Earthquake Performance of Coupled Building by VF Damper

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ABSTRACT :

Earthquake hazard mitigation through structural control approach has become very popular and practicable over last two decades. Researchers have developed various control devices to make the control strategy very effective for seismic response control. Out of various control system, semi-active control devices have emerged as very attractive systems, for their obvious advantages of reliability and versatility, over last one decade. It has been found that pounding between adjacent building have caused significant damage in past major earthquakes, therefore, to address this problem a scheme of coupled building control has been devised by the researchers. Under this the adjoining floors of the two adjacent buildings are rigidly connected through inline dampers, such as a system has dual advantage of pounding avoidance and response control for both the buildings. In the present study the effectiveness of one of the most promising semi-active devices, namely, variable friction (VF) damper is being investigated under coupled building control scheme. The efficacy of the proposed strategy is investigated taking numerical example of two adjacent buildings of twenty and ten stories respectively. Further, the influence of VF damper gain multiplier on the performance of the control strategy is also examined. The results have showed that the effectiveness of VF damper for seismic response control under coupled building control. It has been noted that the performance of the control scheme is influence by the VF damper gain multiplier parameter and there is an optimum value of the same.

KEYWORDS: Adjacent buildings, Coupled building control, Semi-active control, Seismic response.

1. INTRODUCTION

Over the past two decades, a great deal of interest has been generated regarding the use of structural control systems to mitigate seismic hazards for civil engineering structures. The traditional approach for seismic protection has been relied on the structures having sufficient strength capacity and ability to deform in a ductile manner. But inadequacy of this approach has been identified during past major earthquake; therefore, relying and developing aseismic design approach also known as structural control approach is the obvious option. This approach has been pursued effectively by the researchers and being implemented in practices. The structural controls are broadly classified in two three groups, that is, passive controls, active controls and semi-active controls. Amongst the three control strategies the semi-active control systems have attracted the maximum attention or researchers over last one decade as they combine the reliability of passive devices along with versatility of active systems without the use large power requirement. Symans et al. (1999) have provided an excellent review of semi-active devices under a state of the art paper. Some of the common type of semi-active devices is: stiffness control devices, friction control dampers, controllable fluid dampers and fluid viscous dampers. It has been observed by the researchers that dissipation of seismic energy through friction mechanism has been quite effective over a wide range of ground motions and under this as an improvement over passive friction damper has been developed in terms of semi-active friction damper, also known as variable friction (VF) damper. In order to predict the dynamic behaviour of semi-active friction damper researchers have proposed various algorithms (Inaudi, 1997; Xu et al. 2001, Lu, 2004).

It has been noted that control devices are used in buildings systems under various configurations, and out of these the scheme of interconnecting adjacent building through supplemental energy dissipating devices has become an effective approach and gives dual advantage of pounding avoidance and seismic response control. Researchers have been investigating the effectiveness of various devices under coupled building control schemes (Westermo, 1989; Zhang and Xu, 2000; Xu et al. 1999; Matsagar and Jangid, 2003, Bhaskararao and Jangid, 2006 etc). It has been observed that in last one decade the coupled building control has become a viable and effective control strategy for seismic hazard mitigation of adjacent buildings.

The focus of the present study is to investigate the effectiveness of VF damper in a coupled building control scheme. Two dynamically dissimilar adjacent buildings with adjoining floors rigidly connected through VF dampers are considered. The precise objectives of the study are outlined as under

1. Examine the effectiveness of proposed semi-active coupled control system for seismic response control of two adjacent buildings.
2. Study the influence of VF damper gain multiplier parameter on the efficacy of the proposed control strategy.

2 STRUCTURAL MODEL OF COUPLED BUILDINGS

Two buildings of different dynamic characteristics are idealized as linear shear type building with lateral degrees of freedom at their floor levels. The system is assumed to remain in linear elastic state and hence does not yield under excitation. The floors of both buildings are at the same level, but the numbers of stories are different. For general case, Buildings 1 and 2 have (m+n) and n stories respectively, as shown in Figure 3.1. The combined system will then be having (2n+m) degrees of freedom. It is considered that system is subjected to unidirectional excitation and spatial variation of ground motion and any effect due to soil structure interaction is neglected. The gap between two adjacent floors is used to rigidly inter-connect the buildings with MR dampers. The lateral resistance of the buildings is assumed to be so large that it does not affect the dampers performance adversely.

