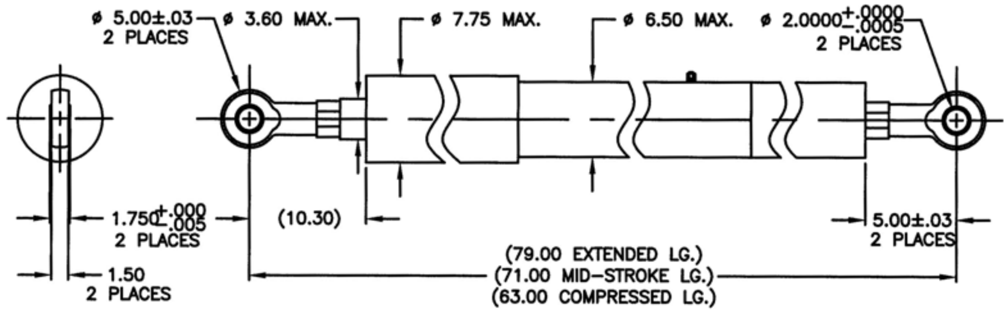

FIGURE 2
HYDRAULIC DAMPER

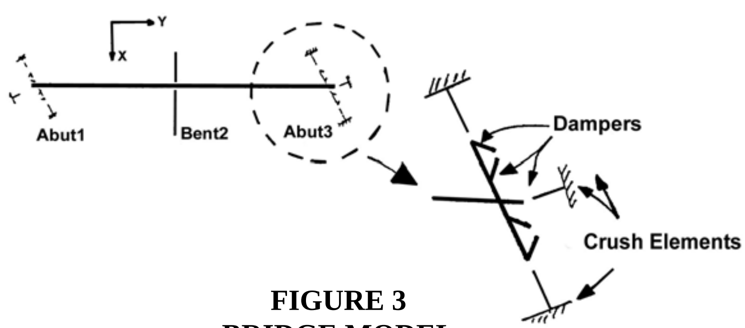

FIGURE 3
BRIDGE MODEL

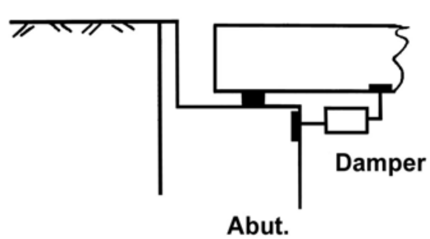

FIGURE 4
LEFT ABUTMENT

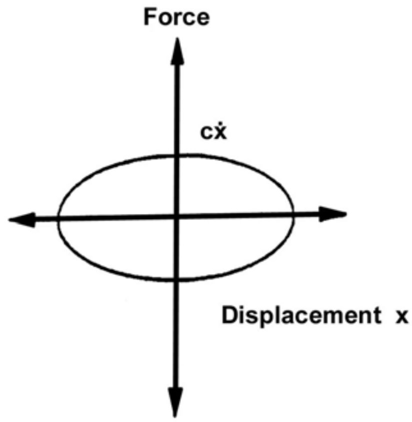

FIGURE 5
FLUID VISCOUS DAMPER

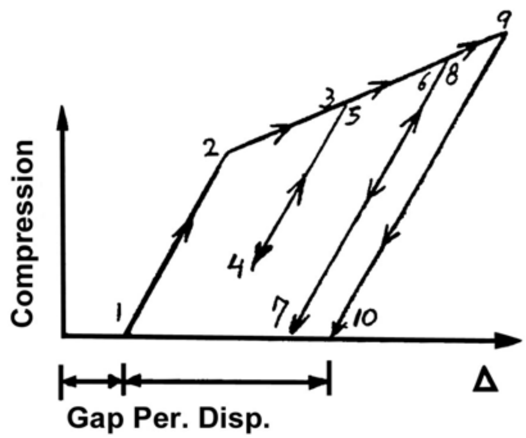

FIGURE 6
ABUTMENT CRUSH ELEMENT

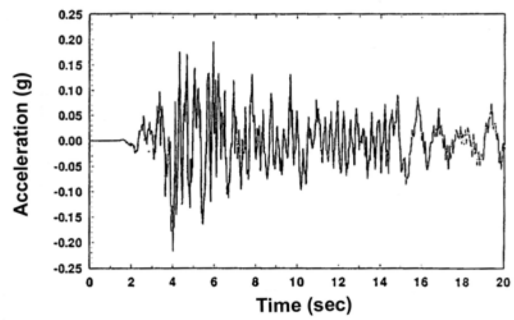

FIGURE 7
STRONG GROUND ACCELERATION

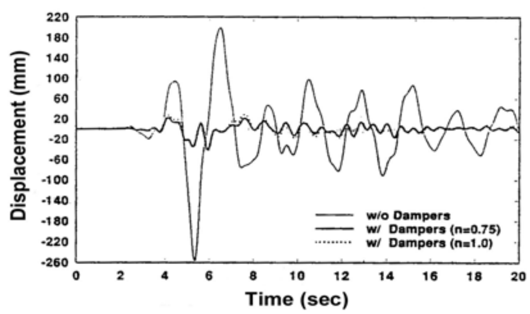

FIGURE 8
LEFT ABUTMENT RESPONSE (LONGITUDINAL DIRECTION)

