International Journal of Engineering

Journal Homepage: www.ije.ir

TECHNICAL NOTE

# Seismic Mitigation of Building Frames using Magnetorheological Damper

C. Daniel*[a], G. Hemalatha[a], L. Sarala[a], D. Tensing[a], S. Sundar Manoharan[b]

[a] *Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India*
[b] *Sathyabama Institute of Science and Technology, Chennai, India*

*PAPER INFO*

*Paper history:*
Received 02 August 2019
Received in revised form 06 September 2019
Accepted 12 September 2019

*Keywords*:
*Magnetorheological Damper*
*Magnetorheological Fluid*
*Mewmark's Nonlinear method*
*Time History Analysis*

*ABSTRACT*

The present study focusses on the damping force control of shear mode magnetorheological (MR) damper for seismic mitigations. Therefore, the semi-active MR damper which can control the vibration is analyzed both experimentally and numerically. Carbonyl iron is used as the magnetic particle and Castrol Magnetec oil as carrier fluid throughout the study. MR damper is designed and fabricated, and its damping force was evaluated experimentally at 2.5 A- 10 V. Shear mode MR Damper is tested in universal testing machine using time history loading. The model was numerically analyzed using Newmark's method for nonlinear system in MATLAB to control the three storey model building frame taken from the literature. The result indicates that 49.42% reduction in displacement at the second storey and 48.14% in the third storey, respectively. Maximum reduction was observed when damper was kept in the ground floor. The maximum force observed for the MR Damper is 0.777 kN.

***doi**: 10.5829/ije.2019.32.11b.05*

## 1. INTRODUCTION

In the current scenario, MR damper offers a vital role in controlling building frames, due to its unique features such as mechanical simplicity, less current, more dynamic, more force and more toughness. It impacts mechanical energy to the structural system. Recently, a model of a typical MR damper, based on Bouc–Wen hysteresis model [1] is proposed in connection with the control of responses of structures like building frames and bridges. The proposed model is shown to well represents a wide variety of hysteretic behavior [2-4]. The model significant was elevated in a consequent study in mainly for considering the MR fluid response, additionally shear thickening and thinning properties of the fluid was also studied [5-8]. Various dynamic models with their comprehensive study is optimized [9,10]. MR Damper is the potential vibration control system for seismic mitigation has more advantages than other semi-active control devices [11]. The unique advantage is when increase in input current, the damping force also increased. This energy dissipating device has less power consumption and various dynamic range with simple mechanical designs. The response in structures like reinforce concrete frame has more reduction in displacement compared with the conventional devices [12-15]. Lot of algorithm studies carried out on MR damper for seismic applications but very few experimental investigation was conducted. Present work is a part of hybrid simulation [16, 17]. The input earthquake data is given to the MTS system, which give a response of the MR damper at various time. This output response of MR damper is the input for MATLAB hybrid simulation program under newmarks non-linear analysi where the device placed diagonally and response of each floor of the structure is studied for with and without MR Damper.

## 2. PREPARATION OF MR FLUID

The carrier oil used in the present work was the commercially available Castrol Magnatec 5W-10. The MR fluid is prepared by mixing the carbonyl iron with

*Corresponding Author Email: *danielckarunya@gmail.com* (C. Daniel)

Please cite this article as: C. Daniel, G. Hemalatha, L. Sarala, D. Tensing, S. Sundar Manoharan, Seismic Mitigation of Building Frames using Magnetorheological Damper, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 32, No. 11, (November 2019) 1543-1547

Castrol magnatec oil in the 20:80 ratio by weight is named as MRF 80 where 20% of Carrier oil and 80% of carbonyl magnetic particles. The mixture is stirred at 400 RPM in the overhead stirrer for 24 hours as depicted in Figure 1.

## 3. SHEAR MODE

In shear mode, the magnetic field produced is perpendicular to the motion of the moving surfaces as shown in Figure 2. The vibration is controlled when shear form along the annular gap direction in the cylinder inner wall and piston outer wall [18]. For civil engineering concerns, the damper is located in several places and direction, the piston inside the damper produces shear due to the annular gap between piston and inner cylinder is 1-2mm.