The governing equations of motion of the coupled system in matrix form is expressed as

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=-[M]\{r\}\ddot{u}_g+[D_p]\{f_d\} \tag{1}$$

where, M, C, and K are mass, damping, stiffness matrices of the combined system respectively; fm is the vector consisting of forces in the MR dampers; D is the damper location matrix; u is the relative displacement vector with respect to the ground and consists of Building 1's displacements in the first (n + m)positions and Building 2's displacements in the last n positions; r is a influence coefficient vector which contains elements equal to unity; and is the earthquake ground acceleration.

The matrices M, K and C are for the combined system are explicitly defined as

$$\underset{(2n+m,2n+m)}{M}=\begin{bmatrix}\underset{(n+m,n+m)}{[M_1]} & \underset{(n+m,n)}{[O_1]}\\ \underset{(n,n+m)}{[O_2]} & \underset{(n,n)}{[M_2]}\end{bmatrix};\ \underset{(2n+m,2n+m)}{K}=\begin{bmatrix}\underset{(n+m,n+m)}{[K_1]} & \underset{(n+m,n)}{[O_1]}\\ \underset{(n,n+m)}{[O_2]} & \underset{(n,n)}{[K_2]}\end{bmatrix};\ \underset{(2n+m,2n+m)}{C}=\begin{bmatrix}\underset{(n+m,n+m)}{[C_1]} & \underset{(n+m,n)}{[O_1]}\\ \underset{(n,n+m)}{[O_2]} & \underset{(n,n)}{[C_2]}\end{bmatrix} \tag{2}$$

The equations of motion (Eq. 1) is represented in the of state-space form.

$$\{\dot{z}(t)\} = [A]\{z(t)\}+[B_d]\{f_d(t)\}+[E]\ddot{u}_g(t) \tag{3}$$

where, z is the state variable, A is the system matrix composed of structural mass, stiffness, and damping, B_d and B_b are the distribution matrices for the damper and bearing forces respectively and E is the excitation matrix and are explicitly given as

$$\dot{z}=\begin{bmatrix}\dot{u}\\ \ddot{u}\end{bmatrix};\ z=\begin{bmatrix}u\\ \dot{u}\end{bmatrix};\ A=\begin{bmatrix}O & I\\ -M^{-1}K & -M^{-1}C\end{bmatrix};\ B_d=\begin{bmatrix}O\\ M^{-1}D_p\end{bmatrix}\ \text{and}\ E=\begin{bmatrix}O\\ -r\end{bmatrix} \tag{4}$$

where, $[I]$ and $[O]$ are the identity and null matrices, respectively; vector $\dot{z}\,(t)$ represents the state of structural system which contains relative velocity and acceleration responses of structure with respect to ground.

Computation of VF Damper Force

In order to compute force in the VF damper, a control algorithm, called predictive control law (Lu, 2004) is used, in which, variable slip force of a semi-active VF damper is kept slightly lower than the critical friction force that allows the damper to remain in slip state during an earthquake, which improves the energy dissipation capacity of the damper. The Eq. (.2) is descritized in time domain (Meirovitch, 1990) and expressed as

$$z(t+\Delta t) = A_d z(t) + B_{dd} f_d(t) + B_{db} f_b(t) + E_d \ddot{u}_g(t) \tag{5}$$

where, (t) and $(t+\Delta t)$ denotes the time step at which a state variable is evaluated, A_d represents the discrete-time system matrix, B_{dd}, B_{db} and E_d are the constant co-efficient matrices which are the discrete-time counterpart of matrices of B_d, B_b and E (Eq. 2.2) respectively and are explicitly expressed as, $A_d = e^{A\Delta t}$, $B_{dd} = A^{-1} (A_d - I) B_d$, $B_{db} = A^{-1} (A_d - I) B_b$, and $E_d = A^{-1} (A_d - I) E$, where, I is the identity matrix.

