Seismic Response Control of High Rise Mass Varied Structures using Friction Dampers

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Abstract— *When a seismic event causes unwanted motion in buildings, energy dissipation techniques in civil engineering are required. There are a variety of structures with passive energy dissipation provided by Passive Constant friction damper systems (CFRD). This technique is being used more and more to increase seismic protection for both existing and new constructions. The CFRD system results are explored in order to compare the structural response with and without this device of energy dissipation compared for low and high rise mass varied buildings, the damper put at different storey and altering the slip force has been focused in this study which gives an insight into the variation of slip load and its locations. The CFRD's potential to boost the structure's dissipative capacities without increasing stiffness was discovered. In the case of high-rise buildings, CFRD performance has been examined using top-storey displacements, allowing for a conclusion.*

***Keywords*— Constant Friction Damper, High Rise Buildings, Seismic Response, Slip load, Tall Structures.**

I. INTRODUCTION

Tectonic plate movement's results in shaking of earth crust which will induce the waves like Primary, Secondary and Love waves on the earth's surface. Structures subjected to seismic excitation results in inertial forces [1] for mass of structure, inherent damping force of structure and resisting force by material stiffness, will try to curb the oscillation. As per IS 875 (Part-3):2015 based on height of structures classified as low and high rise, low rise structures due to stiffness can withstand and reduce the top storey displacement to some extent but not in the case of high rise or mass varying. Dampers which can be the solution for reducing the top storey displacements which it is classified into 4 categories like passive, semi-active, active and hybrid [2], in this study we focus on passive friction dampers [3]. Passive friction dampers are easy to install, effective in reducing energy from the system and requires frequent maintenance, in passive system of damping doesn't require any external power to dissipate seismic energy from the structure, also not required any sensors or external system to monitor, absorption of energy achieved by sliding one plate over another by means of clamping force , clamping force as increases will acts as a strut this phase is called as stick phase once the amount of force is greater than the clamping force from the structure then it will enters to slip phase where the resistance between two plates will be zero, the friction damper is purely displacement dependent device. A 3 [4] low rise and 11 [5] storey high rise benchmark mass varied buildings considered for the study using matlab as a tool by state space [6], frequency of the lumped mass models matches exactly with benchmark problems and hence study focused on reducing the top storey displacement for Elcentro 1940 earthquake for 5 g and 0.3417 g [7] accelerograms both the types of building, using passive friction damper at different location or storey's [8] in the building or structure, finding minimum numbers and location of dampers were discussed in this paper.

II. PASSIVE CONSTANT FRICTION DAMPERS

Passive friction dampers can be implemented in building was invented by Pall and Marsh in 1979 [9], initially it was used in the automobiles to decelerate by means of braking which a large part of kinetic energy dissipated in terms of heat. There are two major types of FRD (Friction Dampers) viz. Pall and Sumitomo friction dampers. FRD were experimentally efficient and it was proved by Skinner et. Al in 1975.

III. MECHANISM OF FRICTION DAMPER

Majorly the FRD works on clamping force, which decides the stick and slip phase of damper based on displacement allowed for the FRD. Parametric studies have shown that the slip load of the FRD plays a vital role, selecting the optimum slip load reduces maximum response of the structure, but ± 20% variation will not affect that much to response [10].

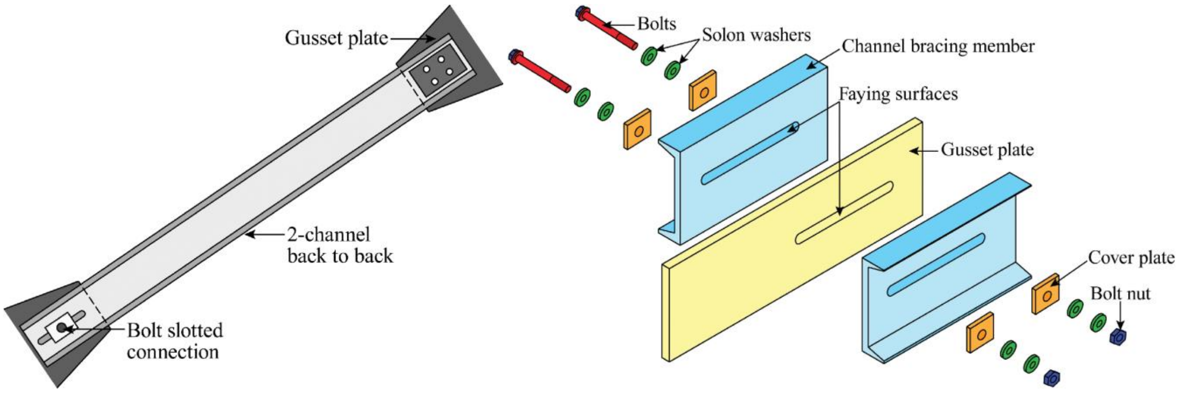

FIGURE 1: Anatomy of Passive Friction Damper [11]

