Seismic Evaluation of a RC Framed Structure Equipped with and without Friction Damper Device

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Abstract - *Generally, Civil engineering structures are susceptible to the severe damage when subjected to significant earth quake forces during a seismic event. Many of the structural failures in buildings during strong earthquake shaking have indicated that stable energy dissipation capability is one of the most desirable parameter to maintain inter story drifts and overall structural displacements within tolerable limits. Friction dampers are one of the best the viable solution for enhancing earthquake energy dissipation capacity. Friction damper is a passive type energy dissipating device which dissipates the seismic energy by virtue of the solid friction developed between the two sliding surfaces. Numerous types of friction dampers have been developed and their energy dissipation capacities have been verified. The advantages of using friction dampers over other types of energy dissipation devices are due to materials are less likely to be affected by degradation due to aging, materials are insensitive to changes in ambient temperature, there are no material yielding problems after a large earthquake and there are no fluid leaking problems. In this paper, a comparative study of seismic response parameters of an RC structure equipped with and without friction damper is done and the optimum slip load of the friction dampers is determined. Also, effective configuration of arrangement of friction dampers is discussed. Nonlinear time history analysis was carried out to assess the structural performance of the dampers under earthquake ground motions. These models are compared in different aspects such as storey displacement, roof acceleration and base shear.*

Key Words: **Passive Energy Dissipation System, Friction Damper Devices, Optimum Slip Load, Time History Analysis, Inter Storey Drifts, Maximum Story Displacement, etc.**

1. INTRODUCTION

Nowadays structural vibration control techniques such as passive, active, semi active and hybrid control techniques, are gaining importance in earthquake resistant design of structures. High rate of energy dissipation during earthquakes is the benefit of using such devices, which results in damage reduction of structural elements. Earthquakes cause economic losses as well as losses of lives due to collapse of structures. During a severe earthquake event, the main structural elements like beams and columns are seriously affected. So, a structural engineer should have great concern in designing earthquake resisting system to dissipate energy effectively from the structure.

1.1 Friction Damper

The friction damping devices have been applied to civil engineering structures either for seismic retrofitting or in new construction Friction damper is a passive type energy dissipating device which dissipates the seismic energy by virtue of the solid friction developed between the two sliding surfaces. A friction damper typically consists of one or more frictional interfaces as well as a clamping mechanism that produces normal contact force on the interfaces. The clamping force is usually a fixed value that is predetermined by the design engineer. Therefore, according to Coulomb's friction theory, the maximum friction force (the slip force) of the damper is also a constant. When excited, a friction damper at any given time, has two possible motion states i.e. a stick or slip state. The damper motion will be between these two states. A friction damper dissipates seismic energy only when it is in its slip state.

1.2 Optimum Slip Load

When the force acting on the friction damper reaches a predetermined value, the sliding surfaces starts slipping, thus dissipates the seismic energy. The slipping should starts before any of the main structural elements starts yielding. The predetermined load at which the slipping occurs and damper starts dissipating the seismic energy is called as slip load of the friction damper. The energy dissipating capacity of the friction damper depends on its slip load and hence the response of the structural system also depends on the slip load of the damper. For a friction damper installed in a structural system, there exists an optimal slip load which corresponds to the least response of the structure. The energy dissipated by the friction dampers is also the maximum at their optimal slip load. Normally 10-15% variation in the optimal slip load does not affect the response of the structure much and many of the previous studies confirms the same.

There are several criteria to select the optimal slip load for a particular structure such as safety of the structure, maximum displacement of the roof, maximum base shear, percentage of input energy dissipated by the friction dampers and the maximum column axial loads due to earthquake.

2. THEORETICAL BACKGROUND

Friction brake is widely used to extract kinetic energy from a moving body as it is the most effective, reliable and economical mean to dissipate energy. For centuries, mechanical engineers have successfully used this concept to control motion of machinery and automobiles. This principle of friction brake inspired the development of friction dampers.

The development of friction damping devices was pioneered in late seventies. In 1980, Avatar s Pall, C Marsh and Paul Fazio proposed a solution in the form of friction joints to reduce seismic responses of large panel structures, and later in 1982 pall and marsh provided sliding friction devices which can be installed in a framed building in x-braced frame as illustrated in figure 1, a and b.