The critical friction force (f_{cr}) of semi-active variable friction damper is given by

$$f_{cr}(t) = \left[G_1 z(t-1) + G_2 f_d(t-1) + G_3 \ddot{u}_g(t-1) \right] \tag{6}$$

where, G_1, G_2 and G_3 are the control gain parameters and are given as $G_1 = k_b D_e (A_d - I)$, $G_2 = k_b D_e B_d + I_e$ and $G_3 = k_b D_e E_d$, where, I_e *is* the another identity matrix with dimension ($N \times N$), k_b is the matrix of bracing stiffness in which diagonal elements and is given as $[k_{br}] = n_b \times k_{br} \times D_e$; where n_b is the number of bracings provided to each story, k_{br} is the bracing stiffness equal to storey stiffness, D_e is a constant matrix composed of damper orientation and is described by the damper displacement and state variable is $u_d(t) = D_e z(t)$

A damper (slip) force from the VF damper is computed by the following equation as

$$f_d(t) = R_f \left[G_1 z(t-1) + G_2 f_d(t-1) + G_3 \ddot{u}_g(t-1) \right] \tag{7}$$

where, R_f is a selectable parameter, called gain multiplier parameter which is the ratio of damper force (slip force) to the critical force of friction.

3 NUMERICAL STUDY

Two adjacent RC buildings of twenty and ten story with same floor mass and interstory stiffness, and inline floors rigidly connected with semi-active VF damper is considered for the study. Both the buildings are idealized as linear shear type buildings with masses lumped at floor levels. The mass and stiffness of the buildings are so chosen to yield the fundamental time period of Building 1 (softer building) and Building 2 (stiffer building) as 2.04s and 1.04s, respectively. The system is subjected to unidirectional excitation for which Imperial Valley earthquake, 1940 (PGA=0.348g) is considered. The VF dampers are used for interconnecting inline adjoining floors with bracing having stiffness (k_{br}) equal to the lateral story stiffness of building (k_s). In order to examine the influence of gain multiplier parameter (R_f) of VF damper on the performance level of the control strategy, four values of R_f, (i.e. 0.1, 0.3, 0.5 and 0.7) are chosen. The response parameters of interest are: top floor displacement and acceleration, normalized story shear and normalized base shear. The story shear and base shear are normalized by weight of respective building.

The time varying response of top floor displacement, acceleration, base shear for Building 1 and 2, are shown in Figures 2 and 3, respectively. It is observed from the figures that significant reduction in response is obtained under coupled building control for both the buildings. The influence of VF damper gain multiplier parameter (R_f) on the control performance in terms of peak floor displacement, acceleration and story shear of both the buildings is depicted in Figure 4. It is noted that there is an optimum value of damper gain parameter for best response control.Hysteresis behaviour of VF damper, connecting 10th floors of two buildings, for all considered values of parameter R_f, is shown in Figures 5. The figure depicts the influence of the parameter on energy dissipating characteristics of the damper. It is noted that increase in value of damper parameter leads to increase in damper force but decrease in damper displacement, however, this may not lead to efficient energy dissipation. Therefore, it is concluded that value of damper gain parameter must be appropriately chosen in order to have efficient hysteresis behaviour of the damper.

4 CONCLUSIONS

The effectiveness of VF dampers for seismic response reduction is examined in a coupled building control scheme. It is observed that the VF damper is an effective device to control the response of both the buildings. However, in order to attain best control performance the VF damper parameter must be appropriately chosen. From the trends of the results of the study the following major conclusions can be drawn.

1. The control scheme of coupling two adjacent buildings using VF damper linkages is very effective for seismic response reduction for both the buildings.
2. The response control is better for shorter building.
3. There exist an optimum value of VF damper parameter R_f for which reduction in overall response is achieved for wide range of ground motions. In the present case VF damper parameter value equals to 0.1 is showing overall best performance.

