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Study on Control Algorithms for Evaluating Seismic Performance of Structures

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Abstract— In active control system, sensors measure the motions of the structure and actuators and a feedback control strategy exert counteracting forces to compensate for the effect of external excitations. The control forces applied depends on the control algorithm that is programmed in the computer. In this paper performance of three different control algorithms namely LQR control algorithm, LMS and a filtered x-LMS control algorithms applied through ATMD system in seismic control of structures are studied.

Index Terms— Active Control Algorithm, Active Tuned Mass Damper, filtered-x LMS control, LMS control, LQR feedback control.

1 Introduction

For the last thirty years or so, the reduction of structural response caused by dynamic effects has become a subject of intensive research. Many structural control concepts have been evolved for this purpose, and quite a few of them have been implemented in practice. Structural control methods can be broadly classified as passive and active control methods. The passive control method is activated by the structural motion. No external force or energy is applied to effect the control. On the other hand, active control method is effected by externally activated device, to change the response.

An active control system can be defined as a system that requires a large power source for the operation of electrohydraulic or electromechanical actuator. These actuators increase the stiffness or damping of the structure. The active control system uses sensors for measuring the ground excitation and structural responses, and actuators for controlling the unwanted vibrations. The working principle of the active control system is that, based on the measured structural response the control algorithm will generate control signal required to attenuate the vibration. With the help of this control signal, the actuators placed at different locations of the structure generate a secondary vibrational response which in turn reduces the overall structural response. The power requirements of these actuators vary from kilowatts to several megawatts with respect to the size of the structure.

There are many active control devices designed for structural control applications. Some of them are active tuned mass damper (ATMD), active tendons, active brace systems, pulse generation systems, etc. Some of the control algorithms are feedback control, adaptive control and hybrid control.

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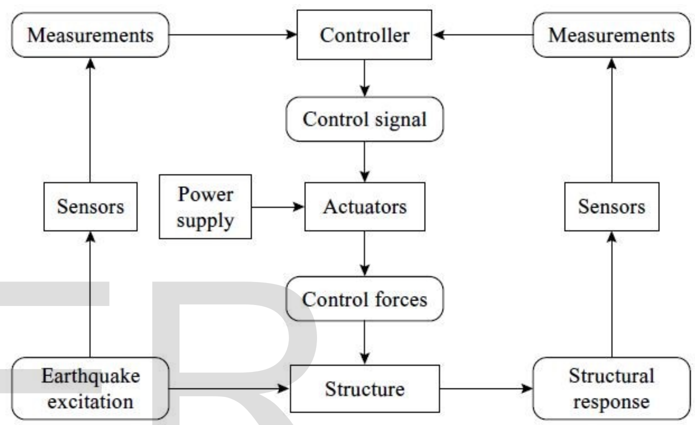

FIG. 1. ACTIVE CONTROL SYSTEM

2 System Identification

When an m-degree-of-freedom discrete system is subjected to external excitation and control forces, its governing equation of motion can be written as (Soong 1990)

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) = B_c f(t) + E_c f_e(t) \quad (1)$$

where M, C, and K are mxm mass, damping, and stiffness matrices, respectively; u(t)=mx1 displacement vector; f(t)=lx1 control force vector; fe(t)=rx1 external dynamic force vector; Bc and Ec=mxl and mxr location matrices which define locations of the control forces and the external excitations, respectively; and t=time. In state-space form, (1) can be written in the form

$$\dot{z}(t) = Az(t) + Bf(t) + Ef_e(t) \quad (2)$$

where

$z(t) = \begin{bmatrix} u(t) \\ \dot{u}(t) \end{bmatrix}$ is the 2mx1 state vector, and

(3)

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} 0 \\ M^{-1}B_C \end{bmatrix} \quad (5)$$

$$E = \begin{bmatrix} 0 \\ M^{-1}E_C \end{bmatrix} \quad (6)$$

are 2mx2m, 2mxl, and 2mxr system, control location, and external excitation location matrices, respectively. The matrices 0 and I in (4), (5) and (6) denote, respectively, the zero and identity matrices of size mxm.

