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Effectiveness of Magneto-Rheological Damper Placement in Seismic Vibration Control

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Abstract*: Earthquake is dangerous natural calamities considered in the nature which will destroy the environment completely. The human life along with the structures will be in threat, so a sophisticated structural design is required and hence efficient control algorithm is required to overcome this hazard. The passive and active control system has been developed to control the structures and it is found that active control strategy performs better than passive but because of some limitation like cost effectiveness and reliability semi-active control system is been adopted in recent years. Therefore this work aims at the design of Robust Proportional Derivative Controller along with semi-active damper like Magneto-rheological damper. This controller is a combination of classical PID controller and state feedback controller. The commanded voltage of this controller will be sent to the current driver. This current driver will convert the voltage to current. Magneto-rheological damper in turn receives this controlled current and produces the force required to control the vibration of the structure. The minimum control effort is simulated by placing MR damper in different floors of the structure and results are demonstrated. Optimum placement of the damper plays an important role because of economy and minimum vibration to the least possible consideration.

***Index Terms*: Magneto-rheological damper, Robust Proportional Derivative (PID) Controller, Semi-active control.**

I. INTRODUCTION

Natural calamities are always hazardous to the environment which includes the structures with its dwellers. These structures are nowadays designed for all forces of nature that move toward it and try to destroy it. In this work earthquake is one of the forces considered and the structure is designed in such a way that structure after experiencing the earthquake will undergo a minimal deformation and sustain in future. These structures need a sophisticated controller design technique to resist earthquakes. Therefore the Magneto-Rheological damper is used to control the deformation of the structure with the Robust PID controller. This damper placement in the different story is important to predict the force required by the damper to reduce the vibration of the structure. The capacity and effective placement is significant because of economy and energy conservation which need to be considered in today's life. Clipped optimal control algorithm was used to reduce response of the system with feedback of the structural acceleration which showed the reduction in the structural response found in [1]. The review paper show the structural control devices used in the past and present, also which could be used in the future is predicted in [2]. Magneto-rheological dampers of different mechanical models were proposed in [3]. The robust PID controller was proposed using linear matrix inequality method [4]. Proportional integral derivative (PID) Controller and a non-chattering robust sliding mode controller (SMC) were used separately to reduce the response of the structure excited for Marmara earthquake of Turkey in 1999 of magnitude 7.4 for a multistoried building [5]. The structure is base isolated with sliding friction pendulum system and low damping rubber bearing with H infinity feedback algorithm is used in [6]. A linear quadratic Gaussian controller is used to control the magneto-rheological damper and to control the structural response [7]. A new control algorithm based on quasi-bang-bang controller is proposed to reduce the response of the structure using magneto-rheological damper [8]. Twin rotor multi-input multi-output system was controlled using robust PID controller with reliable H infinity observer [9]. Classical PID controller was used to control the structure with magneto-rheological damper [10]. Observer based Robust PID controller is designed to mitigate vibration of structure with the estimation of all states of system by using the observer which overcomes the drawback of noise in response capturing [11].

II. EARTHQUAKE DATA

The Northridge earthquake at Newhall fire-station occurred at 1994 which has a peak ground acceleration of 0.5656g which is the near fault earthquake.

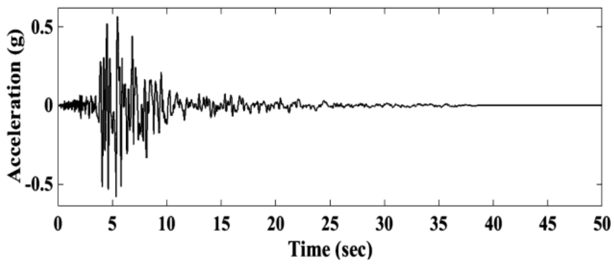

Fig. 1 Time history of Northridge.

III. STRUCTURAL PARAMETER

A benchmark structure and its structural parameters are taken from literature. The structure considered is a three story building with mass, stiffness and damping matrix.

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The structural motion equation is,

$$M\ddot{U} + C\dot{U} + KU = L\,F_u - M\ddot{U}_g \qquad (1)$$

Here M is the mass of the structure, C is the damping of the structure, K is the stiffness of the structure. $\ddot{U}$, $\dot{U}$ and U are the acceleration, velocity and displacement of the structure considered. $\ddot{U}_g$ is the earthquake excited to the structure. L is the location of the damper. F_u is the force predicted by the damper to control the vibration of the structure [12].