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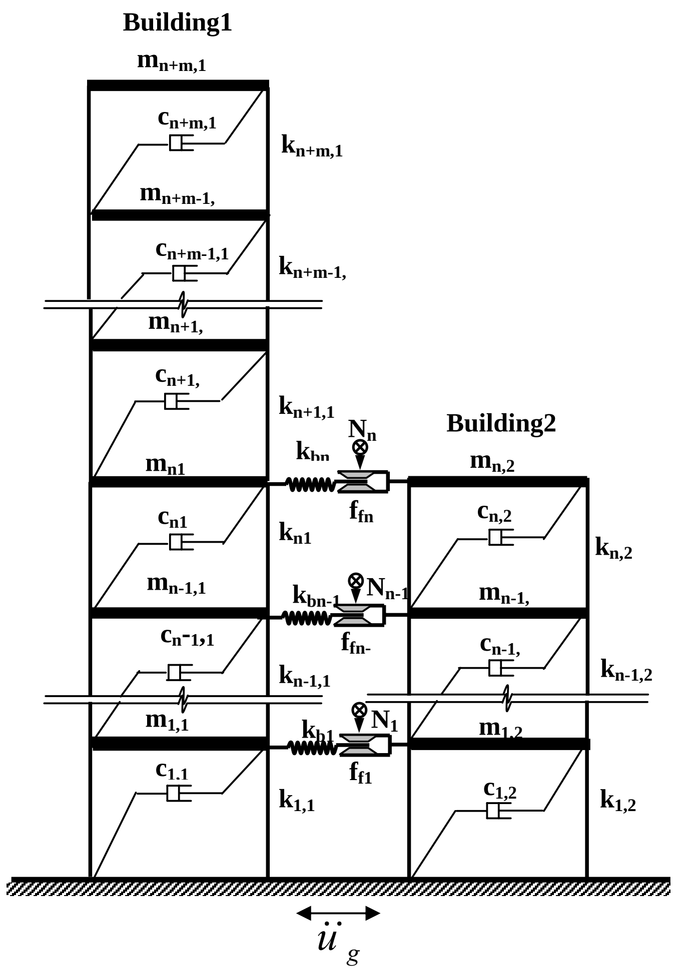

