Development of a nonlinear autonomous semi-active control algorithm

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1. Introduction

Friction dampers show rigid-perfectly plastic behavior that is advantageous to achieve reduction of acceleration with limited damper force. However, transmition of vibrations of high frequensies and appearance of residual displacements at the end of excitation, are the drawbacks of the dampers of this type. For semi-active control of structures, the Pseudo Negative Stiffness (PNS) algorithm was previously proposed and applied to the bridges by the authors **[1], [2].** The pseudo-negative stiffness algorithm describes the applied artificial nonlinear damping with the behavior like rigid perfectly plastic. To take advantage of mentioned systems and avoid of demerits, a new autonumous algorithm is developed to control the variable dampers and to provide semi-active control of structures during earthquake excitations. Numerical calculations are performed using a single-degree-of-freedom system to evaluate the proper performance of the algorithm.

2. Principles of proposed algorithm

For the newly proposed algorithm, the control system can reduce the vibration energy of the structure by applying an artificial nonlinear damping force in the low level excitations and provide a nonlinear behavior for the excitations higher than a certain level in order to suppress the acceleration level, and control the displacement. Suppose a single degree of freedom system shown in Figure 1. In this figure, k_2 and F_d indicate the linear stiffness of the system and the force produced by variable damper, respectively. When subjected to a seismic load, the equation of motion of the system is:

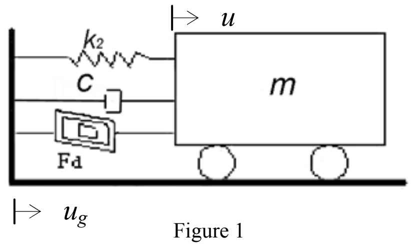

Figure 1

$$m\ddot{u} + c\dot{u} + k_2 u = -m\ddot{u}_g - F_d \qquad (1)$$

where, $\ddot{u}, \dot{u}$ and u are the acceleration, velocity and displacement of the mass m, relative to the ground and $\ddot{u}_g$ is the ground acceleration. c is the damping coefficient of the system. The algorithm utilizes the hysteresis component $Z(t)$, which is given by the equation proposed by Park and Wen **[3]** (Equation 2) in order to produce the required damping force value.

$$\dot{Z} = -\gamma|\dot{u}|Z|\dot{Z}|^{n-1} - \beta\dot{u}|Z|^{n} + A\dot{u} \qquad (2)$$

where, β, γ, A and n are the constants defining the shape of the hysteresis loop and controlling the behavior of the model. The hysteretic component $Z(t)$, has a value in the domain of [-1, 1]. The produced force command for the damper is the summation of the three components: F_1, F_2 and F_3 given by the following expressions:

$$F_1 = (1-\alpha)F_y Z \qquad (3)$$

$$F_2 = k_{d1}.Z.u_y + C_{d1}.\dot{u} \qquad \text{If } Z < 1.0$$
$$F_2 = 0 \qquad \text{If } Z = 1.0 \qquad (4)$$

If $(F_1 + F_2) > F_y$ *then:* $F_2 = F_y - F$

$$F3 = k_{d2}u + \mathrm{sgn}(\dot{u}).C_{d2}.\dot{u}^2 \qquad (5)$$

where $\alpha = \frac{k_2}{k_1}$, $\frac{F_y}{u_y} = k_1$, k_{d1}, k_{d2} and C_{d1}, C_{d2} are the negative stiffness and damping coefficients, corresponding to the F_2 and F_3 components, respectively. The factor $(1-\alpha)F_y$ is defined as the maximum shear force in the system, when F_1 reaches to the certain displacement as u_y. As is observed in the expressions, the algorithm requires only the displacement and velocity of the system at the location of the damper at each time step which limits the number of the required sensors.

The applied load by the variable oil damper is controlled through changing the opening ratio of the flow valve. During the numerical