Friction-based dampers consist of steel plates that are pulled together by high-strength bolts with axial or rotational deformation mechanisms to convert kinetic energy into thermal energy [12]. FRD functions similarly to fuses in that they limit the amount of force that can be applied to the structural members they protect. Because the hysteresis loop is rectangular, it dissipates the most of energy in a given force - displacement, regardless of velocity or frequency. Consistent and repeatable performance against a wide variety of earthquakes, with no maintenance required [13]. The value of damping force F is given by the relationship:

$$F_d = \pm\mu * N \quad (1)$$

Where,

F_d – Damping Force induced by Damper in Newton

μ - is the Coefficient of sliding friction between two plate surfaces, 0.60 for kinetic [14].

N - is Normal force across the moving surfaces also called as clamping force.

A typical force displacement relationship shown in below figure 2 of FRD, Structure and structure installed with FRD.

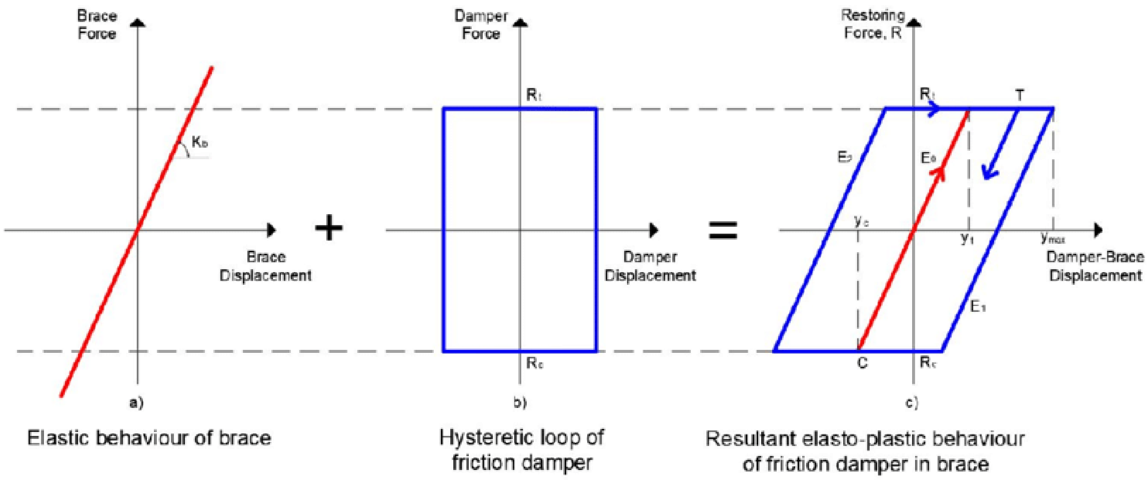

FIGURE 2: Hysteretic Curves of Brace, CFRD and CFRD Installed Structure [11]

The current study focuses on passive friction damping, the two important assumptions made for the study is that *nonlinearity* is concentrated only in FRD not in the structural members and FRD installed structure is to be treated as two different systems to ensure elasto-plastic behaviour, the FRD will have two phases namely 'stick phase' and 'slip phase'[15]. In stick phase the damper acts as a braced frame (it is ignored in study) and once it reach the maximum value of friction force suddenly it will enters into slip phase where the behaviour of the damper changes from tension to compression or vice versa. The study uses only constant friction dampers (CFRD).

IV. GOVERNING EQUATIONS OF MOTION

Mathematically a structure can be modelled as a lumped mass at each storey with multi degree of freedom can be written as:

$$M * \ddot{x(t)} + C * \dot{x(t)} + K * x(t) = -M * \ddot{x(t)}_g \tag{2}$$

In the above equation if we add CFRD it can be rewritten as:

$$M * \ddot{x(t)} + C * \dot{x(t)} + K * x(t) + F_N = -M * \ddot{x}_g(t) \tag{3}$$