Figure 1 Structural model of coupled building with VF damper

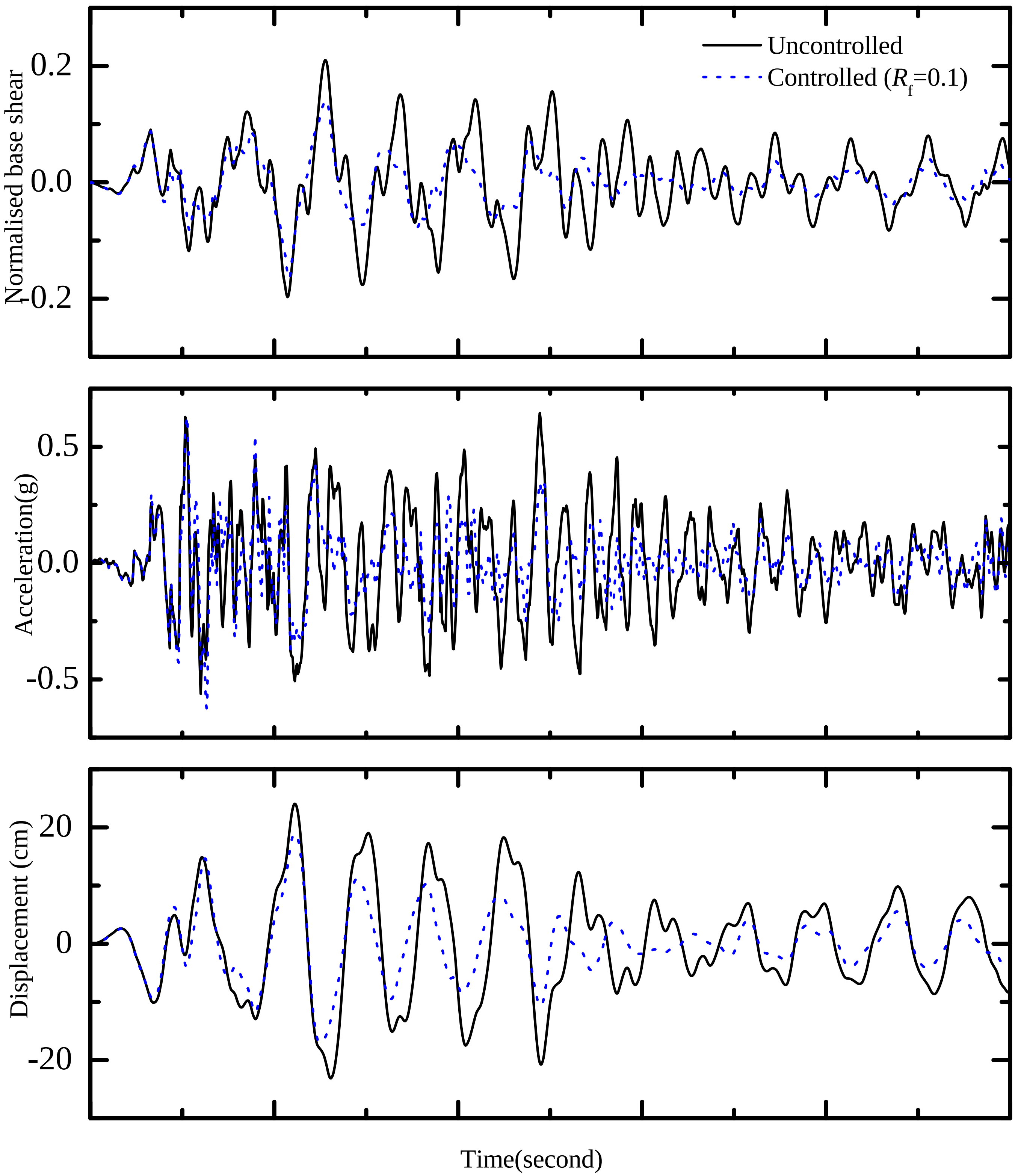

Figure 2. Time response of Building 1