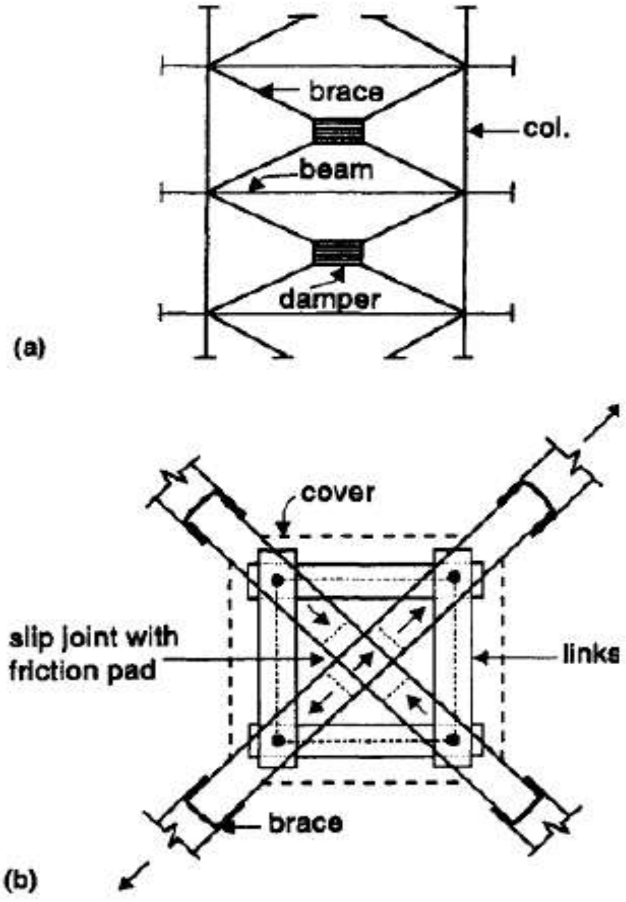

Fig-1: Pall Fiction Damper

Filiatrault and cherry(1989) carried out an extensive study on force displacement response of the pall friction damper and conducted an experiment to study seismic performance of a one three scaled three storied steel braced frame with friction dampers on a shaking table using several earthquake records of varying intensities. The frame structure was tested without friction dampers in both MRF and BMR frame configurations and with friction dampers in a FDB frame configuration. This study concluded that the FDB frame sustained no damage in any of its elements whereas the MRF suffered damage in its beams at the first and second floors and the BMR frame suffered inelastic buckling in the diagonal braces. Further, both deflections and accelerations were significantly smaller in the FDB frame.

In the intervening years, a number of friction devices have been developed such as Sumitomo friction damper and Imad H Mualla damper shown in figures 2.

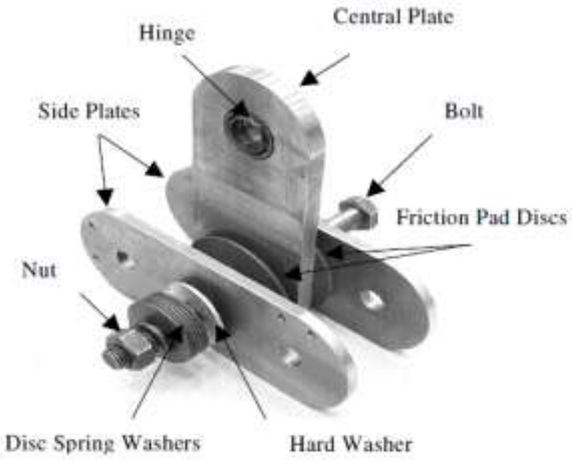

Fig-2: Mualla friction damper

A combination mechanism which incorporates a friction damping device and a viscoelastic damping device has also been a subject of investigations.

3. MODELLING AND ANALYSIS

The primary purpose of structural analysis of building structures is to establish the distribution of internal forces and moments over the whole or part of a structure and to identify the critical design conditions at all sections. The geometry is commonly idealized by considering the structure to be made up of linear elements and plane two-dimensional elements. The program ETABS is employed herein to perform nonlinear dynamic time history analysis to obtain the modal characteristics.

3.1 Modelling Of Friction Damper

The friction dampers are modelled using two-joint link elements (Plastic Wen). Both linear and nonlinear properties are provided for the dampers. The linear properties are used for the linear modal load case and the nonlinear properties are used for the nonlinear time history load cases.

