Optimization of MR Dampers in a Multi-Storey Building

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***Abstract*— Control of civil engineering structures in the area of earthquake mitigation brings out an impending area of research which has claimed a tremendous growth in the past thirty years. Control systems required for these structures have unique requirements and constraints as no two earthquake induced ground motions are the same. For example, during a major seismic trigger, possibilities of damage to the external power source is higher leading to a complete shutdown of power supply for the control system making it ineffective. It is uncertain that if a system proven to work for a structure in one ground motion will work efficiently in another ground motion. Great efforts were carried out to develop the concept of energy dissipation in structures to bring it into an applicable technology. Magnetorheological (MR) dampers have come up as a promising class of device that mesh well with the set of requirements and constraints of seismic applications, including robustness and very low power consumption. Identifying the location and number of dampers plays a major role in the reduction of response of a structure during a seismic event. In this paper different patterns of arrangement of dampers have been analysed for a set of earthquake records with varying current for MR damper in terms of inter storey drift.**

***Keywords*— MR damper; Inter-storey drift; Non-linear time history analysis; Stiffness; Damping coefficient; Damping exponent; Hyperbolic tangent model**

I. INTRODUCTION

On July 2016 a news was released stating that a massive fault could trigger a cataclysmic earthquake beneath Bangladesh, parts of east India and Myanmar [1]. It was found that there is a hidden fault buried under miles of river sediment which could release an earthquake of magnitude 8.2 to 9.0 in one of the most densely populated regions of the world. It is said that they do not know when this earthquake could happen, it could be tomorrow or if it's not going to be for another 500 years. The hazard to be faced is that an earthquake of magnitude 8.0 or above can cause high damage anywhere in the world, but this particular region is very vulnerable. The research gave an estimate that about 140 million people live within 60 miles of the fault. This shows an urgency in the field of earthquake hazard mitigation. When compared with other natural hazards, earthquakes are unique, because there is no warning. We know that we cannot stop the earthquakes from happening but we can reduce the effects caused due to it to the structures.

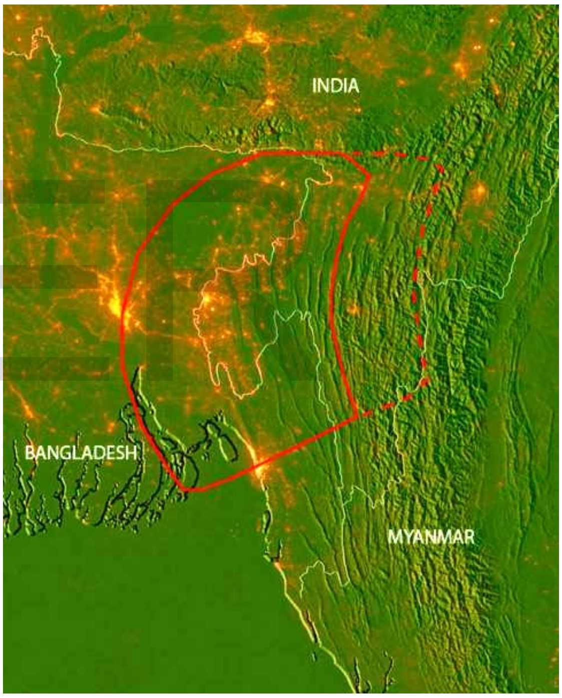

Fig. 1 A subduction zone lying beneath Bangladesh, Myanmar and eastern India that could release a massive magnitude 8.2 to 9.0 earthquake. The red line shows the areas where the fault is likely locked (the solid line showing the more likely location). The glowing city lights in the picture serve as a proxy for population density.

