EARTHQUAKE RESPONSE OF FRAMES EQUIPED WITH EDR DAMPING DEVICES.

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SUMMARY:
The use of passive control systems, aiming to the modification of the dynamic behavior of frame structures under seismic loads, remains an important research topic. This paper is a contribution to that direction. Namely, for each frame, a pair of EDR diagonal dampers is proposed to be used. Usually, the resultant action of an EDR device on the frame is proposed to be modeled by a complex set-up of spring elements, expressing both the elastic and friction component. In this paper, the calculation of the natural period of a dynamic system becomes more accurate: while considering free oscillation of the dynamic system without damping, the contribution of the elastic elements of the EDR devices applied to the structure are taken into account separately.

Keywords: EDR damper, earthquake response

1. INTRODUCTION

The earthquake response of a structure is a quite complex phenomenon, depending on several parameters such as the nature of ground excitation in general, the elastic characteristics of the structure e.t.c. In particular, the natural period and eigenfrequencies of a structure are very important factors which define the dynamics of the system. A common practice to avoid critical excitation of the dynamic system is the modification of the structure's eigenfrequencies mainly by stiffening its structural members. However, in recent years many efforts have been made in the direction of defining the circumstances under which critical excitation occurs, serving the purpose of a more accurate and economic design of structures (Takewaki 2007). In this process an accurate calculation of dynamic characteristics of the oscillating structure is very important.

The implementation of damping devices often affects the stiffness of the structure, thus altering its elastic characteristics and a change of the system's eigenfrequencies is expected. In this paper the influence of Energy Dissipating Restrain (EDR) devices in the elastic characteristics of a dynamic system is investigated. In literature an approach to simulate the resultant action of an EDR device is to set up a complex model of spring in series and in parallel, some of them expressing the elastic components of the device and others the contribution of friction elements. In Soong and Darguish (1999) a detailed presentation of this model, giving many useful information for the principles of an EDR device is provided. In Constantinou, Soong and Darguish (1998), case studies and experimental results are presented evaluating the contribution of implementing EDR devices in the dynamic response of a structure. In the next section, a reformulation of the equations describing the overall reaction of an EDR device is presented. This new form allows distinguishing elastic from friction forces, and therefore to calculate accurately the system's eigenfrequencies.

2. PROPOSED EQUATIONS FOR SIMULATING EDR RESPONCE

2.1. A brief description of an EDR device

A typical setup of an EDR device include steel compression wedges and bronze friction wedges to transform the axial spring force into a normal pressure acting outward the cylinder wall. Thus, the frictional surface is formed by the interface between the bronze wedges and the steel cylinder. Internal stops are provided within the cylinder in order to create the tension and compression gaps as illustrated in Fig. 1. Consequently, the length of the internal spring varies during operation, providing a variable frictional slip force. In this study we assume that the tension and compression gaps are set to zero. By adopting this, the model may be used to describe other friction devices as well, such as Sumitomo device.

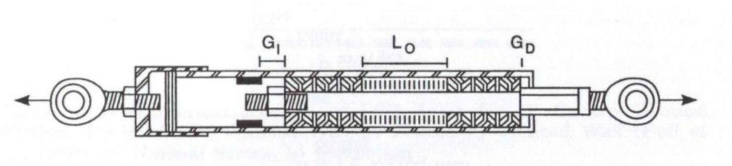

Figure 1. Typical EDR device.

2.2. Introducing the model

As mentioned above, EDR devices are modeled in general by a complex set-up of spring elements as shown in Fig. 2, where K_s represents the constant of the internal spring and K_3 the constant of a spring equivalent to the stiffness of the connection rods. The geometric and Coulomb friction effects involved in transforming the action of the spring force through the wedges into a frictional resistance, are incorporated by a positive factor, name α. For practical designs it is $\alpha < 1$ (Soong and Darguish, 1999). The reaction P of the device is provided as shown in Eqn. (2.1), where Δ denotes the overall displacement and factor Sgm(Δ) denotes the opposition of the friction force to the internal spring force during unloading.

$$P = \frac{(1+Sgm(\dot{\Delta})a)K_s K_3}{(1+Sgm(\dot{\Delta})a)K_s + K_3}\Delta \tag{2.1}$$

