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Decentralized control of tall shear structures against sensor failures and uncertainty in earthquake excitations

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ABSTRACT: This paper uses centralized and decentralized H∞ controllers with static output feedback and linear matrix inequality theory (LMI) as well as a number of changes in LMI variables to retrofit shear structures against a variety of uncertainties. The robustness of this method is evaluated both in centralized and decentralized controls against dynamic forces such as earthquake, uncertainty in earthquake excitation and sensor failure, then structural responses are compared. Finally, the responses of the used control algorithm are compared with the results of the linear quadratic regulator controller (LQR). There are two structural models, including 5 and 20 stories shear structures. The results indicate good robustness of the used control algorithm to the failure of the sensors, the clear difference in response values of the applied algorithm compared to the LQR method, and near results in centralized and decentralized controllers. Although the earthquake excitations uncertainty changes the responses but still controlled responses are clearly less than the uncontrolled responses.

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1. INTRODUCTION

Structural failure due to vibrations is one of the issues that are dealt with extensively today. Various methods are used to reduce the harmful effects of vibrations. One of the most effective methods is centralized and decentralized active controls, [1-5].

Systems equipped with decentralized controllers, similar to centralized controllers, are sensitive to sensor failures as well as actuators. These failures can impair the overall performance of the closed loop system. In this case, in addition to detecting a failure, a program must be developed to maintain system stability despite the failure. Also, since a number of dynamic excitations such as earthquakes and wind loads cannot be measured at the time of occurrence, it is therefore necessary to employ methods that are resistant to such uncertainties, [6]. The robust control method protects the real properties of the control loop for all controlled programs, [7].

In this paper, the robustness of H_∞ controller with static output feedback incorporated with the new linear matrix inequalities (LMI) constraints for the control of the shear structures with centralized, fully decentralized and partial decentralized control methods (coupled and uncoupled) against sensor failures and uncertainty in earthquake excitations is investigated.

2. METHODOLOGY

For control system with sensor failures probability the state space equation takes the following form:

$$\dot{X}(t) = A_f X(t) + E_w \ddot{x}_g(t) \tag{1}$$

$$Z(t) = C_f X(t) \tag{2}$$

Where $X(t) \in R^n$ is the state vector where n is degrees of freedom, $E_w \in R^{2n}$ is coefficient vector for earthquake ground acceleration, z(t) is the controlled output and

$$\begin{aligned} A_f &= A + B_u F k_f C_y \\ C_f &= C_z + D_z F k_f C_y \end{aligned} \tag{3}$$

Where $A \in R^{2n \times 2n}, B_u \in R^{2n \times n}, F \in R^{n \times n}$ are system, control force coefficient and sensor failure matrices respectively. k_f is sensor failure tolerant feedback controller gain matrix and $C_y \in R^{p \times n}, p \prec n$ is fixed real matrix where p indicates the number of outputs. C_z and D_z are real fixed matrices with appropriate dimensions.

For the centralized control system the LMI takes the following form

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$$\begin{bmatrix} QA^T + AQ + Y^T F^T B_u^T + & QC_z^T + \\ B_u FY + EE_w^T \eta & Y^T F^T D_z^T \\ C_z Q + D_z FY & -I \end{bmatrix} \leq 0 \qquad (4)$$

In this paper, to apply the decentralized control algorithms to the static output feedback control system, the sparsity patterns are used. For this reason, some new variables are presented to produce a simple term of the controller gain matrix

$$Q = SQ_S S^T + RQ_R R^T, Y = Y_R R^T \qquad (5)$$

Where $Q_S \in R^{(n-p)\times(n-p)}$ and $Q_R \in R^{p\times p}$ are symmetric matrices, $Y_R \in R^{r\times p}$ where r is the number of actuators. $S \in R^{n\times(n-p)} = \ker(C_y)$ And $\in$ $\times$ is defined as

$$R = C_y^T (C_y C_y^T)^{-1} \qquad (6)$$

Then the LMI in equation (4) converts to

$$\begin{bmatrix} SQ_S S^T A^T + RQ_R R^T A^T + ASQ_S S^T + ARQ_R R^T + RY_R^T F^T B_u^T & * \\ + B_u FY_R R^T + EE_w^T \eta & \\ C_z SQ_S S^T + C_z RQ_R R^T + D_z FY_R R^T & -I \end{bmatrix} \leq 0 \qquad (7)$$

Now static output feedback controller can be calculated as follows:

$$\begin{cases} \max imize \eta \\ subject to Q_S \succ 0 . Q_R \succ 0 . \eta \succ 0 and lmi 21 \end{cases} \qquad (8)$$

To investigate the effectiveness of used algorithm four case for sensor failure and earthquake uncertainties are defined and two structural model including 5 and 20 stories shear structures are modeled:

$$case0 : \Delta\ddot{x}_g = 0\% \; \& \; f_1 = f_2 = f_3 = f_4 = f_5 = 1$$

$$case2 : \Delta\ddot{x}_g = 10\% \; \& \; f_1 = f_2 = f_3 = f_4 = f_5 = 0.9$$

$$\Delta\ddot{x}_g = 60\% \; \& \; f_1 = f_2 = f_3 = f_4 = f_5 = 0.4$$

$$\Delta\ddot{x}_g = 0\% \; \& \; f_1 = f_2 = .3 \; \& \; f_3 = f_4 = f_5 = 1$$

3. DISCUSSION AND RESULTS

According to Fig. 1, in case 3 the value of the inter-story drift is slightly increased compared to case 0. In fact, it can be said that the inter-story drift has corresponded in two cases.