Where,

M – Mass matrix, diagonal matrix in kg

C – Damping matrix, tri-diagonal matrix in N-s/m

K – Stiffness matrix, tri-diagonal matrix in N/m

x(t) – Storey Acceleration vector due to excitation at that storey

x(t) – Storey Velocity vector due to excitation at that storey

x(t) – Storey Displacement vector due to excitation at that storey

xg(t) – Ground acceleration

V. NUMERICAL STUDY

The storey shear building frame model with and without friction damper at different storey's were modelled as linear lumped mass [16], governing equations of motion are stated above. The benchmark problem of 3 storey building configured with MR damper of passive off case [17] is considered with CFRD installed at ground storey. Using state space matrix it can be solved to determine the displacement and acceleration of the storey at the time t for the ground motion of NS component of El-centro 1940 data reproduced at 5 times the original record. The exact modelling of the problem using equations modelled in Matlab. System matrices are as mentioned below [18]:

$$Mass\ matrix = M = \begin{bmatrix} 98.3 & 0 & 0 \\ 0 & 98.3 & 0 \\ 0 & 0 & 98.3 \end{bmatrix} in\ kg$$

$$Damping\ matrix = C = \begin{bmatrix} 50 & -50 & 0 \\ -50 & 100 & -50 \\ 0 & -50 & 175 \end{bmatrix} in\ N-s/m$$

$$Stiffness\ matrix = K = (10^5) * \begin{bmatrix} 6.84 & -6.84 & 0 \\ -6.84 & 13.7 & -6.84 \\ 0 & -6.84 & 12 \end{bmatrix} in\ N/m$$

State Space matrices:

$$A = \begin{bmatrix} -M_i^{-1} * C_i & -M_i^{-1} * K_i \\ 0 & I \end{bmatrix} \qquad B = \begin{bmatrix} M_i^{-1} * \Gamma \\ 0 \end{bmatrix} \qquad E = -\begin{bmatrix} \Lambda \\ 0 \end{bmatrix}$$

State space output matrices:

$$C = \begin{bmatrix} 0 \quad 0 \quad 0 & 0 \quad 0 \quad 1 \\ -M_i^{-1} * C_i & -M_i^{-1} * K_i \end{bmatrix} \qquad D = \begin{bmatrix} 0 \\ M_i^{-1} * \Gamma \end{bmatrix}$$

Where,

$$Damper\ Location\ matrices = \Gamma = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} \qquad State\ matrices = \Lambda = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

i =storey level

$$\dot{z} = A * z + B * F_d + E * \ddot{x_g} \qquad y = C * z + D * F_d$$

Validation or Comparison of results with the benchmark problem (BMP) considered as low rise structure [19]:

TABLE 1
COMPARISON OF STUDY RESULTS WITH BENCHMARK PROBLEM FOR LOW RISE CASE.

Parameter	Storey	Uncontrolled of BMP	Uncontrolled of study[18]	% of difference	Passive off case of BMP with MRD	CFRD installed model of study Target as top storey displ	% of difference
Storey Displacement in mm	Top - 1	9.62	9.647	0.28 %	4.55	4.579	0.63 %
	First - 2	8.20	8.246	0.56 %	3.57	3.500	1.96 %
	Ground - 3	5.38	5.407	0.50 %	2.11	2.011	4.69 %
	Base	0.0	0.0	0.0	0.0	0.0	0.0
Mean Difference				0.45 %			2.42 %
Slip Force in N (0.217 times of Storey weight)		-			258	210	19.20 %

Further the study continuous to keep the damper force constant of 258 N and observing the top storey displacement:

TABLE 2
COMPARISON OF STUDY RESULTS WITH BENCHMARK PROBLEM FOR LOW RISE CASE

Parameter	Storey	Passive off case of BMP with MRD	CFRD installed model of study	% of difference
Storey Displacement in mm	Top - 1	4.55	3.907	14.13 %
	First - 2	3.57	3.083	13.64 %
	Ground - 3	2.11	1.890	10.43 %
	Base	0.0	0.0	00.00 %
Mean Difference				12.73 %
Slip Force in N (As per Ref.)		258	258	0.00 %

Further the study continuous to locating CFRD at different storey's and the top storey displacement reduces from 9.647 to 4.55 mm for that clamping force or damper force 'f' results are listed as below:

TABLE 3
COMPARISON OF CFRD FORCE FOR CD VARIATION FOR DIFFERENT MODELS OF LOW RISE CASE.

