STUDY ON EFFICACY OF ACTIVE CONTROL DEVICES IN VIBRATION CONTROL OF STRUCTURES

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Abstract- Damper application in framed structures is primarily foreseen to improve the structural performance against earthquake. Especially base isolation attached with dampers and controllable devices gaining momentum and popularity for many reasons. By and large, the generation of control strategies along with system dynamics conception was not used for entire structural applications. In this study, a steel frame model integrated with damper was developed. MR (Magneto-Rheological) dampers were fixed at critical joints of steel frame act as control device. A control algorithm has been developed to facilitate MR damper. System approach is stimulated by quasi-dynamic controller; conversely, the developed algorithm assigns weights as like fuzzy logic controller. In addition, Piezo-actuator and force transducers with conditioning amplifier have been used. Currently several strategies followed for ideal placement of sensors in control systems. The compatibility of accelerometers and transducers located at trial spots of structure was quantified. Accelerations and damping force induced in the structure was calculated and found less in structures fixed with dampers, the developed algorithm is compatible to command damper.

Keywords: Structural performance, controllable devices, MR dampers, control algorithm, System approach.

1 INTRODUCTION

Plentiful techniques were developed for installation of controllable devices in control systems used in vibration analysis. At present, idea of implementing controllability in dynamic system gaining popularity in vibration control [1-3]. Generally, controllability characteristics controlled by varying actuator and sensor configurations. The concept of optimization mainly focusing the effective performance of the system with minimal cost. When a system is placed with actuators and sensors at nodes of vibration will entail a control force [4-11]. Hazdan and Nayf found an angle between control device and modal nodes based on categorical relationships of vector spaces. They considered observability as eigenvectors and input of the response as column vectors [12-18]. Besides, the eigenvectors and column vectors have been furthermore upgraded by adding the magnitude, and protracting the results implemented in ordinate system. This system is generally advantageous since it consider controllable forces of the system [19-25].

This study momentarily explains the concept of controllability approach in structural systems. Controllability approach consists of reckoning of system norms for located devices at chosen modes, devices are graded based on their enactment of control system norm. Linear Quadretic algorithm and its cost function is 2-norm and very simple compared to other algorithms [26-28]. Hankel singular norm method is proposed in this study. It is most preferable because it greatly responds for controllability. If sensors are not exactly located at critical evaluation locations and actuators are not located at critical disturbance points then fixation indices have to be considered with closed-loop effects. New control algorithm is employed for MR damper for vibration control in G+2 building model. To make this approach more appropriate for civil applications, this study anticipates only two conditions, actuator placement with disturbances and sensor collocation with performances. The normalization procedure is much effective in plummeting floor accelerations and inters storey drifts without excess control force [29-32].

2 OUTPUTS OF CONTROL SYSTEM WITH FEEDBACK LOOP

Control system comprises of two inputs viz. control and disturbances, in addition plant outputs consist of outputs of control element and response measurements. In vibration control, sensors and control devices are located at suitable location, fixing devices near disturbance and outputs are not necessary. Cross couplings in feedback loop is considered between inputs and outputs of control system, scrutinizing the effects for placing devices as per structural norms becomes essential to assess performance. Initially inputs and outputs of control model are anticipated.

Control input u produced by feedback control system of the plant. Control system has two outputs measurement and regulated output **y** and **z** respectively. Close loop of the system is padlocked among the inner response generated by the controller and output of system. Commonly measurement output will differ from regulated output based on certain applications.

$$I_{uz}(s) = X_Z(sI - A)^{-1}B+Q_Z, \quad I_{uy}(s) = X_{\mathbf{y}}(sI - A)^{-1}B+Q_y$$

$I_{wz}(s) = X_Z(sI - A)^{-1R} + R_z$, $I_{wy}(s) = X_{\mathbf{y}}(sI - A)^{-1R} + R_y$ (1)
Closed loop function becomes,

$$I_{\mathbf{wz\text{-}cl}} = I_{\mathbf{uz}}\,(K - I_{\mathbf{cy}}\,I_{\mathbf{uy}})^{-1} K I_{\mathbf{wy}} + I_{\mathbf{wz}} \quad (2)$$

$I_{\mathbf{uy}}$ is the functional matrix of **u** to **y,** $\mathbf{I}_{wy}$ be the transfer functional of **w and y**, $\mathbf{I}_{wz}$ is the functional matrix of **w** and **z,** $\mathbf{I}_{uz}$ is the transfer matrix of **u** to **z.** The transfer function of open-loop expressed by Equation (5) specifies performance of feedback system through different input responses from **u** to **y** along with **u** to **z** and **w** to **y.** Conversely if the functional matrix of $\mathbf{I}_{wy}$ or $\mathbf{I}_{uz}$ found zero then the loop could not find any influence response.