The bracing and the friction damper is together modeled as a damped brace having yield strength equal to the slip load of the friction damper. Only one active degrees of freedom U1 was specified for the friction damper as it is active only in its local axial direction. A yielding exponent of 10 indicating sharp transition from linear to nonlinear phase and a post yield stiffness ratio of 0.0001 indicating rectangular hysteresis loop as suggested by Pall, were used to describe the damper properties. The slip load of the friction damper is specified in terms of the yield strength which is the primary variable and have more impact on the response of the frame.

3.2 Modelling Of RC Structure

In the finite element analysis software ETABS, building is idealized as an assemblage of area, line and point objects. Those objects are used to represent members like wall, floor, column, beam, and brace and link/spring.

A 10 storey RCC special moment resistant framed structure is considered.as the case study model. The building plan and elevation are shown in figures 4 and 5 respectively. The plan is symmetrical in shape and having an area measurement of 21x21 m2. The total height of the building is 35 m. each story has a height of 3.5m including ground floor. The base is fixed to restrain in all 6 DOFs.

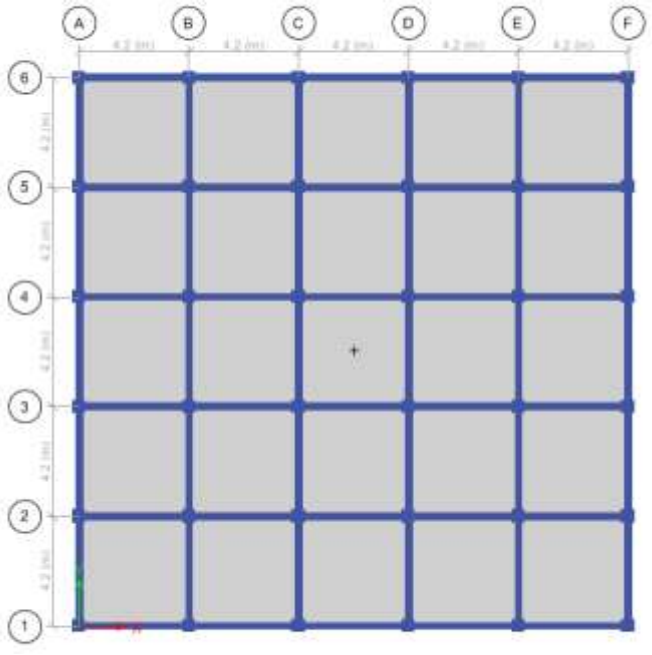

Fig-3: Plan of the building

Beam and column sizes are given in table 1. Slab thickness is 120mm, 1.0 kN/m2 finish load, 4 kN/m2 live load on floors and 1.5 kN/m2 live load on roof were considered. A live load reduction factor of 0.5 for all floors and 0 for the roof was considered in the earthquake analysis as per IS 1893:2002. A modal damping of 5% of the critical was considered to account for the material damping.

Table -1: Dimensions of structural components

Building data	Dimension	Remarks
B250X450 (beam)	450x250	All beams
C800X800 (column)	800X800	Columns in ground floor
C700x700 (column)	700x700	Columns in 2nd floor
C600x600 (column)	600x600	Columns in 2nd to 6th floor
C500x500 (column)	500x500	Columns in 7th to 10th floor