## 4. MR DAMPER

A magnetorheological damper is a type of damper where it contains MR fluid, controlled by an external magnetic field, using an electromagnet [19]. This makes the damping property of the vibration to be controlled by changing the current and voltage of the external electromagnet. The schematic representation of shear mode magnetorheological damper is depicted in Figure 3. The proposed damper has a pay load of 2.28 kg. The fabricated magnetorheological damper is depicted in Figure 4. The MR damper is tested by exciting the damper with the amplitude ±5 mm, current range from 0 – 2.5A and frequency 0.5 Hz using MTS Universal

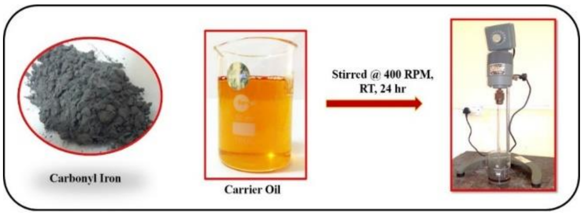


**Figure 1.** Schematic representation for preparation of MR Fluid

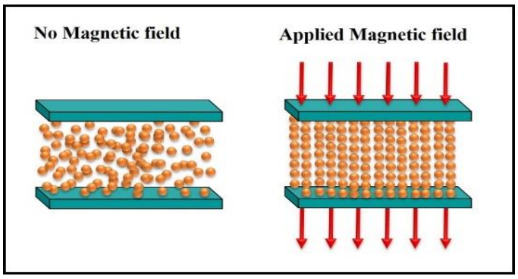


**Figure 2.** Shear mode

Testing machine. This vibration is similar to the cyclic load test. The resulted damping force of the proposed MR damper is measured by a data acquisition system and accelerometer was used to measure movement of the magnetorheological damper. The measured damping force with respect to displacement is represented in Figure 5. The damping force for 0A is 328 N and the maximum damping force at 2.5A is 536 N. The damping force obtained in the test is appropriate for vibration control.

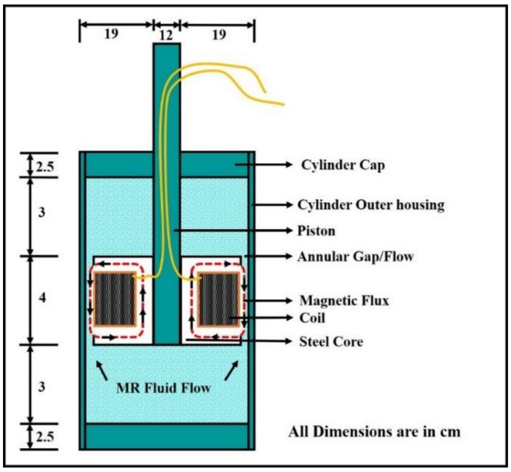


**Figure 3.** Schematic shear mode Magnetorheological damper

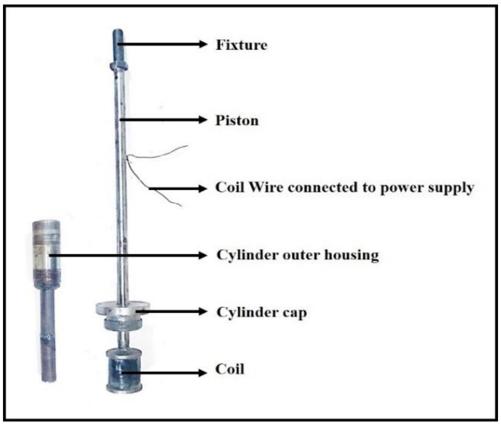


**Figure 4.** Fabricated Magnetorheological damper

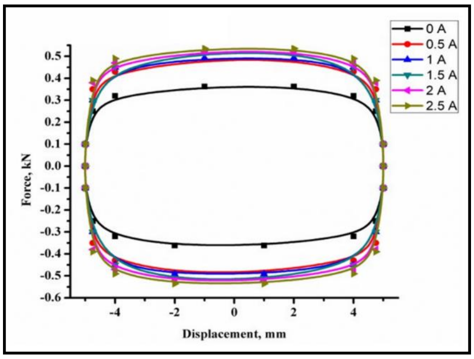


**Figure 5.** Damping force - MRF 80

## 5. DYNAMIC BEHAVIOR OF MR DAMPER

The time history data of El Centro is given for the MR Damper as a input in MTS Universal Testing machine is depicted in Figure 6. The displacement - time and force - time is observed in the experimental investigation of shear mode MR damper shown in Figure 7. The excitation frequency is depending on the ground acceleration data [20, 21]. The coil is wounded with 260 turns of coil and wires are connected to the power supply. The current supplied is 2.5 Amp for MRF 80 fluid configuration and annular gap of 1mm is obtained in the Damper. The displacement is reduced 68.29 % compared to the uncontrolled. The maximum damping force 0.777 kN obtained in Figure 8.