In past thirty years many researchers have worked with Magneto rheological dampers, which has proved to have attained the desired results by reducing the response of a structure to a great extent. It also shows remarkable hysteric behaviour over a wide range of temperature. The next step is to find the optimal position and number of dampers required to reduce the structural response. Optimizing the position of control devices has been an interesting area of research since the year 1980. One of the early major works in this direction was the study carried out by De Silva (1981) [2] where he derived gradient algorithm for controlling the vibration of a system by optimally placing the control devices. E. Stanley Lee (1985) [3] has worked on a scheme for active control based on the use of the transfer matrix between the applied controls and the structural natural modes. Zhang and Soong (1992) [4] pioneered an extension to the above described controllability index method for locating passive dampers. Milman and Chih (1993) [5] has put forth accurate methods for functional and gradient evaluation, including a Ritz reduction technique and a Newton algorithm. Whereas Izuru Takewaki (1997, 1998) aimed at minimizing the sum of amplitudes of the transfer functions evaluated at the undamped fundamental natural frequency of a structural system. But Izuru Takewaki et al. 1999 [6] has shown that the ratio of the fundamental natural period of the structure to that of the surface ground is a key parameter for characterizing the optimal damper placement. Shukla and Datta (1999) [7] reconfirmed the efficiency of the sequential search algorithm (SSA) method through a parametric study using visco-elastic dampers. Moreschi (2000) and Singh and Moreschi (2001, 2002) [8] introduced a gradient based approach and also employed genetic algorithm approaches as an alternative to address the problem of optimal placement of dampers. Garcia (2001), and Garcia and Soong (2002) [9] developed the simplified sequential search algorithm method (SSSA). Yoshida and Dyke (2003) [10] applied GA for placement of MR dampers when applied to numerical models of full scale irregular buildings. Carolina Tovar et al. (2004) [11] gave results that large number of dampers do not always lead to the best benefit in terms of drift reduction for all stories. Wongprasert and Symans (2004) [12] used genetic algorithm with integer representation to determine the damper locations. Ajeet S. Kokil et al. (2007) [13] has taken maximum Inter-story drift and maximum base shear as the objective function for finding the optimal location. It showed that the efficiency of optimally placed dampers is maximum in symmetric buildings and its efficiency reduces as plan irregularity increases. Lavan et al (2008) [14] developed a non-iterative optimization procedure for seismic weakening and damping of inelastic structures. N.M. Kwok et al. (2007) [15] has worked on the placement of dampers as a multi objective optimization problem. Khosravian and Hosseini (2011) [16] used genetic algorithm to find the optimal position for metallic dampers. Genetic algorithm is also used by A. Khosravian et al. by using inter storey drift and base shear as functions. Heuristic search methods have been investigated by Gian Paolo Cimellaro et al. (2012) [17] in detail using four different objective functions. Carlos A. Martínez et al. (2014) [18] has used a simple procedure to optimally define the location and size of nonlinear hysteretic dampers to meet an expected level of performance on structures under seismic excitation is proposed. The above literatures have shown that the position of dampers depends on parameters such as inter-storey drift, base shear, fundamental natural frequency, energy dissipation, acceleration etc. Optimization techniques like genetic algorithm, sequential search algorithm and heuristic search methods has been adopted to find the optimal position and number of dampers. In this study a simple method based on inter-storey drift is adopted for a MR damper model. There are different models available for MR damper in which hyperbolic tangent model is adapted here for the analysis. Three benchmark earthquake ground motion data are used for non-linear time history analysis for varying current.

II. BACKGROUND

A. *Magneto-rheological damper*

In the past few decades much efforts were made in bringing control devices to an applicable technology. Passive control devices such as base isolation, metallic yield dampers, friction dampers, visco-elastic dampers, viscous dampers, tuned mass dampers and tuned liquid dampers have been studied and well understood in the area of energy dissipation and reduction in the response of structures including buildings and bridges.

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Although these devices gave good results, they showed limitations of not being capable of adapting to variable patterns and load conditions.

An alternate approach which brought reliability and versatility when compared to passive devices are the semi-active devices. Electro-rheological and magneto-rheological fluid dampers, variable orifice damper, variable stiffness devices. Magneto-Rheological (MR) fluid damper appears to be a particularly promising type of semi active control device (Dyke et al., 1997; Johnson et al., 1998, etc.)

B. Hyperbolic tangent model

A number of models have been proposed with controllable fluid or MR fluid which showed varying results. For this research, a 200kN MR damper hyperbolic tangent model proposed by Bass and Christenson (2008) [19] is adopted. The hyperbolic tangent model is composed of two sets of spring dashpot elements that are connected by a mass element as shown in the Figure 2.

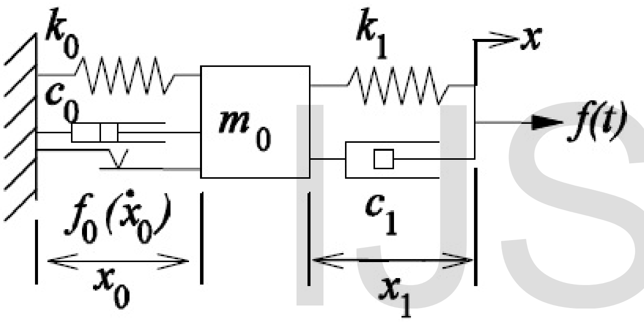

Fig. 2 A schematic of MR damper hyperbolic tangent model.