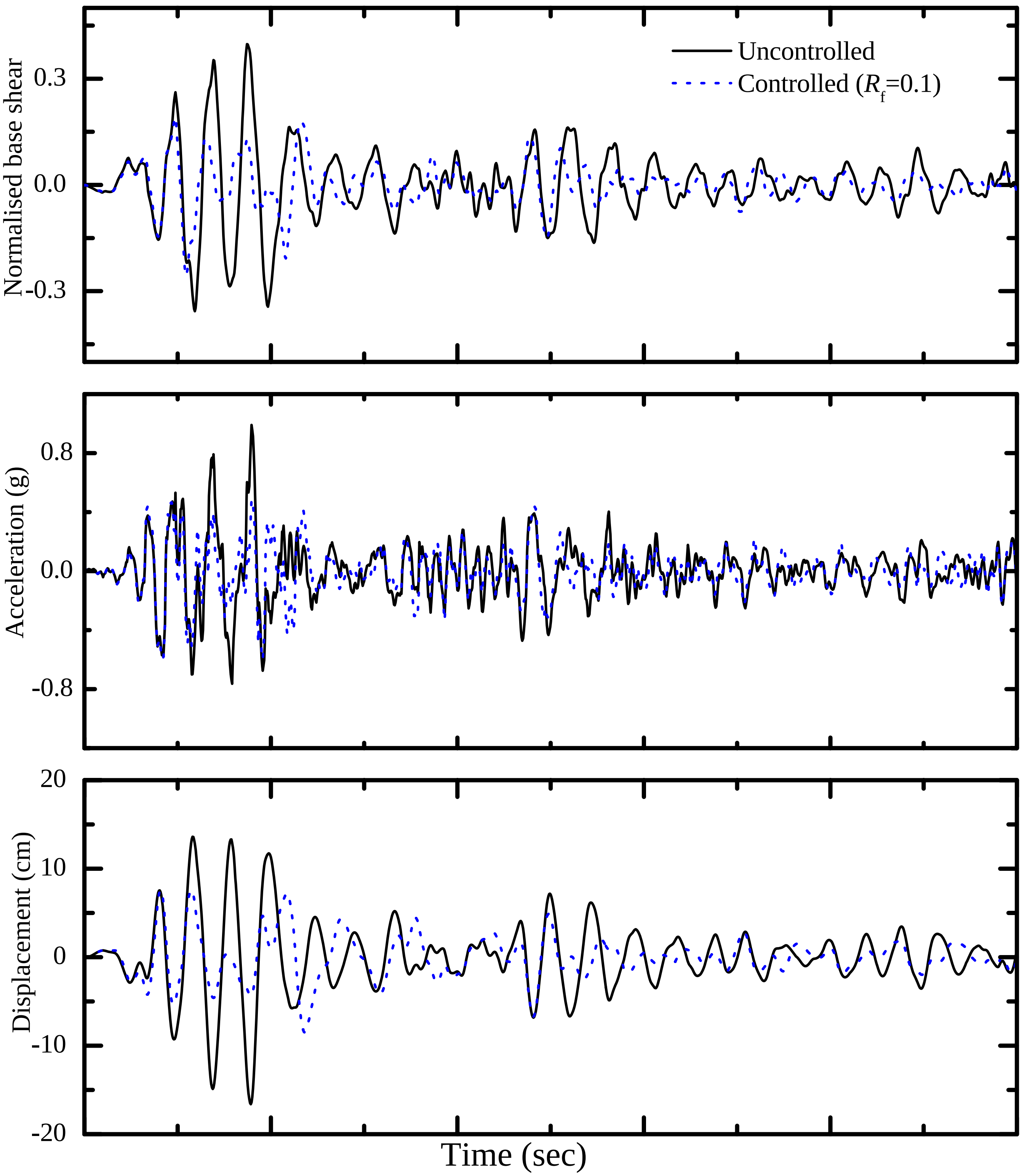

Figure 3. Time response of Building 2

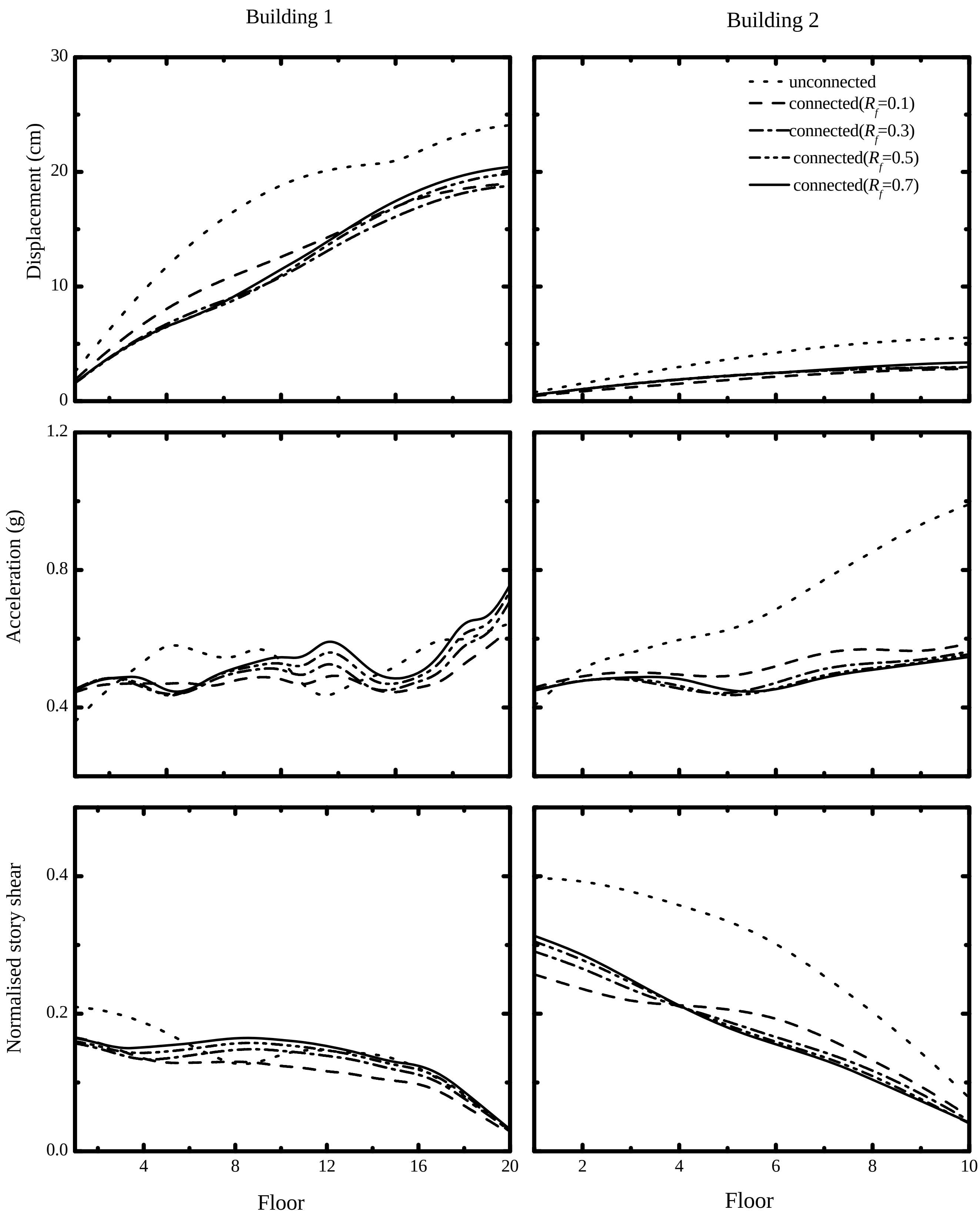