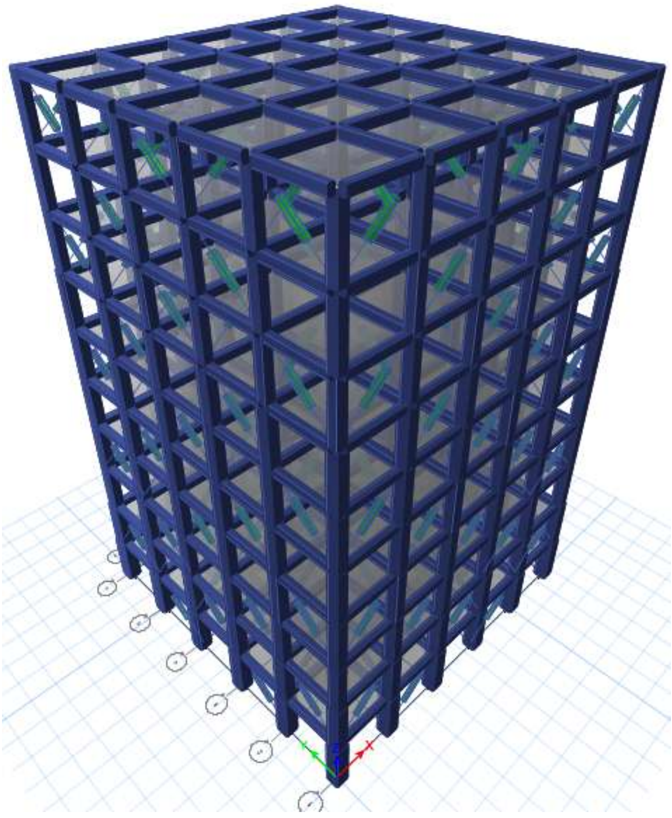

Fig-4: 3D Model of the building

3.3 Nonlinear Time History Analysis

A set of three time history records, given in table 2 at 0°, 90° and Z direction have been used. This time history function data has been matched to response spectrum function to generate synthetic accelerogram for the assumed site condition. The spectral matching has been done in frequency domain. The matching parameter is set in a frequency range of 0.01 cycles/sec to 100 cycles/sec. The 3 synthetic accelerogram in 3 directions (U1, U2 and U3) are applied simultaneously to create realistic ground motion condition. Each of the time history data is scaled to 1g.

Table -2: time history records

RSN	Event	Year	Station	Magnitude	PGA	PGV
174	Imperial Valley	1979	El Centro Array # 11	6.53	0.3746	38.41
766	Loma Prieta	1989	Gilroy Array #2	6.93	03529	35.10
960	North Ridge	1987	Canyon Country – W Lost Cany	6.69	0.4355	43.33

4. RESULT AND DISCUSSIONS

4.1 Optimum Slip Load of Friction Damper

The slip load range at minimum roof displacement was obtained for dynamic analysis as illustrated in charts 1, 2, and 3. The least value of slip load in the common range of all three analysis results was taken as the optimum slip load as given in table 3.the optimum slip load for the dampers is found to be 400KN.

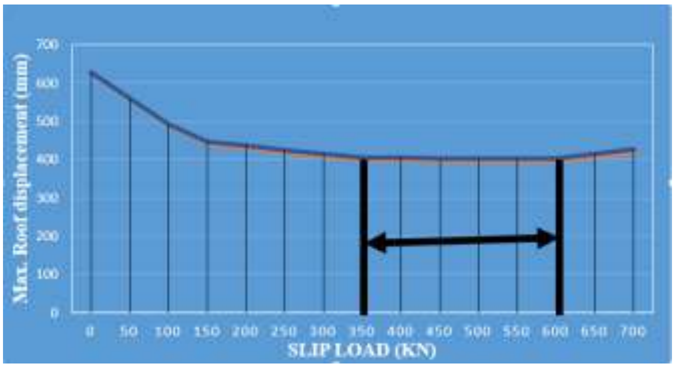

Chart -1: Variation of maxi. Roof displacement with slip load (Imperial Valley)

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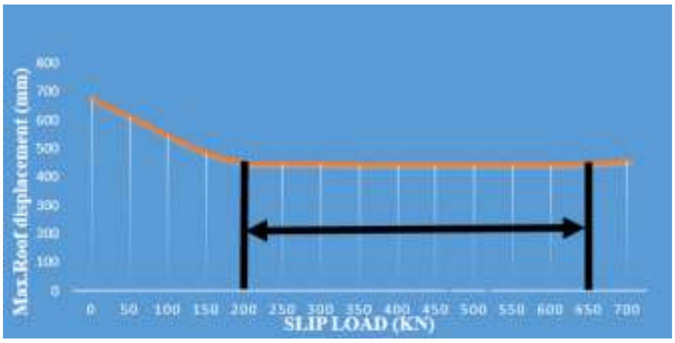

Chart -2: Variation of maxi. Roof displacement with slip load (Loma Prieta)

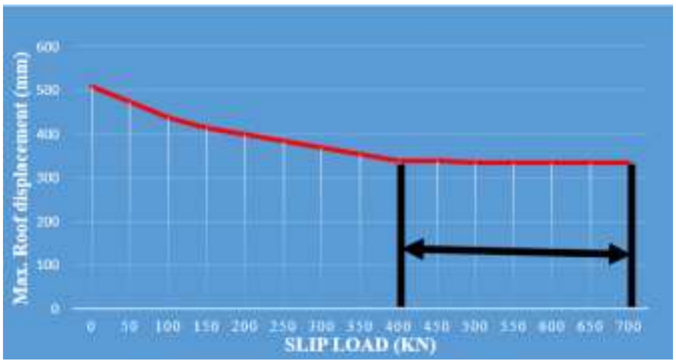

Chart -3: Variation of maxi. Roof displacement with slip load (North Ridge)