The dynamics of the system and force output can be described in state space form as

$$\begin{bmatrix} \dot{x}_0 \\ \ddot{x}_0 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ (-k_0 - k_1)/m_0 & (-c_0 - c_1)/m_0 \end{bmatrix} \begin{bmatrix} x_0 \\ \dot{x}_0 \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ k_1/m_0 & c_1/m_0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \end{bmatrix} + \begin{bmatrix} 0 \\ -1/m_0 \end{bmatrix} f_0 \tanh(\dot{x}_0/V_{ref})$$

and the MR damper force, f is a function of the state of the above equation and the displacement and velocity across the damper as

$$f = \begin{bmatrix} -k_1 & -c_1 \end{bmatrix} \begin{bmatrix} x_0 \\ \dot{x}_0 \end{bmatrix} + \begin{bmatrix} k_1 & c_1 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \end{bmatrix}$$

The parameters of hyperbolic tangent model are in terms of current. Out of the seven parameters we have taken stiffness and damping co-efficient for our analysis.

III. STRUCTURAL MODELLING AND ANALYSIS

C. Building models

1) *Six-storey RCC building*: The typical storey height, floor to floor is 3.0m. The sections of columns are considered as 650X650mm, 600X600mm, 550X550mm, 500X500mm and the section of beams are considered as 250X450mm. It consists of three bays of 5.0m distance.

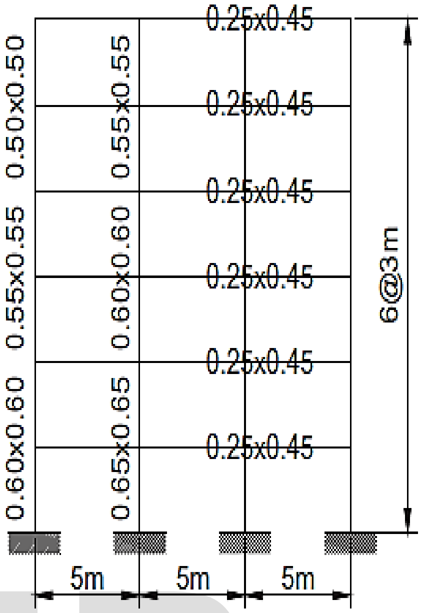

Fig. 3 Six storey three bay RCC building.

2) *Nine-storey two bay RCC building*: The typical storey height, floor to floor is 3.0m. The sections of columns are considered as 450X450mm and the section of beams are considered as 250X450mm. It consists of two bays of 6.0m distance.

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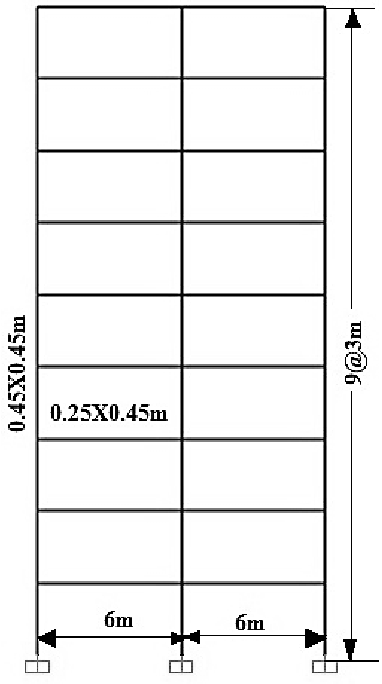

Fig. 4 Nine storey two bay RCC building.

3) *Nine-storey three bay RCC building*: The typical storey height, floor to floor is 3.0m. The sections of columns are considered as 450X450mm and the section of beams are considered as 250X450mm. It consists of three bays of 6.0m distance.

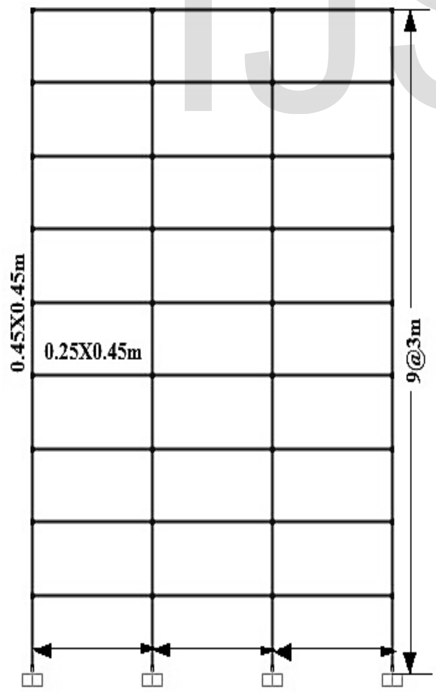

Fig. 5 Nine storey three bay RCC building.