Sl. No.	Model	Description	Damper Force in N	Top Storey Displ In mm
1	M-1	CFRD installed at ground storey only	210	4.579
2	M-2	CFRD installed at first storey only	210	3.323
3	M-3	CFRD installed at top storey only	210	2.344
4	M-4	CFRD installed at all storey	210	0.670
5	M-5	CFRD installed at ground & top storey only	210	1.349

The force displacement curves are as follows for the different models as mentioned in the above table:

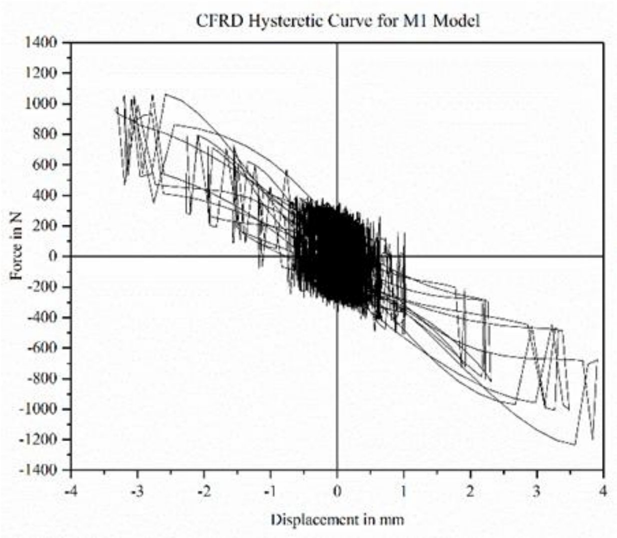

FIGURE 3: M1 model

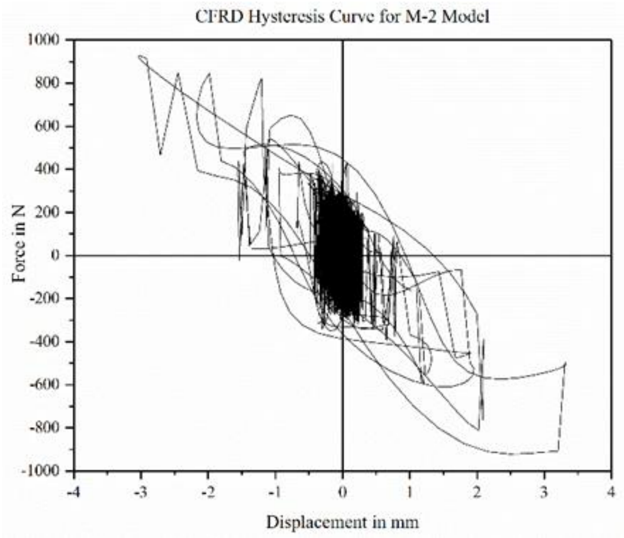

FIGURE 4: M2 model

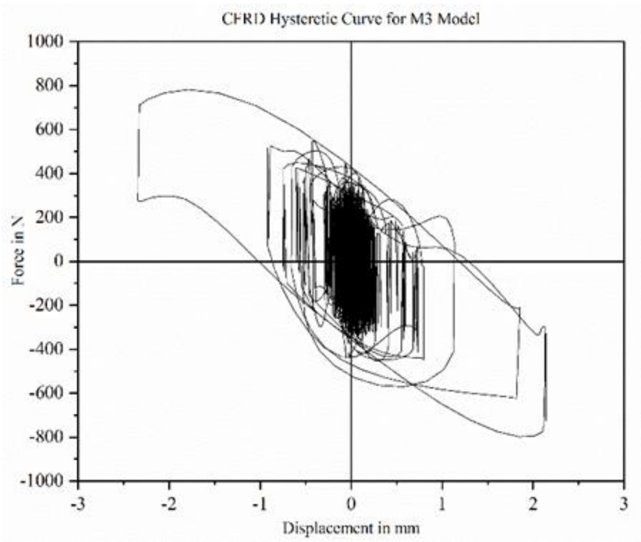

FIGURE 5: M3 model

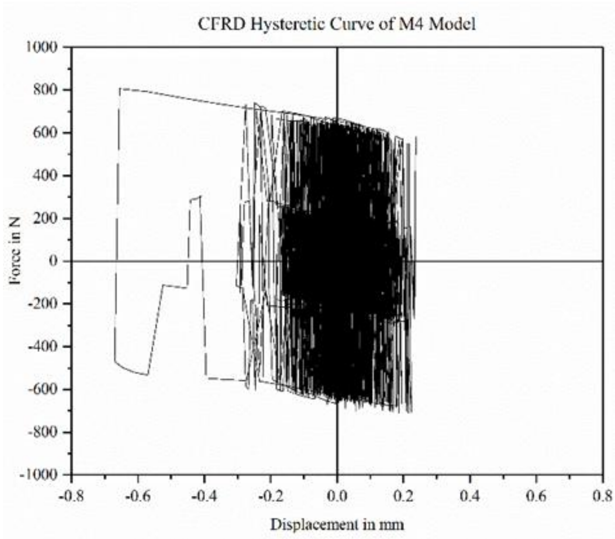

FIGURE 6: M4 model

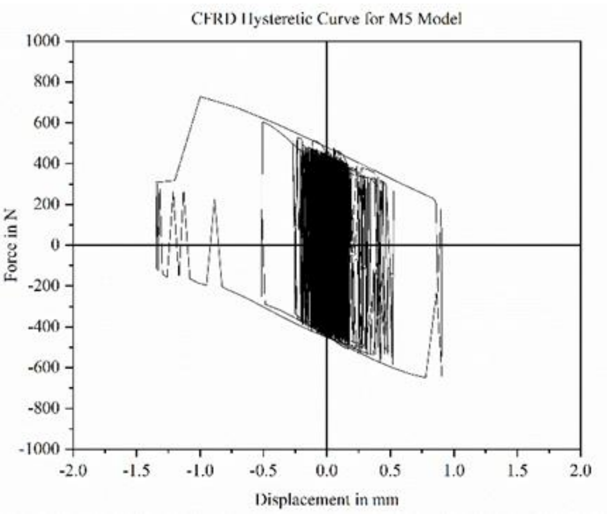

FIGURE 7: M5 model

Top storey displacement curve for NS component of Elcentro 1940 earthquake force for CFRD installed models:

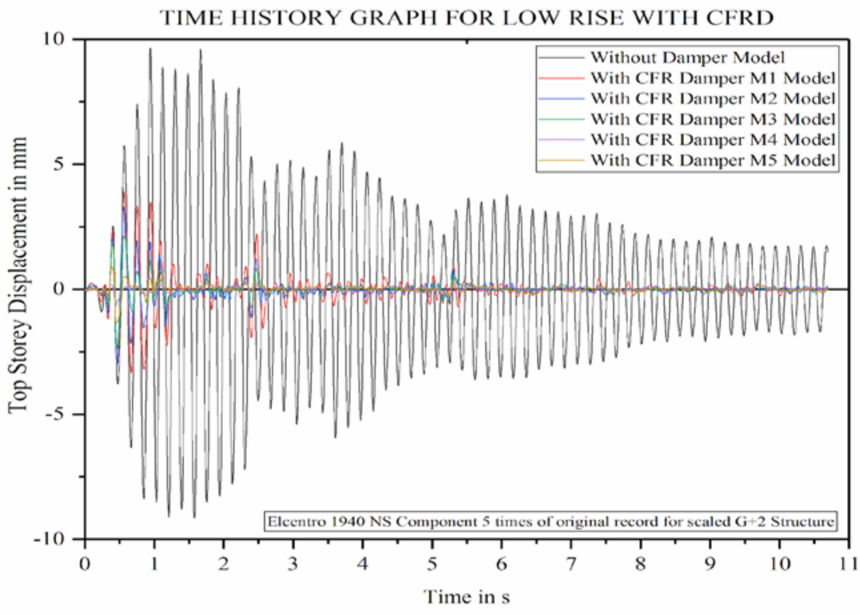

FIGURE 8: Top Storey displacement v/s time graph for constant friction damper.

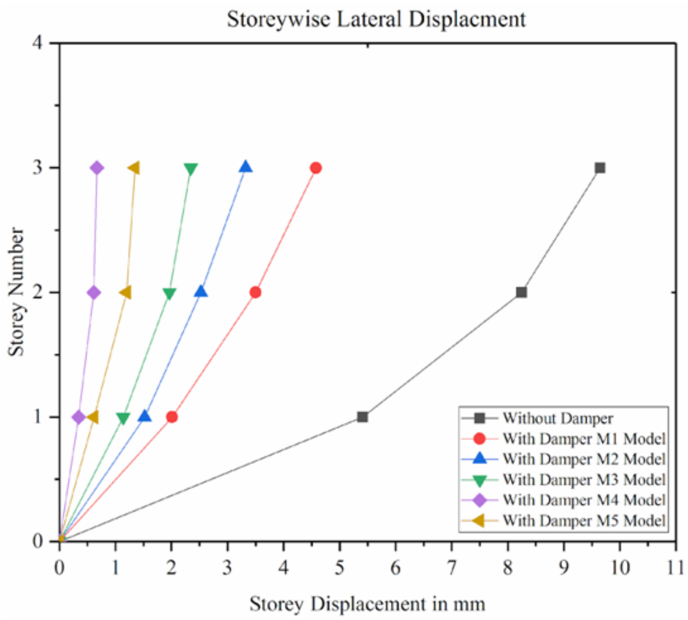

FIGURE 9: Lateral displacement for CFRD installed models

VI. HIGH RISE BUILDING

Further the study evaluates for the tall structure (high rise building 11 storey) [5], [19] are as follows:

$$Mass\ matrix = M = \begin{bmatrix} 1.76 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.01 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.01 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2.01 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.00 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.01 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.01 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.15 \end{bmatrix} (1 * 10^5) in\ kg$$