Table -3: Determination of Optimum slip load

Event	Slip load range at min.Roof displacement (KN)	Optimum Slip Load (KN)
Imperial Valley	350-600	400
Loma Prieta	200-650	
North Ridge	400-700	

4.1 Maximum story Displacement

Results have been represented in the charts shown below. From charts 4, 5, 6, 7, 8, 9, and 10, it is clear that story displacement has been reduced by introducing friction dampers. Lateral displacement increases as storey height increases. Minimum is at base level. When friction dampers are introduced, the value of lateral displacement decreases due to increased energy dissipation.

Chart -4: maximum story displacement in x-direction (Imperial Valley)

Chart -5: maximum story displacement in y-direction (Imperial Valley)

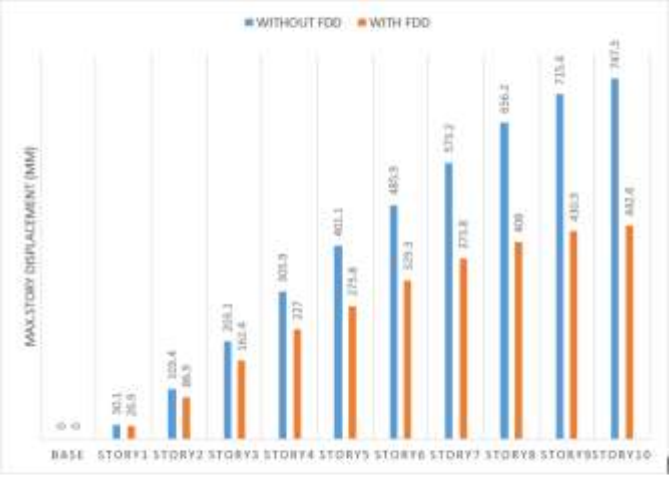

Chart -6: maximum story displacement in x-direction (Loma Prieta)

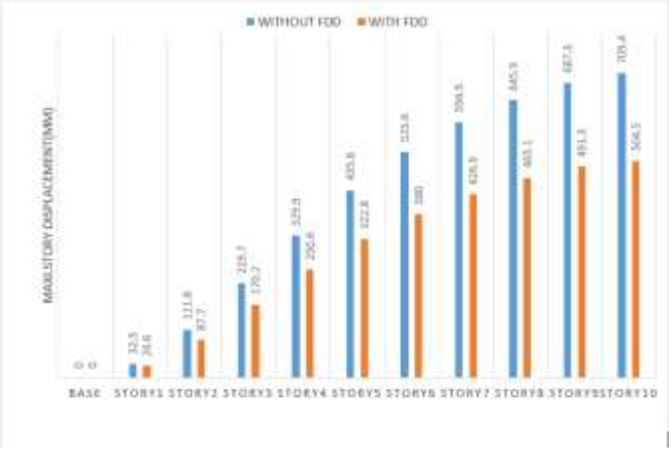

Chart -7: maximum story displacement in y-direction (Loma Prieta)

Chart -8: maximum story displacement in x-direction (North Ridge)

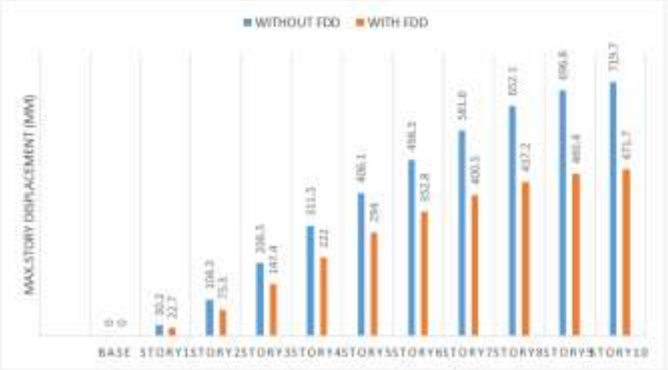

Chart -9: maximum story displacement in y-direction (North Ridge)

4.2 Maximum story Displacement

Plots of roof acceleration with and without supplemental friction dampers under seismic loading have been generated, shown in chart 10. The use of dampers has successfully reduced the roof acceleration values for structure with dampers in comparison to that without dampers.