D. Earthquake ground motions

Three benchmark earthquake ground motion data, Imperial valley (1938), El Centro (1940) and Northridge (1994) are used for the analysis.

E. Non-linear time history analysis

It is assumed that nonlinear time history analysis defines structure behaviour ideally because of the seismic loads directly applied to structure (Li 1996). The aim of nonlinear time history analysis is to integrate the equations of the motion of the system step by step by taking into consideration the nonlinear behaviour of bearing system. It is calculated for each time increment that displacement, peak acceleration and forces occurred in the system, and maximum values of them were observed during earthquake.

Non-linear time history analysis was conducted for the building models using SAP2000 V19 software. From the analysis results, it was found that displacement inter-storey drift was slightly higher in all the three buildings for El Centro earthquake. Whereas for Imperial Valley and Northridge, the displacement and inter-storey drift was found to be less and the structures could withstand during the seismic event. The limiting value for inter storey drift according to IS 1893 part 1(2002) is 0.004 times the storey height.

In all the three cases the storey height is 3meters. And therefore, the limiting value of inter storey drift is

$$\Delta = 0.004 \times h = 0.004 \times 3 = 0.012m$$

The analysis gave values of maximum drift for six-storey three bay as 0.0206m, for nine-storey two bay as 0.0480m, for nine-storey three bay as 0.0490m. The result show that for the El Centro Earthquake the storey drift exceeds beyond the limiting value of 0.012m for six-storey as well as nine-storey building. This concludes that there is a need for addition of dampers to reduce the response of the structure.

Dampers where added to the structures where inter-storey drift was found maximum. The properties of dampers were given in terms of stiffness and damping co-efficient. These parameters depend on the supply of current. For this purpose, a varying current of 0 Amp to 2 Amp was used to study the change in inter-storey drift. A change in damping exponent values of 0.5 and 1.0 were also carried out as a part of the study. Analysis were run for several patterns of damper position to find the optimal location and number of dampers.

IV. OPTIMAL DAMPER PLACEMENT

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The optimal position and number of dampers were derived by comparing the drift values for a) Passive-off MR damper – zero current supply, b) Passive-on MR damper – moderate supply (1 Amp) and maximum supply (2 Amp). Damper properties (stiffness and damping co-efficient) were found out with hyperbolic tangent equation.

F. Six-storey RCC building

15 models of damper arrangements were analysed to get the optimum number of dampers. Out of all the models, horizontal arrangement of dampers proved to give the best results. From Figure 7 it is found that the values of inter-storey drift fall within the permissible limit. The optimal placement of dampers shows a reduction of 93% in terms of drift.

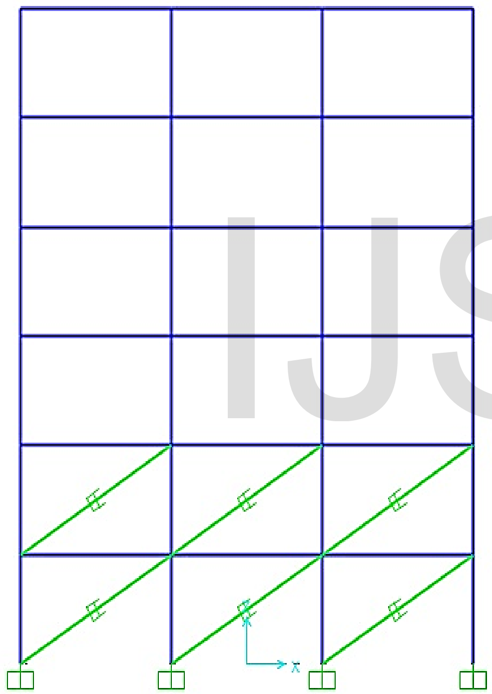

Fig. 6 Optimal damper location for six-storey building.