This dynamic equation is then converted into state space form. The state space form of the equation is,

$$\dot{x}(t) = Ax(t) + Bu \qquad (2)$$

$$y(t) = Cx(t) + Du(t) \qquad (3)$$

Here equation 2 is a set of linear differential equation and equation (3) is a set of algebraic equation. Here $x(t)$ is the state vector, $u(t)$ is the input vector and $y(t)$ is the output vector. Here the three story displacement and velocity is considered as the state vector of dimension n x 1, the input vector consist of the force produced by the MR damper in the three floors and the earthquake considered of dimension m x 1 and the output vector of the structure are the three story velocity of dimension p x 1 . A, B, C and D represents system matrix, input matrix , output matrix and feed forward matrix. The matrix A is of dimension n x n, matrix B is of dimension n x m, matrix C of dimension p x n and matrix D is of dimension p x m [13].

IV. ROBUST PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER

Proportional Integral Derivative controller is one the most frequently used controller in the industry. To overcome the limitation of classical PID controller the Robustness is incorporated in the system by feed backing all the states of the system. The response of the system which is corrupt because of some noisy output due to which the controller output voltage is altered and produces unwanted output. This controller is designed by Ziegler-Nichols tuning rule in which ultimate tuning rule adopted [13].The equations below are the Robust PID algorithm equations.

$$\dot{x}(t) = Ax(t) + Bu(t) \qquad (4)$$

$$u(t) = -Kx + K_p\,(Ref) + K_d\,(\dot{Ref}) \qquad (5)$$

$$y(t) = Cx(t) + Du(t) \qquad (6)$$

$$e = (\mathrm{Ref}) - y(t) \qquad (7)$$

$$K = [Kp, Ki, Kd] \qquad (8)$$

Here $x(t)$ is state vector, $u(t)$ is output of the controller, K is feedback controller gain of Robust PID controller and $y(t)$ is output of the structure these are clarified [4, 9, 11].

V. MAGNETO- RHEOLOGICAL DAMPER

The Magneto-Rheological damper is one of the most assuring devices which are used for the structure vibration control. This damper shows the good force producing capacity and hysteresis behavior. The mechanical model of the MR damper is given in figure 3,

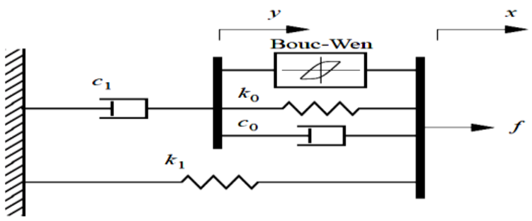

Fig. 3 Mechanical model of MR damper [1, 3]

The force predicted by the MR damper is,

$$f = \alpha z + c_o(\dot{x} - \dot{y}) + k_o(x - y) + k_1(x - x_0) \qquad (9)$$

$$\dot{z} = -\gamma|\dot{x} - \dot{y}|z|z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y}) \qquad (10)$$

$$\dot{y} = \frac{1}{(c_o + c_1)} \times \{\alpha z + c_o\dot{x} + k_o(x - y)\} \qquad (11)$$

Here z is the evolutionary variable, k_1 is the accumulator stiffness; c_o represents the viscous damping at the large velocity. k_o control the stiffness when there are large velocity, x_0 represents initial displacement of spring associated with the nominal damper force due to the accumulator. c_1 is non-linearity in the force velocity loop. The equation of the current driver is given by,

$$\alpha = \alpha(u) = \alpha_a + \alpha_b \qquad (12)$$

$$c_1 = c_1(u) = c_{1a} + c_{1b}u \qquad (13)$$

$$c_o = c_o(u) = c_{oa} + c_{ob}u \qquad (14)$$

$$\dot{u} = -\eta(u - v) \qquad (15)$$

Where output of the controller is u and the voltage commanded sent by the controller is v. The details of parameters are given in table 3.2 are obtained from the paper. The other 14 parameters of the MR damper is adopted form the literature [1, 3, 7, 8].

VI. RESULTS

The result depict the response of the structure excited for Northridge earthquake. The displacement verses time and acceleration verses time of the structure subjected to the earthquake is depicted as the results. The force predicted by MR damper is also shown in the results. The result are predicted for MR damper placement in the different stories. The peak response of the structure is tabulated in the table for all the simulation performed.