Chart -10: Roof acceleration (North Ridge)

4.3 Base Shear

Base shear force in X direction has been plotted for building with and without friction dampers, shown in figure 7.13. It can be seen from the plot of base shear force that the overall effect of damper in reducing the base shear is insignificant as such the maximum shear value of 44858 KN for building with FD is more than the shear value of 40538 KN for building without damper for Imperial Valley record. As can be seen the base shear for building with damper against the building without damper has higher values. This increased force is evidently resisted by the FD brace system and can be attributed to increased mass due to addition of damper brace system to the building. The same tendency is seen loma prieta and north ridge records also.

Chart -10: base shear

5. CONCLUSIONS

The seismic performance of a reinforced concrete (RC) building structure was evaluated and concluded that the structure can be strengthened by incorporating friction dampers. The effectiveness of technique can be increased by determining exact values of slip load for the dampers. This was found out by analysis of maximum roof displacement of the structure changing the values of slip load.

The response parameters such as maximum story displacement, roof accelerations and base shear are compared for both structures with and without friction dampers. The storey displacement is decreased due to introduction of friction dampers as the energy dissipation is increased. The roof accelerations decreases with the addition of friction dampers subjected to same earthquake record. Optimum slip load of the friction damper is determined with respect to peak roof displacement and base shear has increased due to additional mass of brace and friction damper system.

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REFERENCES

[1] A. Pall *et. al* (1980), Friction Joints for Seismic Control of Large Panel Structure Journal of the Prestressed Concrete Institute, 25(6), 38-61,

[2] Pall AS and Marsh C (1982), Response of Friction Damped Braced Frames, J. of the Structural Division, American society of civil engineers, 108, ST6.

[3] Filiatrault. A and Cherry. S (1990), Seismic Design Spectra for Friction Damped Structures, Journal of Structural Engineering, American Society of Civil Engineers, 116, 1334-1355

[4] Aiken D *et. al* (1993), Testing of passive energy basis dissipation systems, Earthquake Spectra, 9(3), 335-370

[5] Sumitomo Metal Industries, Friction Damper for Earthquake Response Control, In House Report, 1987-12

[6] I.H. Mualla and Belev B, "Performance of steel frames with a new friction damper device under earthquake excitation", Engineering Structures, vol. 24, 2012, pp. 365–371

[7] G.W Housner, L.A. Bergman and T.T. Soong, "Structural Control: Past, Present, Future", journal of engineering mechanics, Sep. 1997, 123(9):897-971.

[8] G. S. Adithya and H. Narendra, "Performance evaluation of friction dampers under seismic loads", International Journal of Research in Engineering and Technology (IJRET), Sep. 2016, 05(14): 10-15.

[9] ETABS 2015. Analysis Reference Manual, Version 15, 2015, Berkeley, California. Computers and Structures, Inc.

[10] FEMA 356. (2000), Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Report No. FEMA-356, SAC Joint Venture, Federal Emergency Management Agency, Washington DC

[11] IS 1893 (Part I, Indian Standard- Criteria for earthquake resistant design of structures, part 1 general provisions and buildings, Bureau of Indian Standards, New Delhi, June 2002.

[12] A. Jaferzadeh, A.L.Y. Mohammad and R Sabetahd, "Evaluation of Pall Friction Damper Performance in Near-Fault Earthquakes by Using of Nonlinear Time History Analysis", World Applied Sciences Journal, vol.

20, Feb. 2012, pp. 264-270, doi: 10.5829/idosi. wasj.2012.20.02.2487.

[13] Pall A.S, Pall R.T, “performance-based design using pall friction dampers - an economical design solution”, 13th World Conference on Earthquake Engineering, 1995.

[14] PEER. “Technical Report for the Ground Motion Database web”, California Pacific Earthquake Engineering Research Centre, 2010 http://peer.berkeley.edu/peerground_motion_database

[15] Sinha A. K, Sharad Singh, (2017), “Seismic Protection of RC Frames Using Friction Dampers”, International Journal of Civil Engineering and Technology (IJCIET), vol. 8, Feb. 2017, pp. 289-299.