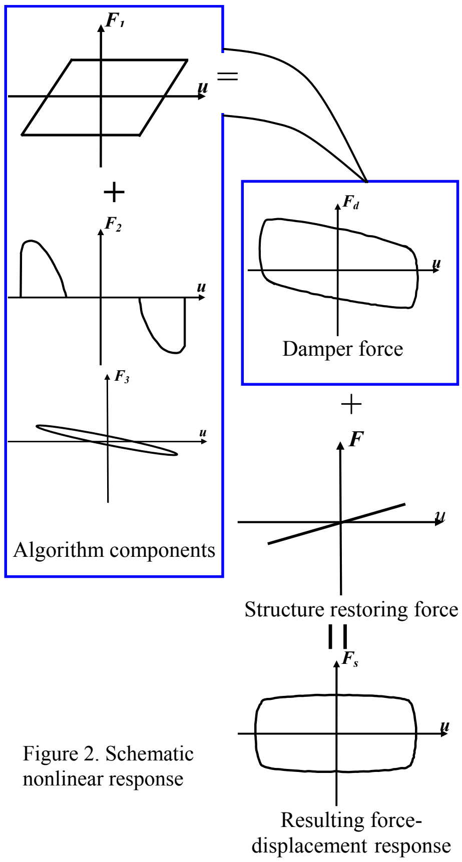

Figure 2. Schematic nonlinear response

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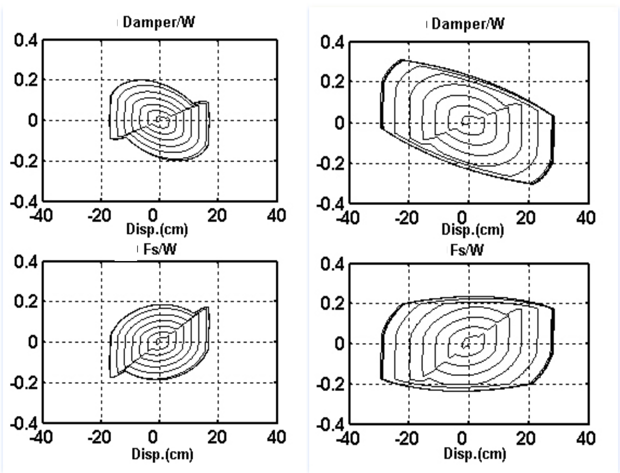
studies, a mathematical model of the available variable oil damper **[1]** is used as a filter to make sure that the computed damper force command can be produced by the variable damper device. An illustration of F_1, F_2, F_3, elastic force F and final base shear force F_s is depicted in the Figure 2.

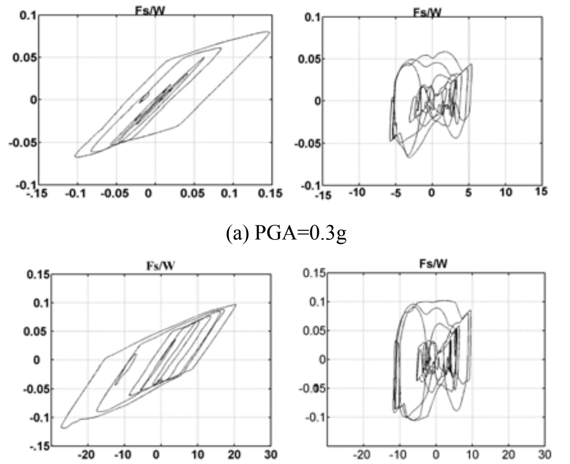
3. Numerical Studies

To assess the efficiency of the proposed control strategy, the discussion is extended to a numerical study for a single-degree-of-freedom case for the system $T_1=1.55sec.$ $F_y=0.25W$, $W=m.g.$ $u_y=15cm$ and $\alpha=\frac{k_2}{k_1}=0.3$ in which T_1 is defined as $2\pi\sqrt{\frac{m}{k_1}}$. The ratios of the damper force to the weight (Damper/W) and the base shear to the weight (F_s/W) under resonance ($\omega=\omega_1=\frac{2\pi}{T_1}$) harmonic load with amplitude of 3 $\frac{m}{s^2}$ (case a) and 5 $\frac{m}{s^2}$ (case b) are depicted in Figures 3-a and 3-b, respectively. In order to evaluate the behavior of the control algorithm under stochastic loads, El Centro 1940 ground motion with two levels of PGA=0.3g and PGA=0.6g, are applied to the system. The response of the system then is compared with a case facilitated by a bearing which has bilinear behavior which can be a representative of the systems isolated by lead rubber bearings. For this purpose the new system characteristics are as: $T_1=1.63sec.$, $F_y=0.15W$, $W=m.g.$ $u_y=10cm$ and $\alpha=\frac{k_2}{k_1}=0.3$. The ratio of the base shear to the weight (F_s/W) and the displacement (cm) are depicted and compared with a bilinear system in Figures 4-a, 4-b. The maximum response of displacement and F_s/w under El Centro 1940 ground motion with PGA=0.3g are 6cm, 0.07 and 15, 0.08 for the controlled and bilinear system, respectively and under PGA=0.6g, 11cm, 0.11 and 27, 0.12 for the controlled and bilinear system, respectively. The control device is shown to be able to control the base shear and displacement response of the system successfully by producing a proper artificial nonlinear damping force command.



(a) 3 $\frac{m}{s^2}$ (b) 5 $\frac{m}{s^2}$

Figure 3. Damper force and Base shear response under resonance harmonic load



(a) PGA=0.3g

(b) PGA=0.6g

Figure 4. Response of a bilinear model and proposed system under El Centro 1940 ground motion

4. Conclusion

A new nonlinear autonumous semi-active control algorithm is proposed. The algorithm requires the values of displacement and velocity only at the location of damper in each time step to compute the control load. Numerical studies showed that in two levels of excitations the algorithm can produce a proper artificial nonlinear damping force and produces a proper hysteresis loops in order to dissipate maximum amount of energy while keeping the force in a reasonable level. Numerical results confirmed the proper behavior of the control on seismic response control of the system.

5. References

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