Fig. 2 shows the maximum inter-story drift in the 20-story shear structure in the uncontrolled model as well as the centralized, fully decentralized and partial decentralized controller model in case 2. As shown in the figure, despite uncertainty and sensor failures, responses are decreased to the uncontrolled model.

Fig. 3 shows the maximum values of the drifts in the 20-storey shear structure in different controllers in case3. Responses have decreased despite the failure of the sensors compared to the uncontrolled model. The centralized controller has the worst performance.

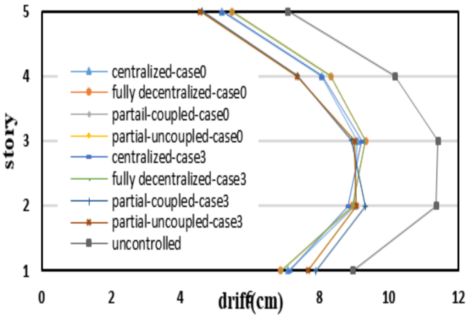

Fig. 1. Maximum inter-story displacement (drift) at cases 0 and 3 in 5-story shear structure

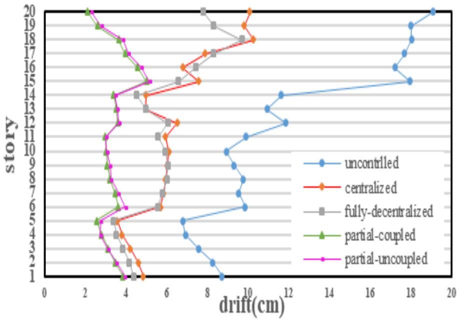

Fig. 2. Maximum inter-story displacement in case 2 on 20-story shear structure

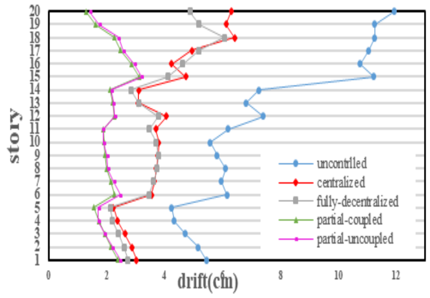

Fig. 3. Maximum inter-story displacement in case 3 on 20-story shear structure

4. CONCLUSIONS

In this paper, the centralized and decentralized H_∞ controllers with static output feedback, uncertainty in seismic excitation and probability of sensor failure with linear matrix inequalities have been used. Numerical models including 5 and 20 story shear structures have been studied. Under the acceleration of the north-south Kobe earthquake of 1995, the response of the structures is evaluated.

The results show good performance of decentralized controller compared to centralized, good resistance of centralized and decentralized control algorithm against sensor failure and good control method performance with increasing number of stories. Also, despite the earthquake uncertainty, although the responses are much lower than the uncontrolled model, they increase relative to the former state where the earthquake acceleration change was not applied. Among the decentralized control methods, the partial decentralized controller performs very well, but requires more control force, which is why a fully decentralized controller seems to be a good alternative to a centralized controller.

REFERENCES

[1] S. Beheshti-Aval, M.J.S.S. Lezgy-Nazargah, Systems, Assessment of velocity-acceleration feedback in optimal control of smart piezoelectric beams, 6(8) (2010) 921-938.

[2] K. Dhanalakshmi, M. Umapathy, D. Ezhilarasi, B.J.S.S. Bandyopadhyay, Systems, Design and implementation of fast output sampling feedback control for shape memory alloy actuated structures, 8(4) (2011) 367-384.

[3] Z. Cao, Z.J.S.E. Lei, Mechanics, Feedback control design for intelligent structures with closely-spaced eigenvalues, 52(5) (2014) 903-918.

[4] H. Ghaffarzadeh, K.J.S.S. Aghabalaei, Systems, Adaptive fuzzy sliding mode control of seismically excited structures, 19(5) (2017) 577-585.

[5] S.-Y. Chu, S.-W. Yeh, L.-Y. Lu, C.-H.J.E. Peng, Structures, Experimental verification of leverage-type stiffness-controllable tuned mass damper using direct output feedback LQR control with time-delay compensation, 12(4) (2017) 425-436.

[6] Y. Lei, D.-T. Wu, S.-Z.J.E.S. Lin, Integration of decentralized structural control and the identification of unknown inputs for tall shear building models under unknown earthquake excitation, 52 (2013) 306-316.

[7] A.L. Materazzi, F.J.S.C. Ubertini, H. Monitoring, Robust structural control with system constraints, 19(3) (2012) 472-490.

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