3 Modal Parameters

In this paper two lumped mass models are considered. Model 1 is assumed to have a mass of 1224Kg and stiffness of 2805000 kN/m which is the idealisation of a 2-D frame. Model 2 considered is having a mass of 114844 Kg and stiffness of 66488880 kN/m which is the idealisation of a 3-D frame. Both the models are assumed as fixed support system. Each model consists of three sets of system having 2-storey, 5-storey and 10-storey. An Active Tuned Mass Damper(ATMD) is modelled on the top floor of the structure. The mass ratio of ATMD is assumed as 1% and damping ratio as 7.5%.
The earthquake data is taken from PEER strong motion database. These lumped mass models with ATMD were subjected to El Centro, Kobe, Northridge and Sanfernado earthquakes and the resulting responses were noted. The same structures were then controlled with three different algorithms that is, LQR, LMS and filtered-x LMS and the corresponding displacements were recorded. The results obtained are presented below.

4 Linear Quadratic Regulator (LQR) Control

The Linear Quadratic Regulator algorithm is the most commonly used control algorithm due to its simplicity in application. The basic idea of LQR control is to minimize the quadratic cost function i.e.,

$$J = \frac{1}{2}\int_0^\infty (x^T Qx + u^T Ru)dt \quad (7)$$

with $x(t)\epsilon R^n, u(t)\epsilon R^m$ and state-variable feedback (SVFB) control $u = -Kx + v$. The parameters Q and R can be used as design parameters to penalize the state variables and the control signals. The larger these values are, the more you penalize these signals.

The following results are obtained by applying LQR control to the above mentioned models.

Table 4.1 Peak Displacement of model 1 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	LQR B	((A-B)/A) X100
1	EQ 1	2-storey	4.2	2.6	38
		5-storey	20	13	35
		10-storey	42	28	33
2	EQ 2	2-storey	3.8	2.2	42
		5-storey	10	6	40
		10-storey	40	25	37.5
3	EQ 3	2-storey	4	2.3	42
		5-storey	9.8	5.7	41
		10-storey	52	38	39.5
4	EQ 4	2-storey	2	1	45
		5-storey	8	4.5	43.8
		10-storey	30	17	42.7

Table 4.2 Peak Displacement of model 2 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	LQR B	((A-B)/A) X100
1	EQ 1	2-storey	8	5.2	35
		5-storey	31	21	32
		10-storey	90	63	30.5
2	EQ 2	2-storey	7	4.2	40
		5-storey	20	12.4	38
		10-storey	62	40	36
3	EQ 3	2-storey	7	4.2	41.2
		5-storey	19	12	40.2
		10-storey	60	37	38.2
4	EQ 4	2-storey	6	3.4	44
		5-storey	18	3.4	43
		10-storey	58	34	41

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5 Least Mean Square (LMS) Control

Least mean squares (LMS) algorithms are a class of adaptive filter used to mimic a desired filter by finding the filter coefficients that relate to producing the least mean square of the error signal (difference between the desired and the actual signal). The aim of adaptive algorithm is to adapt the filter coefficients such that the error sequence is as close to zero.

The results obtained by applying LMS control algorithm is tabulated as follows.

Table 5.1 Peak Displacement of model 1 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	LMS C	((A-C)/A) X100
1	EQ 1	2-storey	4.2	1.4	66
		5-storey	20	7	65
		10-storey	42	15	63
2	EQ 2	2-storey	3.8	1.2	68.4
		5-storey	10	3.4	66
		10-storey	40	14	64.2
3	EQ 3	2-storey	4	1.3	68
		5-storey	9.8	3.3	66.4
		10-storey	52	22	65.1
4	EQ 4	2-storey	2	0.6	70
		5-storey	8	2.5	68.6
		10-storey	30	9.8	67.2