$Stiffness\ matrix = K$

$$= (1 * 10^8) \begin{bmatrix} 3.12 & -3.12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.12 & 7.49 & -4.37 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -4.37 & 8.74 & -4.37 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -4.37 & 8.74 & -4.37 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -4.37 & 8.87 & -4.50 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -4.50 & 9.00 & -4.50 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -4.50 & 9.00 & -4.50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -4.50 & 9.00 & -4.50 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4.50 & 9.18 & -4.68 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4.68 & 9.44 & -4.76 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4.76 & 9.44 \end{bmatrix} in\ N/m$$

$Damping\ Matrix = C$

$$= (1 * 10^6) \begin{bmatrix} 1.30 & -1.70 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1.70 & 3.02 & -1.70 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1.70 & 3.50 & -1.70 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1.70 & 3.50 & -1.76 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1.76 & 3.56 & -1.76 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1.76 & 3.61 & -1.76 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1.76 & 3.61 & -1.76 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1.76 & 3.61 & -1.82 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.82 & 3.68 & -1.86 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.86 & 3.78 & -1.82 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.82 & 3.79 \end{bmatrix} in\ N-s/m$$

Validation or Comparison of results with the benchmark problem (BMP) considered as high rise structure:

TABLE 4
COMPARISON OF STOREY WISE DISPLACEMENT FOR HIGH RISE CASE [18].

Parameter	**Storey**	**Uncontrolled of BMP** [5]	**Uncontrolled of study** [18]	**% of Difference**
Storey Displacement in mm	11	147.0	148.26	0.86
	10	140.0	144.62	3.30
	9	140.0	139.10	0.64
	8	130.0	130.80	0.62
	7	120.0	119.88	0.10
	6	100.0	106.95	6.95
	5	90.0	91.97	2.18
	4	74.0	75.23	1.66
	3	57.0	57.06	0.10
	2	39.0	38.53	1.20
	1	19.0	19.62	3.26
	0	0.00	0.00	0.00
Mean Difference				1.90 %

Constant Friction Damper parameters: Clamping force N = 25 kN, Slip force = 0.6*N = 15 kN [20]

Model 1: Dampers Installed at all storey's

TABLE 5
COMPARISON OF STOREY WISE DISPLACEMENT FOR CFRD INSTALLED AT ALL STOREY FOR HIGH RISE CASE.

Storey No.	Storey Displacement for without Damper in mm [5]	Storey Displacement for with Damper in mm	% reduction	CFRD force Developed in Damper in kN
11	148.2	49.17	66.82%	15 in each storey
10	144.6	47.03	67.48%	
9	139.1	44.26	68.18%	
8	130.8	40.60	68.96%	
7	119.8	36.60	69.45%	
6	106.9	32.71	69.40%	
5	91.9	28.86	68.60%	
4	75.2	24.78	67.05%	
3	57.0	19.85	65.18%	
2	38.5	13.97	63.71%	
1	19.6	7.27	62.91%	
0	0.00	0.00	0.00	-

Model 2: Dampers Installed at alternate storey's

TABLE 6
COMPARISON OF STOREY WISE DISPLACEMENT FOR CFRD INSTALLED AT ALTERNATE STOREY FOR HIGH RISE CASE.

Storey No.	Storey Displacement for without Damper in mm [5]	Storey Displacement for with Damper in mm	% reduction	Force Developed in Damper in kN
11	148.2	57.23	61.38%	15
10	144.6	54.67	62.19%	-
9	139.1	51.36	63.08%	15
8	130.8	47.39	63.77%	-
7	119.8	43.96	63.31%	15
6	106.9	41.09	61.56%	-
5	91.9	37.15	59.58%	15
4	75.2	31.95	57.51%	-
3	57.0	25.33	55.56%	15
2	38.5	17.69	54.05%	-
1	19.6	9.17	53.21%	15
0	0.00	0.00	0.00	-

Model 3: Dampers Installed at alternate two storey's

TABLE 7
COMPARISON OF STOREY WISE DISPLACEMENT FOR CFRD INSTALLED AT ALTERNATE TWO STOREY FOR HIGH RISE CASE.