In case of placement indices, the control device connectivity $\mathbf{I}_{uy}$ is one of the important factors which govern the performance of closed-loop. This make placement indices problem complicated if $\mathbf{I}_{uy}$ or $\mathbf{I}_{wz}$ decreases with ith mode and eminence of location is recognized by $\mathbf{I}_{uy.}$, the modal norms of control system holds

$$\|\mathbf{I}_{wz,i}\|\|\mathbf{I}_{uy,I}\| \cong \|\mathbf{I}_{wy,I}\|\|\mathbf{I}_{uz,I}\| \quad (3)$$

Where ||.|| symbolizes Henkal norms for ith mode. Functional property may be resolute directly by the indefinite relationship between transfer functions. This property prefigures norms of performance loop found to be identical for every mode i.e responses received as input from actuators and sensors which is almost similar to norms of cross-couplings related to sensors, and actuators of the control system. It also signposts that enhancement in $\mathbf{I}_{wy}$ spontaneously leads to enhancement in $\mathbf{I}_{\mathbf{z}y}$ and $\mathbf{I}_{uz.}$ Thus, deploying $\mathbf{I}_{uy}$ with out considering other factors can results in sensors and actuators locating complications. The output is vital for locating devices. Equation. (3) Indicate Laplace transforms of vectors. The functional element of the ayaten is

$$\begin{bmatrix} Q \\ R \end{bmatrix} = I(s) \begin{bmatrix} U \\ Y \end{bmatrix} = \begin{bmatrix} I_{uz} & I_{wz} \\ I_{uy} & I_{wy} \end{bmatrix} \begin{bmatrix} U \\ Y \end{bmatrix} = \begin{bmatrix} I_{uz}\ U + I_{wz} & Y \\ I_{uy} U + I_{wy} & Y \end{bmatrix}. \quad (4)$$

Transfer function of control system is

$$X = \lfloor I_{cr} \quad I_{cy} \rfloor \begin{bmatrix} R \\ Y \end{bmatrix} = I_{cr}\, R + I_{cy}\, Y. \quad (5)$$

Changing the input variable the above equation becomes

$$X = (K - I_{cy}\, I_{uy})^{-1}\ I_{cy}\ I_{wy}\ W. \quad (6)$$

3 RESULT AND DISCUSSIONS

3.1 Locating Control Devices

To outline the placement indices based on sensor and actuator location model, the following information (i.e location of actuator in input influence matrix B and location of sensor response matrix C) is needed. This placement stratagem applicable for the cases where actuators synchronized with disturbances. Sensors are synchronized with performance. Fixation or placement of control devices at critical collateral locations becomes inevitable. Appropriate locations only give suitable responses to the control devices.

Accelerometers should mount on all boundaries of floor as well as the base. Totally two accelerometers should be place. One accelerometer should be place in x direction and another should be placed in y direction, 12 accelerometers have been placed in all floor. 3 number of sensors have been placed and it is sufficient since each floor has three DOFs. Fixed sensors will capture the responses of the floors. Foremost priority should be given to the task of placing devices at desired modes and sensible locations to attain higher controllability, a realistic subset of sensors having higher absorbability is much preferable.

Hankel norm for each mode is the root mean square of single control device,

$$r_i = \sqrt{\sum_{j=1}^{s} \gamma_{ij}{}^{2}} \text{ or } \gamma_i = \sqrt{\sum_{k=1}^{r} \gamma_{ik}{}^{2}} \quad (7)$$

As a final point, Hankel norm is the prevalent norm of ith mode,

$$\|Z\|_h \cong \max_i \|Z\|_h = \mu_{max} = 0.48\,\|Z\|_\infty. \quad (8)$$

Where, μ_{max} is considered as maximum output value of control device. Above mentioned equations provides normalized indices using Hankel norms. Hence indices range around 0 to 1. In case of actuator placement, the index $\boldsymbol{\rho}_{ij}$ that appraises the jth iteration mode regarding Hankel norm for common modes is formulated as

$$\boldsymbol{\rho}_{ij} = \frac{\| Z_{ij} \|_h}{\| Z \|_h}. \quad (9)$$

Likewise, the placement index of the control device that appraises the *i*th mode of the *k*th sensor is defined as

$$\boldsymbol{\rho}_{ij} = \frac{\| Z_{ik} \|_h}{\| z \|_h}. \quad (10)$$

Locating sensor devices in nearby localities are not preferable because the enactment gains at nearby locations by devices subjected to response adjustments. The paramount stratagem is to identify locations that are not disturbed by gain adjustment.