Figure 4. Peak response of floors of Building 1 and 2

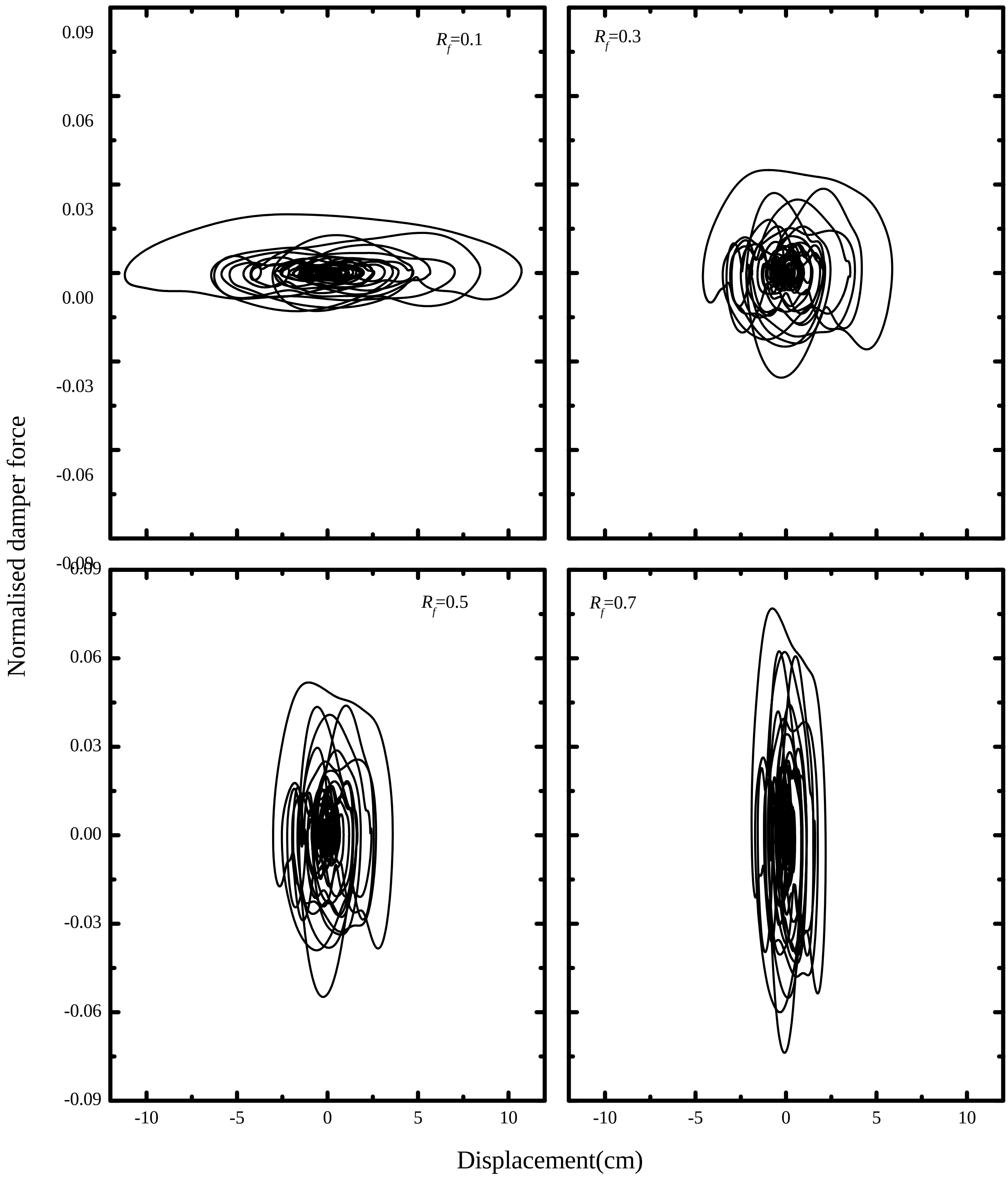

Figure 5. Hysteresis behaviour of VF damper under El-Centro, 1940