Table 5.2 Peak Displacement of model 2 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	LMS C	((A-C)/A) X100
1	EQ 1	2-storey	8	2.8	35
		5-storey	31	12	32
		10-storey	90	35	30.5
2	EQ 2	2-storey	7	2.3	40
		5-storey	20	7.1	38
		10-storey	62	23	36
3	EQ 3	2-storey	7	2.3	41.2
		5-storey	19	6.5	40.2
		10-storey	60	20	38.2
4	EQ 4	2-storey	6	1.9	44
		5-storey	18	1.9	43
		10-storey	58	19	41

6 Filtered-x LMS Control

The well-known filtered-x LMS-algorithm is an adaptive filter algorithm which is suitable for active control applications. It is developed from the LMS algorithm, where a model of the dynamic system between the filter output and the estimate, i.e. the forward path is introduced between the input signal and the algorithm for the adaptation of the coefficient vector. This algorithm can handle the modelling error including the effect of soil-structure interaction and hence it is more stable.

The results obtained by applying LMS control algorithm is tabulated as follows.

Table 6.1 Peak Displacement of model 1 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	Filtered-x LMS D	((A-D)/A) X100
1	EQ1	2-storey	4.2	1.2	71.4
		5-storey	20	6	70
		10-storey	42	12	69
2	EQ2	2-storey	3.8	9.5	75
		5-storey	10	2.8	72
		10-storey	40	12	70
3	EQ3	2-storey	4	9.8	75.6
		5-storey	9.8	2.6	74
		10-storey	52	17	72.8
4	EQ4	2-storey	2	0.5	75
		5-storey	8	2.1	73.8
		10-storey	30	8.4	72

Table 6.2 Peak Displacement of model 2 (x10^ (-3)) m

Sl. no	EQ	No. of stories	Without control A	Filtered-x LMS D	((A-D)/A) X100
1	EQ1	2-storey	8	2.4	70
		5-storey	31	9.5	69.4
		10-storey	90	29	67.1
2	EQ2	2-storey	7	1.9	73
		5-storey	20	6	70
		10-storey	62	19	68.8
3	EQ3	2-storey	7	1.9	75
		5-storey	19	5.1	73
		10-storey	60	17	71.3
4	EQ4	2-storey	6	1.6	73
		5-storey	18	1.7	72
		10-storey	58	17	70

7 Conclusion

In this paper the application of different control algorithms in response reduction of structures during a seismic event is studied. Following conclusions are drawn from the results

1. It has been found out that the three control algorithms can be successfully used to control the vibration of structures.
2. For the models considered the reduction in peak displacement with LQR control algorithm isin the range of

30-40%.
3. The peak displacement is reduced by 60-70% with the use of LMS control algorithm.
4. Filtered-x LMS reduces the responses of the models considered in the range of 68-80%.

APPENDIX

As an example Figure 2 to 6 shows the displacement of model 2-10 story subjected to El-Centro earthquake.