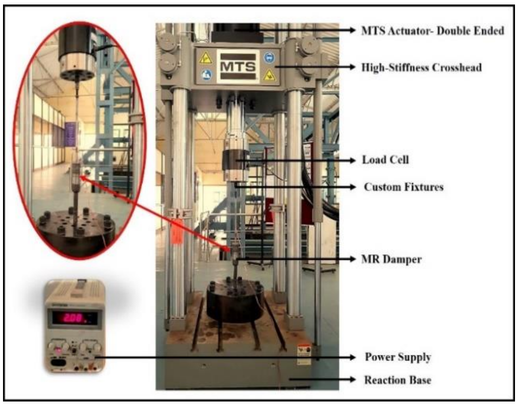


**Figure 6.** MTS Universal Testing Machine

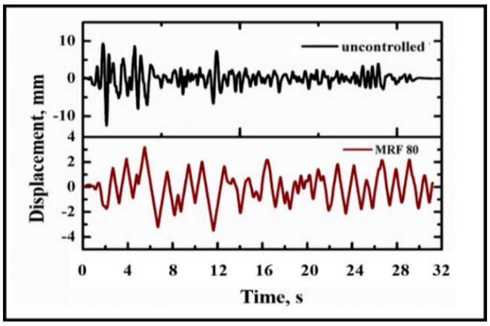


**Figure 7.** Displacement vs. Time

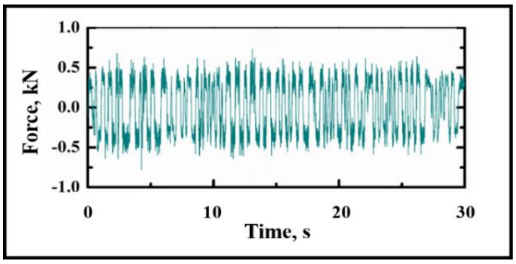


**Figure 8.** Force vs. Time

## 6. NUMERICAL SOLUTION AND DISCUSSION

From the literature [1] a sample problem was taken to describe the above method which is used mainly to control the vibration response depicted in Figure 9. For 3 dof the building undergoes ground acceleration (El-Centro). Here, K, M, C represents the mass, stiffness and damping matrixes of a certain size in the structure [22]. The structure has n degree of freedom subjected to elcentro earthquake ground acceleration $\ddot{x}$ and f is the control force. The equation of motion is given below:

$$M\ddot{x} + C\dot{x} + Kx = \Gamma f - M\Lambda\ddot{x}_g \quad (1)$$

x is the displacement, $\dot{x}$ is the velocity, $\ddot{x}$ is the acceleration, M,C, K are mass , damping coefficient and stiffness in 3*3 matrix form. Γ represents the location of MR Damper (ie. Ground floor, first floor and second floor). For the study MR damper placed in ground floor. Λ is the vector of unity. Newmark's nonlinear integration method using computer programs (MATLAB) to conduct a typical dynamic analysis and flow chart for the analysis is shown in Figure 10.

$$K = 10^5 \begin{bmatrix} 12.0 & -6.84 & 0 \\ -6.84 & 13.7 & -6.84 \\ 0 & -6.84 & 6.84 \end{bmatrix} \text{N/m}$$

$$M = \begin{bmatrix} 98.3 & 0 & 0 \\ 0 & 98.3 & 0 \\ 0 & 0 & 98.3 \end{bmatrix} \text{Kg}$$

$$C = 10^5 \begin{bmatrix} 175 & -50 & 0 \\ -50 & 100 & -50 \\ 0 & -50 & 50 \end{bmatrix} \text{Ns/m}$$

The behavior is obtained using Magnetorheological damper of various features. The efficacy of magnetorheological damper behavior is studied under various parameters. The constraints contain damping force and its location on the structure. In the presence and absence of dampers in ground floor is numerically analyzed in MATLAB. Controlled and uncontrolled response of first, second and third floors are studied with MR dampers, depicting their Displacement-Time characteristics under time history analysis in Figures 10-12. Maximum force and percentage control in each storey is shown in Table 1.