With respect to the above approach, placement indice has been customized for 3D benchmark base isolation problem, locating sensor is much malleable, and hence actuator positions are uncompromising initially. The brief procedure is mentioned below :

- Placement of control devices at critical nodes, locating devices in 2D direction. It is assumed that, each position is located with two sensors, one in *x*- and another in *y*-direction, based on this C_m matrix is fixed. For every location, the modal matrix B_m is calculated and the Hankel for locadted modal point i.e 40×14 placement indices matrix was formed.
- Almost 18-22 locations have been selected for locating control device in the lower portion of modes.
- Correlation coefficients have been calculated for chosen locations. Discard actuators having I(k) = 0. The resultant values (if 8) that is the final one. If obtained number is <10, additional locations have to be included in step2. In case, number is <10, condense the locations.
- Fix B_m matrix based on the set of control device locations. Calculate the sensor placement indices, considering sensors were placed at corners of the model and none on floors for determining C_m matrix. Repeat the procedure until 8×24 index matrix has been formed.
- Eliminate inconsequential floors which have low sensor placement indices.
- Corner indices are calculated for other outstanding floors.

3.2 Placement of Sensor for Benchmark Problem

In benchmark problem of 3D structure, different parameters of structure are known. The damping effect and bearing stiffness have been considered as optimal parameters for rheological dampers. These parameters are calculated. The model has 4 corners, hence eight locations are selected for fixation of accelerometers for the floor, and few of them are redundant. Totally six accelerometers 3 per floor fixed to measure the various motions of the floor. Above mentioned steps are computed for corner indices of 3 to 8floors. At each corner 2 accelerometers were placed in the direction of x and y of the floor. Compute the indices and replicate the same procedure for remaining floors.

3.3 Performance of Active Control Devices

Performance of set of sensors was calculated and compared for responses of structures. Linear Quadratic Graph has been chosen as control algorithm, and MR dampers have been used as active controller to investigate the behavior of structural systems under excited state. Counter drifts are calculated along base accelerations. The top floor accelerations of the model also calculated and found to be 4.26 m/s^2 whereas the top floor accelerations of the model with control device were found to be 3.96 m/s^2. Similarly, the acceleration induced in first floor of the model without control device was found to be 1.96 m/s^2 whereas acceleration with control device was found to be 1.86 m/s^2. The acceleration of the structure during excitation is shown fig.1 and fig.2