In this paper, the resultant force of Eqn. (2.1) P during slippage is represented as the linear sum of a force due to elastic elements, name P_s of the device and another due to friction, name P_f, as shown in Eqn. (2.2).

$$P = P_s + P_f \tag{2.2}$$

From Eqn. (2.1), solving for P_f it is:

$$P_f = P - P_s \tag{2.3}$$

The elastic force P_s can be easily calculated by setting in Eqn. (2.1) factor α equals to zero. We obtain the following expression:

$$P_s = \frac{K_s K_3}{K_s + K_3}\Delta \tag{2.4}$$

Substituting Eqn. (2.1) and Eqn. (2.4) in Eqn. (2.3) we obtain that:

$$P_f = \left[\frac{K_3^{\,2}}{K_s + K_3} - \frac{K_3^{\,2}}{(1+sgm(\dot{\Delta})a)K_s + K_3}\right]\Delta \tag{2.5}$$

The elastic force P_s is constant throughout the dynamic response of the system and its contribution to the elastic response of a dynamic system (in which an EDR device has been implemented) can be easily taken into account.

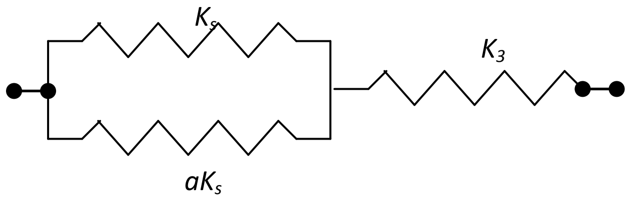

Figure 2. Typical EDR device.

3. EQUATIONS OF MOTION

A SDOF frame structure with two EDR devices implemented in its diagonals is considered, as shown in Fig. 3. The system is subjected to a seismic excitation which is simulated with a sinusoidal seismic wave. The characteristics of this wave are introduced in ground motion equation, in general, as:

$$U_g = \langle \bar{\omega} t - \phi \rangle^0 a \sin(\bar{\omega} t - \phi) \tag{3.1}$$

where α is the amplitude of the seismic wave, $\overline{\omega}$ is the frequency and φ the phase angle due to the non-zero distance L between the bases of the frame's columns. The phase angle is equal to:

$$\phi = \bar{\omega} L / V_s \tag{3.2}$$

where V_s is the velocity of the wave. The symbolic expression $h(x) = \langle x \rangle^0$ represents the *Heaviside* function.

Neglecting the contribution of the phase angle, the equation of motion can then be written as follows:

$$M\ddot{u} + C\dot{u} + K'u + P_f = -MU_g \tag{3.3}$$

where M denotes the mass, C the viscous damping of the structure and K′ the stiffness of the dynamic system including the contribution of the EDR devices. Namely, the factor K′ can be expressed by Eqn. (3.4), as follows:

$$K' = K + 2\frac{K_s K_3}{(K_s + K_3)\cos\theta} \tag{3.4}$$

where K is the stiffness provided by the structural members of the frame considered, and θ is the angle between the diagonals of the frame and the horizontal.

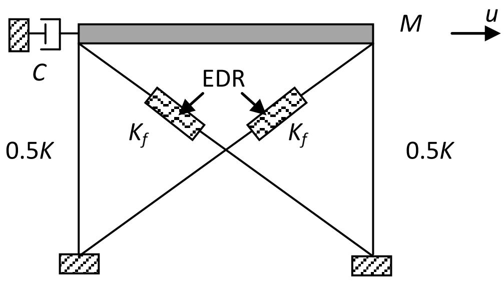

Figure 3. SDOF frame with EDR devices.

It is noted that since the resultant friction force P_f in Eqn. (2.5) can be expressed in the form:

$$P_f = K_f \Delta \quad , \quad \Delta = u/\cos\theta \tag{3.5}$$

the stiffness of the dynamic system is being affected by the contribution of the factor K_f. Of course, K_f takes different values during loading or unloading cycles of the EDR device. This results forcing the structure's overall stiffness to change, when the direction of the mass velocity throughout the loading cycles changes.

The frequency ω_D of the system is given as follows:

$$\omega_D = \omega_{nf}\sqrt{(1-\xi^2)} \tag{3.6}$$

where ω_{nf} is the eigenfrequency of the system due to K' and K_f as well, and ξ is the damping ratio due to the viscous damping of the structure.