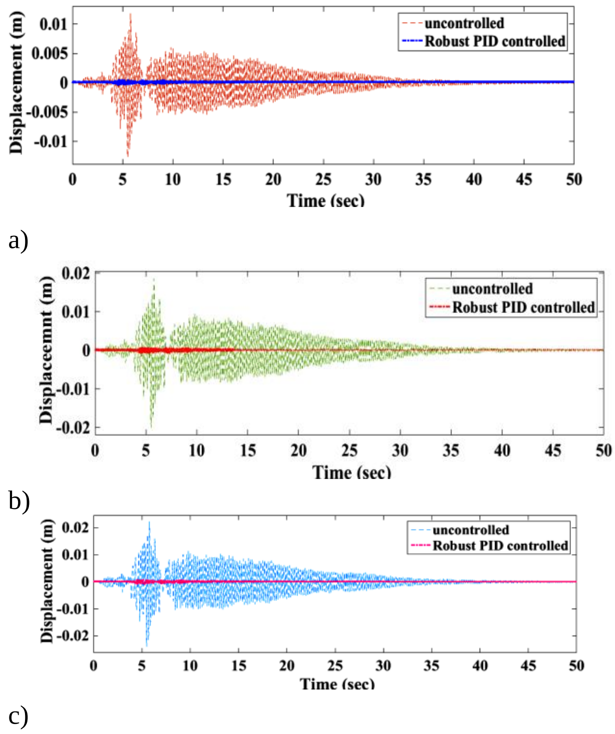

Fig. 4 a) Displacement verses time graph of the first floor, b) displacement verses time graph of the second c) displacement verses time graph of third floor, for Northridge earthquake.

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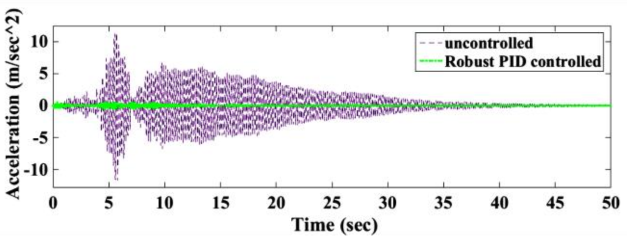

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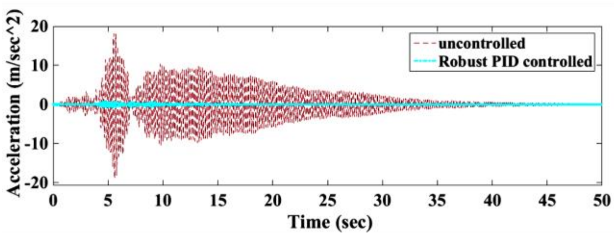

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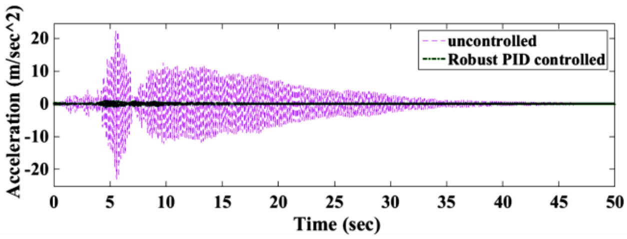

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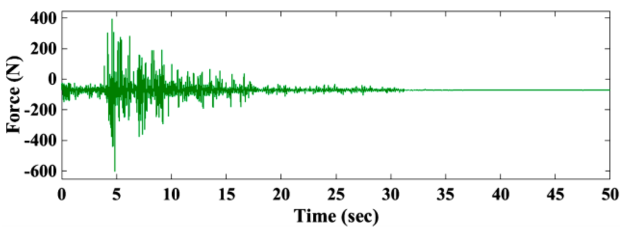
Fig. 5 a) Acceleration verses time graph of the first floor, b) Acceleration verses time graph of the second c) Acceleration verses time graph of the third floor, for Northridge earthquake.



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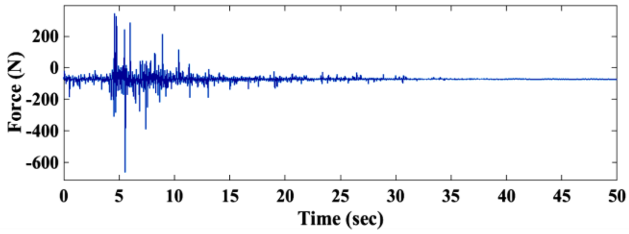

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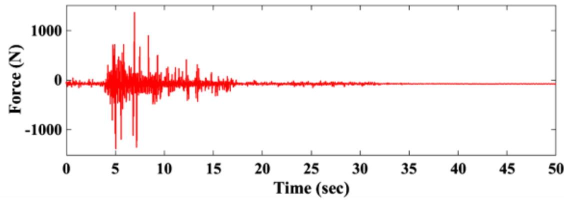

c)

Fig. 6. Force predicted by MR damper when placed in between a) ground and first floor b) first and second floor c) second and third floor.