Storey No.	Storey Displacement for without Damper in mm [5]	Storey Displacement for with Damper in mm	% reduction	Force Developed in Damper in kN
11	148.2	88.93	39.99%	-
10	144.6	86.70	40.04%	15
9	139.1	83.38	40.06%	-
8	130.8	78.37	40.08%	-
7	119.8	71.76	40.10%	15
6	106.9	63.98	40.15%	-
5	91.9	54.97	40.18%	-
4	75.2	44.91	40.28%	15
3	57.0	34.03	40.30%	-
2	38.5	22.96	40.36%	-
1	19.6	11.67	40.46%	15
0	0.00	0.00	0.00	-

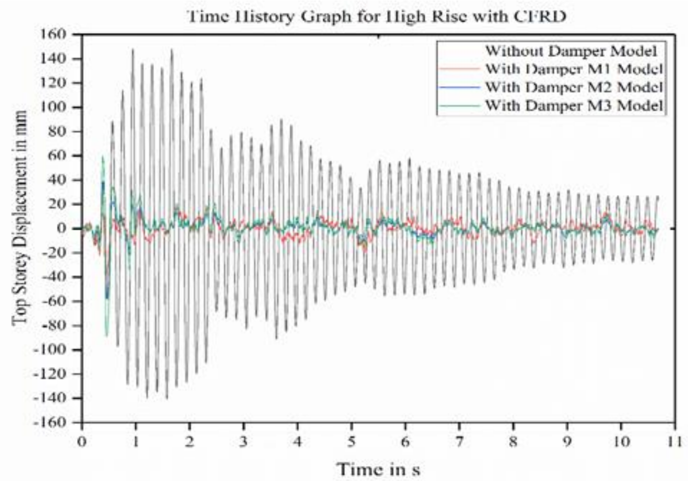

FIGURE 10: Top Storey displacement v/s time graph for with and without dampers

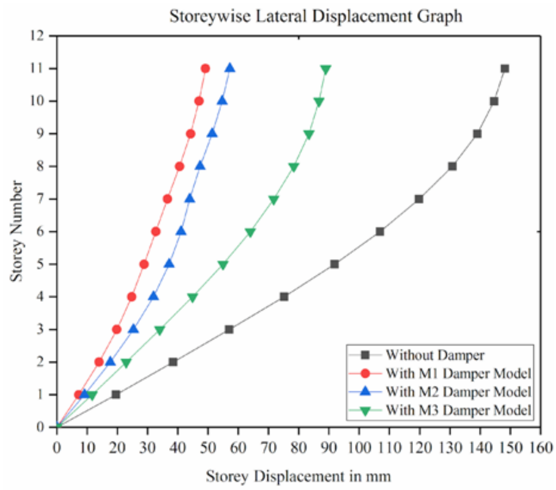

FIGURE 11: Lateral displacement for CFRD installed models

VII. RESULTS & DISCUSSIONS

Low Rise Case:

1. Validating benchmark problem to 0.45 % difference in results led to the conclusion that modelling of the structure is effective.
2. When the friction force is constant hysteretic curves are almost rectangular.
3. When the CFRD numbers varied in buildings force developed by damper is constant.
4. The M-4 model acquired the lowest top storey displacement, but it is uneconomical, thus the M-5 model fetched the next better results when compared to the M-4 and M-5 models, as shown in table 3.

5. Models without dampers follow a linear pattern as seen in fig.2, whereas M-2 to M-5 models follow a hysteretic curve.
6. Slip load of 0.217 times of storey weight considered and obtained less force generated by the damper when compared with BMP.

High Rise Case:

1. The 11-story high rise mass and stiffness have been varied as it rises.
2. The friction force kept constant here based on the storey shears.
3. The lateral displacement curve is parabolic as per the fig.16.
4. The tall structure's average storey-wise displacement difference is 1.90%..
5. When CFRD are put at different places in tall structures, as mentioned in tables 5, 6, and 7, the number of dampers as high as the storey displacements are likewise minimal.
6. When compared to WOD, the optimum models for tall structures are dampers put at alternative 2 storeys with fewer dampers but up to 40% lower displacements achieved.

VIII. CONCLUSIONS

1. Mass kept same in all storey's with CFRD to reduce the top storey displacements required 19 % less force compared to BMP.
2. Mass and stiffness are varied with CFRD to reduce top storey displacements upto 40 %.
3. It is nearly hard to maintain the same mass throughout all storeys in real time.
4. CFRD at two alternate storey in low and high rise cases shows good results when compared to CFRD installed at all storey's.