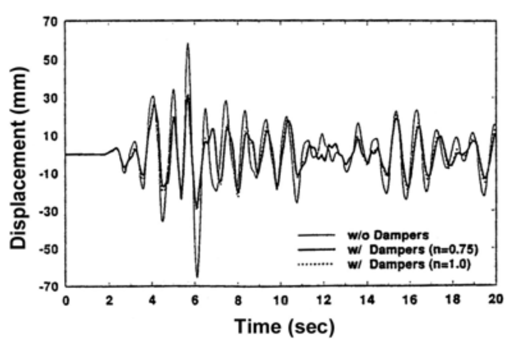

FIGURE 9
LEFT ABUTMENT RESPONSE (TRANSVERSE DIRECTION)

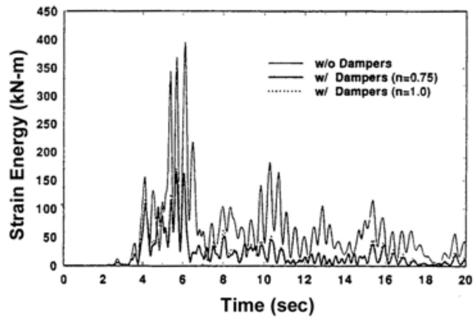

FIGURE 10
SYSTEM STRAIN ENERGY

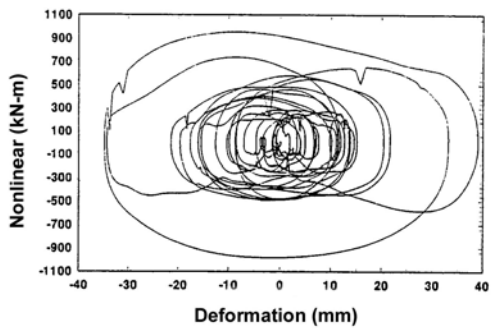

FIGURE 11
FORCE/DEFORMATION DIAGRAM FOR DAMPER w/n = 0.75

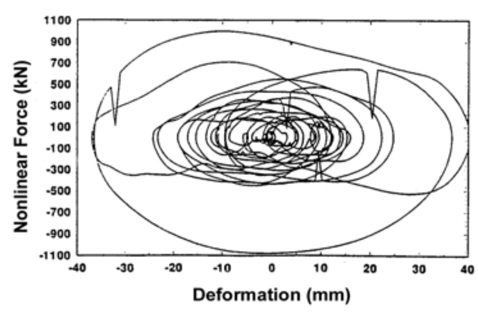

FIGURE 12
FORCE/DEFORMATION DIAGRAM FOR DAMPER w/n = 1.0

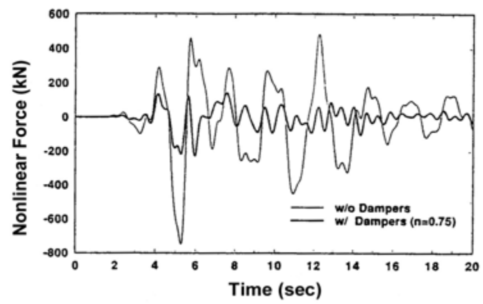

FIGURE 13
LEFT ABUTMENT RESPONSE (LONGITUDINAL DIRECTION)

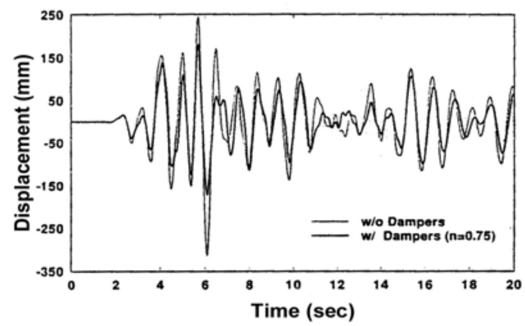

FIGURE 14
LEFT ABUTMENT RESPONSE (TRANSVERSE DIRECTION)

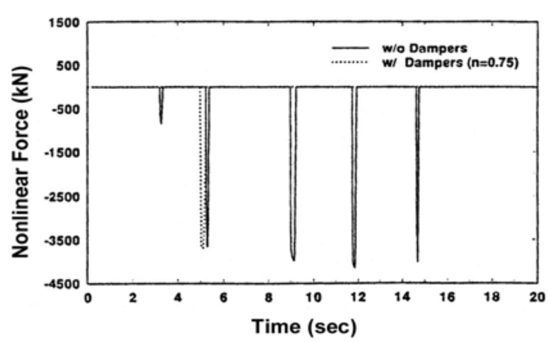

FIGURE 15
LEFT ABUTMENT CRUSH ELEMENT WITH AND WITHOUT NONLINEAR DAMPERS