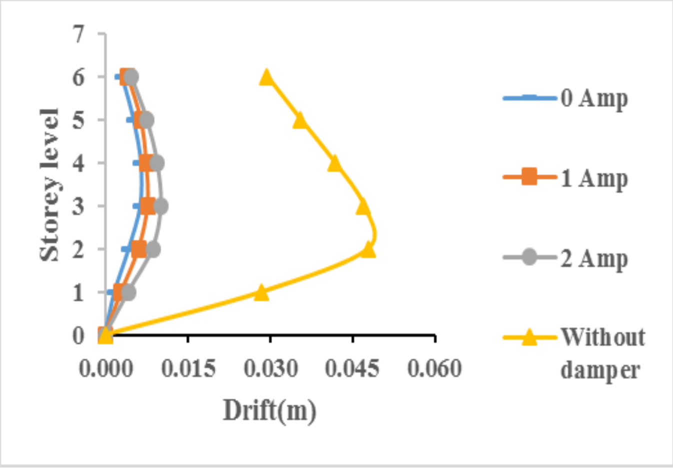

Fig. 7 Graph showing the values of inter-storey drift for passive-off MR damper (0 Amp) and passive-off MR damper (1 Amp and 2 Amp) for six-storey three bay RCC building.

G. Nine-storey two RCC building

The optimal number of damper was found as 9 for nine-storey two bay RCC building. 5 different damper arrangements patterns were analysed to arrive at the optimum values. From Figure 9 it is found that the values of inter-storey drift fall within the permissible limit. And also the addition of dampers has resulted in reducing the inter-storey drift up to 92%.

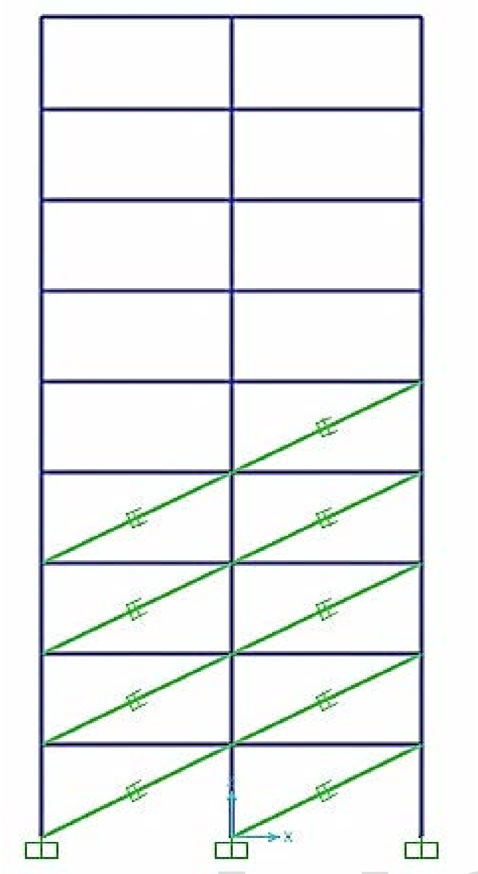

Fig. 8 Optimal damper location for nine-storey two bay building.

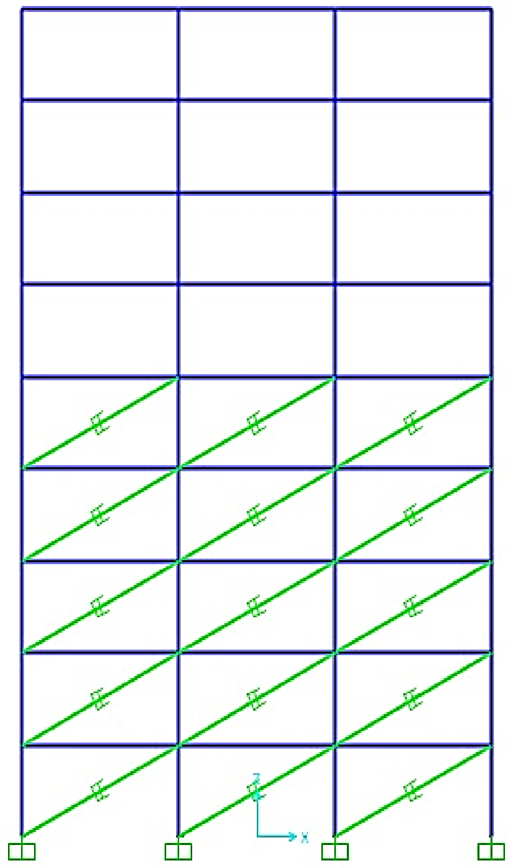

Fig. 10 Optimal damper location for nine-storey two bay building.