REFERENCES

[1] G. B. M., "Principia Mathematica," *Nature*, vol. 87, no. 2183. pp. 273–274, 1911, doi: 10.1038/087273a0.

[2] T. E. Saaed, G. Nikolakopoulos, J. E. Jonasson, and H. Hedlund, "A state-of-the-art review of structural control systems," *JVC/Journal of Vibration and Control*, vol. 21, no. 5, pp. 919–937, 2015, doi: 10.1177/1077546313478294.

[3] D. P. Taylor, "History, design, and applications of fluid dampers in structural engineering," *Passive Structural Control Symposium, 13-14 December, Tokyo Institute of Technology, Japan*, pp. 17–34, 2002, [Online]. Available: http://taylordevices.com/papers/history/design.htm.

[4] S. J. Dyke and B. F. Spencer, "A comparison of semi-active control strategies for the MR damper," *Proceedings - Intelligent Information Systems, IIS 1997*, no. January 1998, pp. 580–584, 1997, doi: 10.1109/IIS.1997.645424.

[5] S. Pourzeynali, H. H. Lavasani, and A. H. Modarayi, "Active control of high rise building structures using fuzzy logic and genetic algorithms," *Engineering Structures*, vol. 29, no. 3, pp. 346–357, 2007, doi: 10.1016/j.engstruct.2006.04.015.

[6] R. L. W. Ii *et al.*, *Linear State-Space Control Systems*. 2007.

[7] B. Halldórsson, G. P. Mavroeidis, and A. S. Papageorgiou, "Near-fault and far-field strong ground-motion simulation for earthquake engineering applications using the specific barrier model," *Journal of Structural Engineering*, vol. 137, no. 3, pp. 433–444, 2011, doi: 10.1061/(ASCE)ST.1943-541X.0000097.

[8] M. P. Singh and L. M. Moreschi, "Optimal placement of dampers for passive response control," *Earthquake Engineering and Structural Dynamics*, vol. 31, no. 4, pp. 955–976, 2002, doi: 10.1002/eqe.132.

[9] R. S. P. PALL, AVATAR S PALL, "*Friction Dampers for Seismic Control of Buildings 'A Canadian Experience,'" In 11th World Conference on Earthquake Engineering*, 1996, pp. 497–505.

[10] A. Pall and R. T. Pall, "13 th World Conference on Earthquake Engineering *Performance-Based Design using Pall Friction Dampers - An Economical Design Solution.*," no. 1955, 2004.

[11] V. M. Suhasini Madhekar, Passive Vibration Control of Structures. Newyork: Taylor & Francis, 2022.

[12] T. H. Babak ESMAILZADEH HAKIMI, Alireza RAHNAVARD, "SEISMIC DESIGN OF STRUCTURES USING FRICTION DAMPER BRACINGS," in *13th World Conference on Earthquake Engineering*, 2004, pp. 1–6.

[13] C. Marsh, "The control of building motion by friction dampers," *12th World Conference on Earthquake Engineering*, pp. 1–6, 2000.

[14] J. F. Sullivan, "THE PHYSICS FACT BOOK." https://hypertextbook.com/facts/2005/steel.shtml.

[15] H. M. Aktan, "Abating earthquake effects on buildings by active slip brace devices," *Shock and Vibration*, vol. 2, no. 2, pp. 133–142, 1995, doi: 10.3233/SAV-1995-2204.

[16] M. Paz and W. Leigh, "Structural Dynamics Theory and Computation By Mario Paz." 2004.

[17] S. J. Dyke, B. F. Spencer, M. K. Sain, and J. D. Carlson, "Modeling and control of magnetorheological dampers for seismic response reduction," *Smart Materials and Structures*, vol. 5, no. 5, pp. 565–575, 1996, doi: 10.1088/0964-1726/5/5/006.

[18] A. K. G. S and J. G. Kori, "Seismic Response Control of High-Rise Mass Varied Structures Using Linear Fluid Viscous Damper," no. May, 2022.

[19] IS: 875 (2015), "Indian Standard design loads (other than earthquake) for buildings and structures-code of practice,part 3(wind loads)," *BIS, New Delhi*. p. 51, 2015.

[20] M. Armali, J. Hallal, and M. Fakih, "Effectiveness of friction dampers on the seismic behavior of high rise building VS shear wall system," no. November, pp. 1–14, 2019, doi: 10.1002/eng2.12075.