Table 1: Peak response of the structure when MR damper is placed in between ground and first floor.

Control strategy	Story number	Uncontrol-led	Robust PID control	Peak reduction in %
Displace-ment (cm)	U_1	0.31	0.051	83.54
	U_2	0.47	0.0748	84.08
	U_3	0.55	0.0912	83.41
Acceler-ation (cm/sec^2)	$\ddot{U}_1$	238.3	63.45	73.37
	$\ddot{U}_2$	282	86.58	69.29
	$\ddot{U}_3$	344.2	114.67	66.68
Force(N)	F_u	0	605.89	-

Table 2: Peak response of the structure when MR damper is placed in between first and second floor.

Control strategy	Story num-ber	Uncontrol-led	Robust PID controlled	Peak reduction in %
Displace-ment (cm)	U_1	0.31	0.0567	81.7
	U_2	0.47	0.0783	83.34
	U_3	0.55	0.0956	82.61
Accelera-tion (cm/sec^2)	$\ddot{U}_1$	238.3	61.41	74.22
	$\ddot{U}_2$	282	96.18	65.89
	$\ddot{U}_3$	344.2	105.57	69.32
Force(N)	F_u	0	664	-

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Table 3: Peak response of the structure when MR damper is placed in between second and third floor.

Control strategy	Story numb-er	Uncontr-olled	Robust PID controlled	Peak reducti-on in %
Displace-ment (cm)	U_1	0.31	0.068	78.06
	U_2	0.47	0.11	76.59
	U_3	0.55	0.12	78.18
Accelera-tion (cm/sec^2)	$\ddot{U}_1$	238.3	78.23	67.17
	$\ddot{U}_2$	282	106.4	62.26
	$\ddot{U}_3$	344.2	126.49	63.25
Force(N)	F_u	0	1380.5	-

As shown in the graph the displacement and acceleration of the structure is reduced by using the Robust PID controller when compared with uncontrolled system. The uncontrolled and Robust PID controlled system when MR damper is placed in between ground and first floor the response of the first floor displacement is reduced by 83.54%, for second floor by 84.08 % and third floor by 83.4%. The acceleration of the structure for first floor is reduced by 73.37%, for second floor by 69.29% and third floor by 66.68%. The force produced by MR damper to reduce the vibration by Robust PID controller is 807.89N.

As shown in the graph the displacement and acceleration of the structure is reduced by using the Robust PID controller when compared with uncontrolled system. The uncontrolled and Robust PID controlled system when MR damper is placed in between first and second floor the response of the first floor displacement is reduced by 81.7%, for second floor by 83.34 % and third floor by 82.61%. The acceleration of the structure for first floor is reduced by 74.22%, for second floor by 65.89% and third floor by 69.32%. The force produced by MR damper to reduce the vibration by Robust PID controller is 664N.

As shown in the graph the displacement and acceleration of the structure is reduced by using the Robust PID controller when compared with uncontrolled system. The uncontrolled and Robust PID controlled system when MR damper is placed in between second and third floor the response of the first floor displacement is reduced by 78.06%, for second floor by 76.59 % and third floor by 78.18%. The acceleration of the structure for first floor is reduced by 67.17%, for second floor by 62.26% and third floor by 63.25%. The force produced by MR damper to reduce the vibration by Robust PID controller is 1380.5N.

VII. CONCLUSION

The placement of damper in different position shows variation in the response of the structure and the force produced by the MR damper. When damper placed in any of the floor shows reduction in the response but damper predicted force and response control vary. Therefore from the result it can be inferred that MR damper placement in first floor is better situated to mitigate response of the structure because the force required to reduce the response is small when compared to other positioning of MR damper. Therefore optimum positioning of the damper and economy plays a very important role in the structural control. Further the experimentation should be conducted to put forth the simulation into practice. Further simultaneous two or more damper with lower capacity can be used in reducing the response of structure which can be the future work.

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