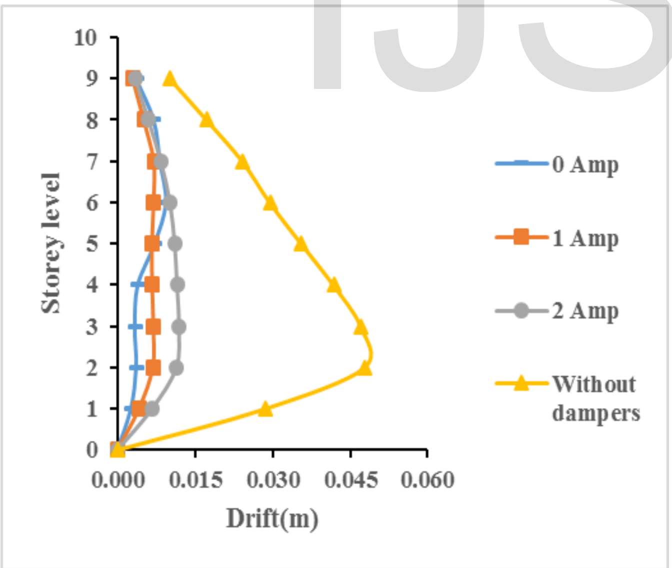

Fig. 9 Graph showing the values of inter-storey drift for passive-off MR damper (0 Amp) and passive-off MR damper (1 Amp and 2 Amp) for nine-storey two bay RCC building.

H. Nine-storey three bay RCC building

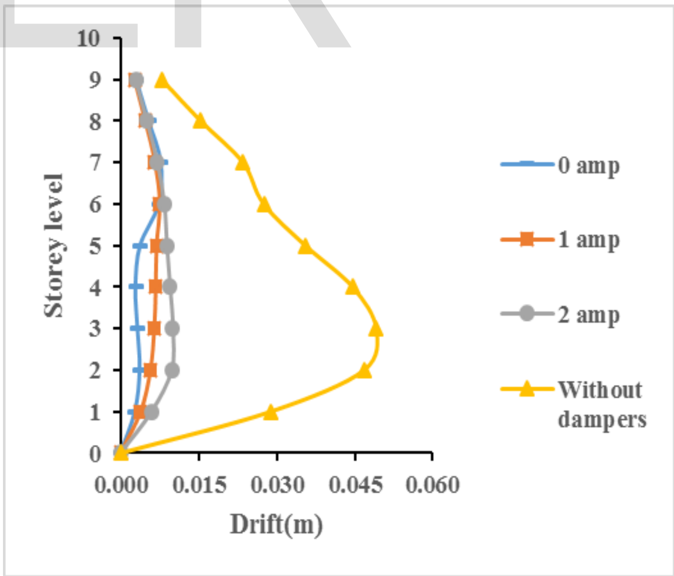

Fig. 11 Graph showing the values of inter-storey drift for passive-off MR damper (0 Amp) and passive-off MR damper (1 Amp and 2 Amp) for nine-storey three bay RCC building.

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23 models were analysed with different damper arrangement to get the optimised value. The optimal number of damper was found as 15 for nine-storey three bay RCC building. From Figure 11 it is found that the values of inter-storey drift fall within the permissible limit. There is a reduction of 93% in the drift value due to the addition of dampers in the optimal location.

V. Conclusions

1. The analysis of the three buildings models using SAP2000 V19 showed exceeding displacement and inter-storey drift when subjected to El Centro earthquake. The response of these structures for Imperial Valley and Northridge was within the permissible limits.
2. The permissible limit of inter-storey drift as per IS 1893 (part 1) 2002 is 0.004 time the height of the storey which is 0.012m.
3. Dampers were added to the structures to bring the drift within the permissible value. A number of patterns of damper placements were analyzed. The analysis was done for varying current values.
4. The derived optimal position and number of dampers (Table I) showed drift values within the permissible limit for the three cases of supply of current.
5. In addition to this, these structures were analyzed with varying damping exponent value of 0.5 and 1.0. the results showed that 0.5 gave the best results and 1.0 gave very worst results.
6. It can be also noticed that from Figures 3, 5, 7 that the dampers are placed at the bottom storey rather than the top storey. Horizontal arrangement of dampers showed better results than horizontal arrangement.

TABLE I

Optimal Number of Dampers

Building model	Number of dampers
Six-storey three bay	6
Nine-storey two bay	9
Nine-storey three bay	15

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