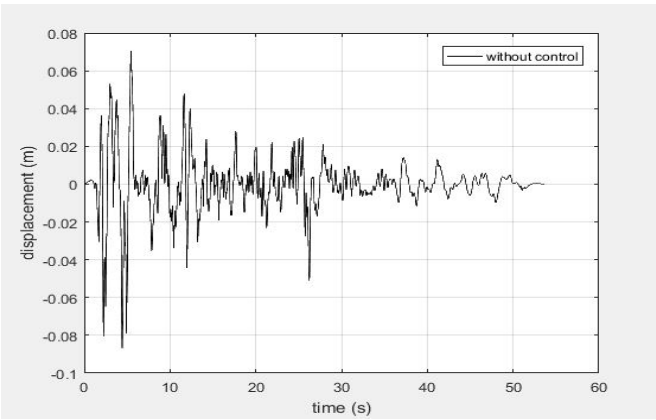

FIG.2. MODEL-2-10-STOREY WITHOUT CONTROL

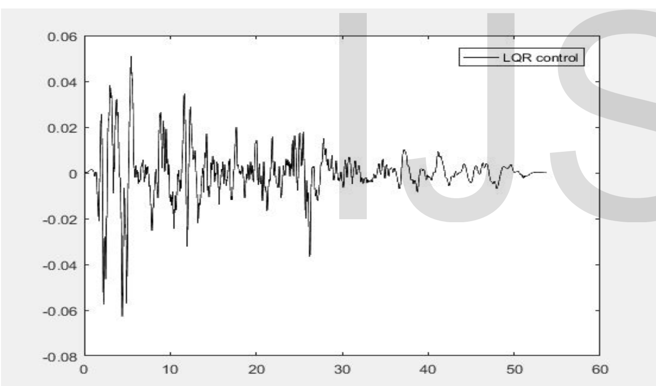

FIG.3. MODEL-2-10-STOREY LQR CONTROL

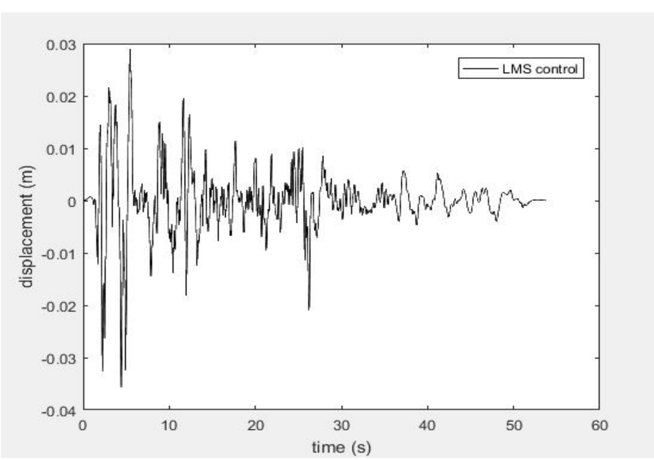

FIG.4. MODEL-2-10-STOREY LMS CONTROL

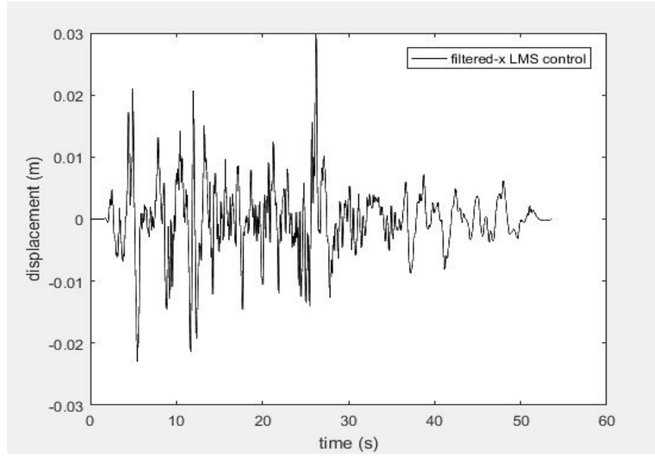

FIG.5. MODEL-2-10-STOREY FILTERED-X LMS CONTROL

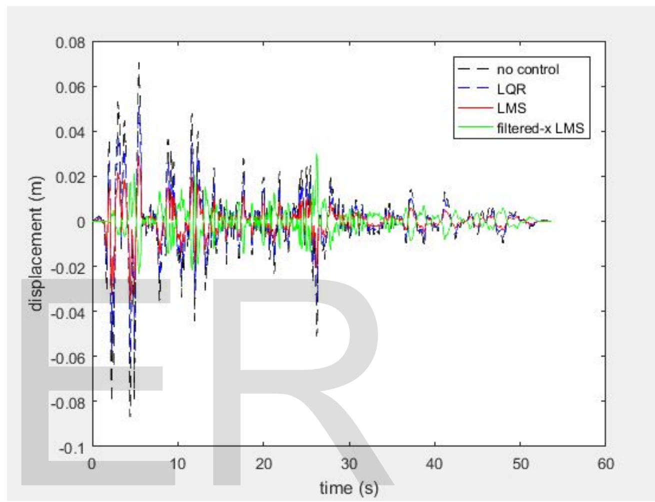

FIG.6. COMPARISON OF LQR, LMS AND FILTERED-X LMS ON MODEL-2-10-STOREY

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