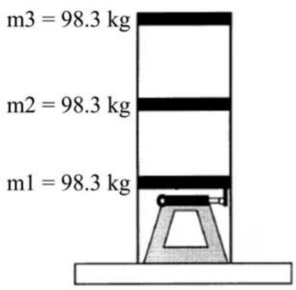


**Figure 9.** Example building frame

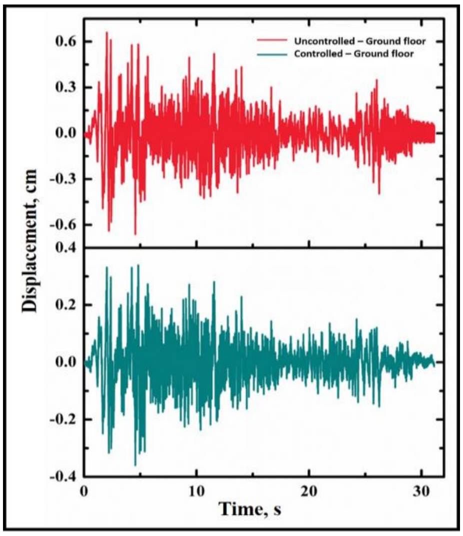


**Figure 10.** Controlled and uncontrolled response of first floor

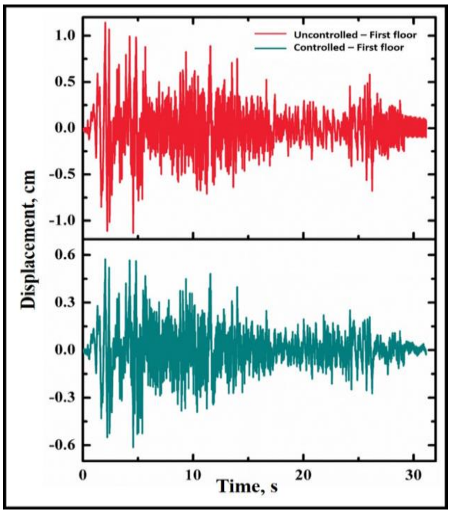


**Figure 11.** Controlled and uncontrolled response of second floor

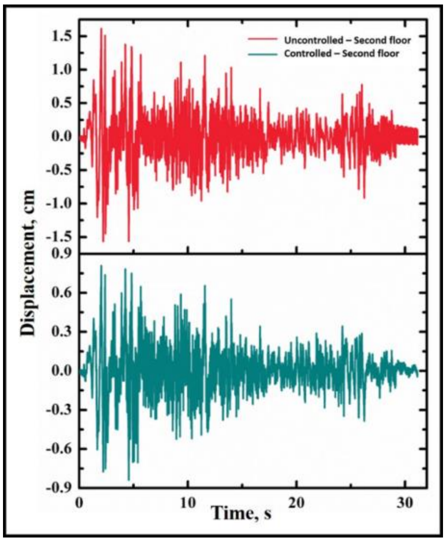


**Figure 12.** Controlled and uncontrolled response of third floor

**TABLE 1.** Maximum force and percentage control

| Responses measured at | Maximum Displacement | | Percentage control | Maximum control force (kN) |
|---|---|---|---|---|
| | Uncontrolled | Controlled | | |
| First storey | 0.661 | 0.339 | 48.71% | |
| Second storey | 1.133 | 0.573 | 49.42% | 0.777 |
| Third storey | 1.560 | 0.809 | 48.14% | |

## 7. CONCLUSION

In the present work, a semi-active control of responses for a 3 storey model structure was tested using shear mode magnetorheological damper. force-time results obtained for the magnetorheological damper from the experimental investigation; it can be directly used to develop the control in Newmark's nonlinear method in MATLAB. Additionally, parametric study is also analyzed to study the influence of the constraints on the behavior of the structure. The experimental test results can be directly incorporated towards the damper position. Significant control of response was achieved with small control force; therefore, with 2.5 A-10 V was used. Position of the damper has made significant note on the effect of control of response. Further, the damper position is also optimized and found lower storey affords the maximum control of response for all storeys. The maximum control force is found to be 0.777 kN. The maximum percentage control of 49.42 % at second storey.

## 8. ACKNOWLEDGEMENT

The authors thank Department of Science and Technology (Grant No: DST/TSG/STS/2015/30-G) for their financial support.

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**چکیده**


مطالعه حاضر بر کنترل نیروی میراگری (MR)برای برطرف کردن زلزله زدگی تمرکز می کند. بنابراین ، میراگر MR نیمه فعال که می تواند لرزش را کنترل کند ، به صورت تجربی و عددی مورد بررسی قرار می گیرد. در طول مطالعه از آهن کربنیل به عنوان ذره مغناطیسی و روغن کاسترول مگنت استفاده می شود. دمپر MR طراحی و ساخته شده است ، و نیروی میرایی آن به صورت آزمایشی در حالت ۲.۵ A- 10 V.ارزیابی شده است. حالت برشی MR دمپر در دستگاه تست جهانی با استفاده از بارگذاری تاریخ زمان مورد آزمایش قرار می گیرد. مدل با استفاده از روش مارکر جدید برای سیستم غیرخطی در MATLAB برای کنترل فریم ساختاری مدل سه طبقه که از منابع گرفته شده بود ، تحلیل شد. نتایج نشان می دهد که کاهش ۴۹/۴۹٪ در جابجایی در طبقه دوم و ۴۸.۱۴٪ در طبقه سوم است. حداکثر کاهش در هنگام نگه داشتن دمپر در طبقه همکف مشاهده شد. حداکثر نیرو مشاهده شده برای MR دمپر ۰.۷۷۷ کیلو نیوتون است.


***doi****: 10.5829/ije.2019.32.11b.05*