4. ILLUSTRATIVE EXAMPLE

For the illustration of the process proposed, the following example is presented. A SDOF oscillator with dynamic characteristics: ω=14.1421rad/sec, T=0.4442sec and $\xi = 0.05$, is subjected to a sinusoidal ground motion with an amplitude of $\alpha = 0.02$ m and frequency $\overline{\omega} = 4\pi$ rad/sec. The frequency corresponds to period of seismic wave $T_s = 0.5$ sec. The oscillator is equiped with two diagonal EDR devices. The dynamic system is depicted in Fig. 3. The characteristics of the EDR devices K_s, K_3 and α as shown in Eq. (5) is assumed to have the reasonable values of 3500 kN/m, 200000 kN/m, and 0.9 respectively.

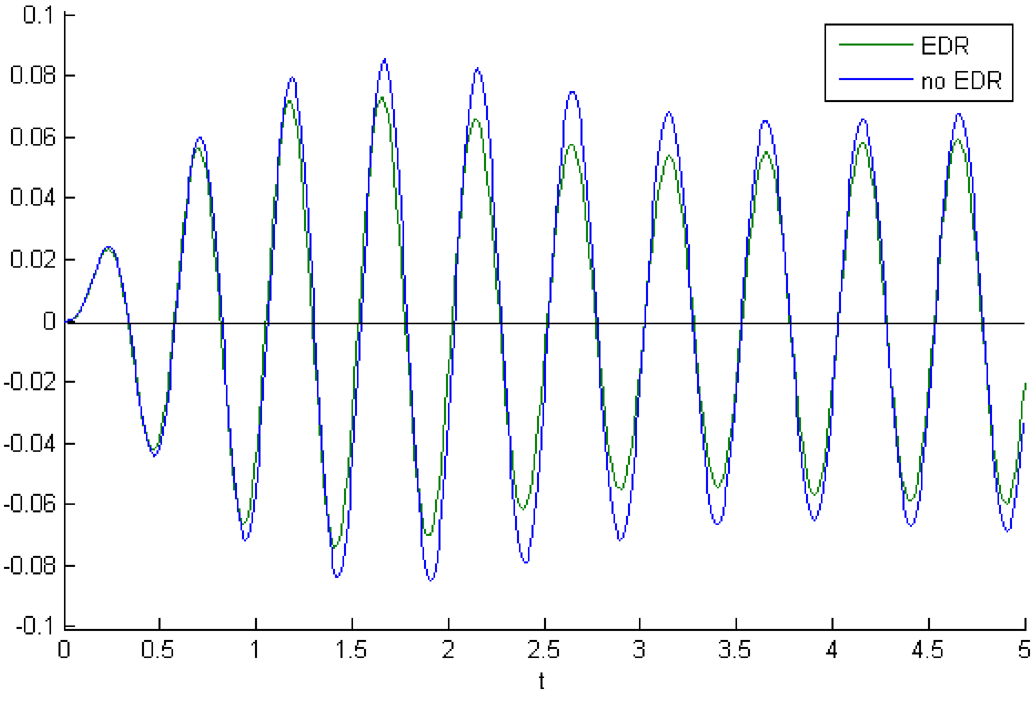

Figure 4. Comparison of the dynamic response of the oscillator with and without EDR

In Fig. 4 the response of the dynamic system considered is depicted. Due to the different frequency obtained per semi-cycle of oscillation, the response of the system equipped with EDR devices is observed to be aperiodic. Moreover, due to energy dissipation from the passive dampers considered, the relative displacement of the system is significantly reduced, as expected.

5. CONCLUSIONS

The case study investigated shows that the implementation of EDR devices leads to a strongly non linear dynamic behavior of the system considered. In particular, the approach proposed in this paper leads to equations of motion in which the elastic characteristics of the system continuously change per semi-cycle of oscillation. Thus, the natural frequency of the system changes accordingly. Based on the aforementioned remarks, the following conclusions can be treated:

- Decomposing Friction from Elastic forces leads to different frequency values, which alter “semi-periodically”.
- Critical excitation is avoided due to continuously altered frequency
- The process proposed leads to strongly nonlinear phenomenon

Further investigations needed, can conduct to practical recommendations for the designers.

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