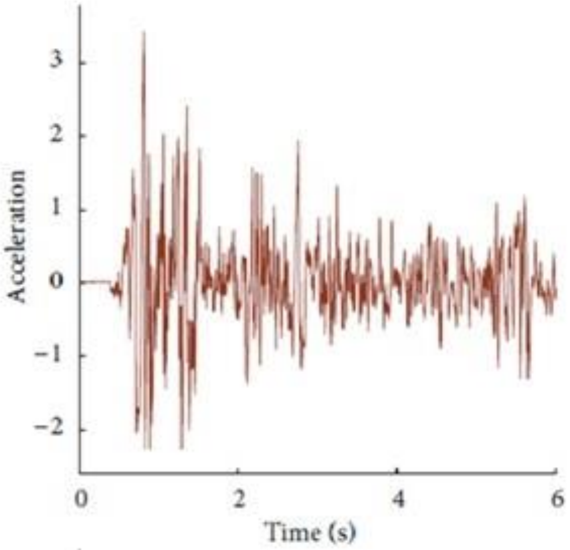

Figure 1 Acceleration induced in top floor

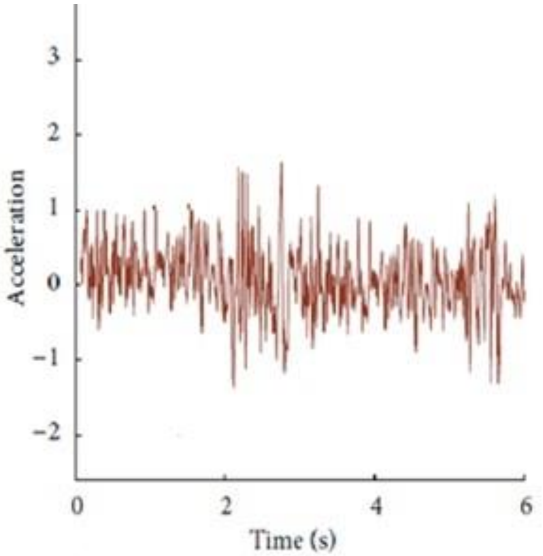

Figure 2 Acceleration induced in first floor

Relevant velocity has been deliberate for the applied force for two conditions i.e with and without control device. The responses were recorded and denoted by passive on, passive off. The velocity of the system increases with respect to the force. For passive on condition, considerable velocity reduction for observed in the system. It is evident that installation of control device considerably reduces the velocity induced by the force. Force Vs velocity of the system is shown in fig.3.

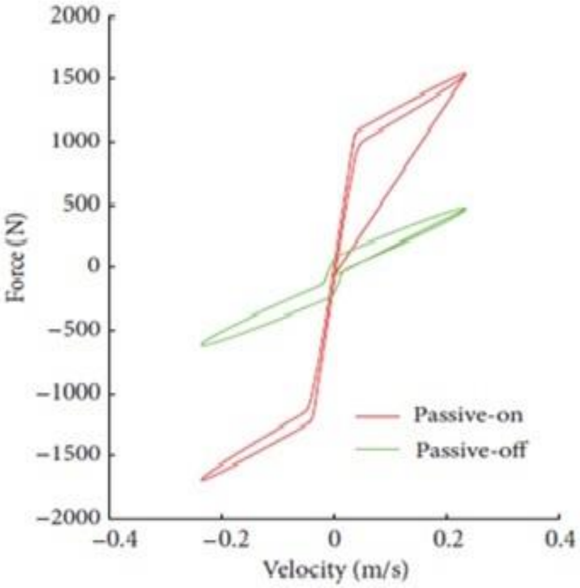

Figure 3 Force Vs Velocity of response system

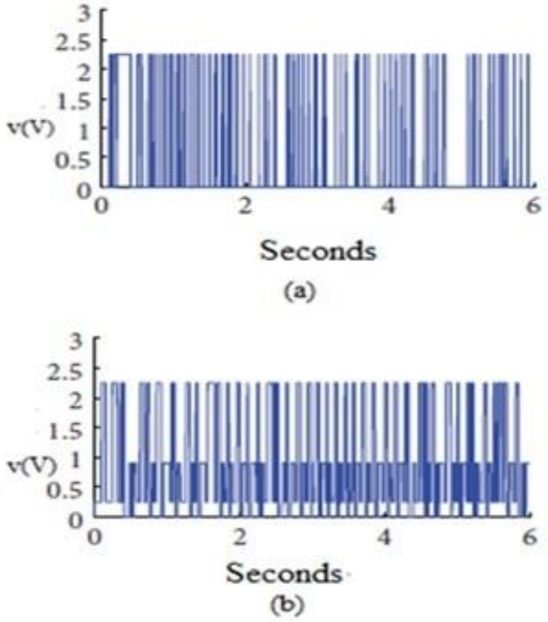

Figure 4 Control voltage passed to damper (a) Passive on (b) Passive off

Noise induced in sensors is pretend by toting a range of noise induced by signal have been scaled a RMS value of 2.8% of the analogous RMS responses of the passive system. Time history responses were calculated between 2nd and 3rd floors. Base drift, roof accelerations and inter-story drift were measured for sensor placed in *x* direction of the floor. It was found that, response values are in very close and variations in the performance of 2 systems are not extensive.

Control voltage passed to the damper for both conditions are shown in Figure 4. Controller produced constant voltage of 2.2 volt to rheological damper. The input varied from 0.2 to 2.2 with respect to time to reach the peak response. However, constant input voltage of 2.2 V has been identified as the optimal voltage.

4 CONCLUSION

Controllability approaches have been anticipated to adopt actuators and sensors effectually. Placing control devices are invariant. Based on Hankel singular values, control devices are adopted for balanced and unbalanced systems. Validation for MR dampers that are not collocated with disturbances are mandatory to eliminate duplication locations with high correlations is neglected. The reduction in floor drift confirms the potential use dampers against seismic vibrations. This divulges that MR dampers are auspicious and capable of protecting building against earthquake. Hence usages of control devices for several vibration control applications under different excitations are recommended.

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