Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 3, Issue 8; July-September, 2016, pp. 690-695

http://www.krishisanskriti.org/Publication.html

Performance of Soft Storey Building Subjected to Earthquake Excitation

Pritam Hait[1], Nirmalendu Debnath[2] and Satyabrata Choudhury[3]

[1,2,3]Deptt. Of Civil Engg. NIT Silchar
E-mail: [1]pritamhait15@gmail.com, [2]nirmalendu.nits.civil@gmail.com, [3]scnitsilchar@gmail.com

Abstract—*The damage indices are a concepts introduced by researchers in the recent past. These indices have not only become important tools for the evaluation of damage level of structures, but also they have become important design variables in Performance-Based Design (PBD). The focus of this paper is to estimate of damage indices in terms of inter storey drift ratio (IDR) of some references Reinforced Concrete (RC) building structures under varying soft storey height and no. of storey. The study is roughly divided into two parts, first part includes observing formation of plastic hinge of structural members of the buildings with four, seven and ten storey, and the second part includes evaluation of damage index of the same buildings with varying soft story height. 2D modeling of a building using SAP2000 Version 14.0 and the performance study of the model was done. Static nonlinear pushover analysis and Time History analysis was carried out using SAP2000. The work was also examined key structural issues such as strength, storey drift, plastic hinges formation in column etc.*

Keywords: - *Inter storey drift (IDR), RC frame, Soft storey, Bracing system, IS-456-2000, Strong column-weak beam.*

1. INTRODUCTION

Since the early 1970's, there has been considerable research on the assessment of damage of RC and other buildings. As proposed by many researchers (Park *et al.* 1984, Chung *et al.* 1987, Williams 1995, Fajfar 1994) damage indices can be classified as local damage indices and global damage indices. A local damage index is an indicator of damage for a part of the structure such as a member or a storey while a global damage index involves the damage to the whole structure. Until now, lot of research has been carried out to evaluate the local damage indices of RC structures.

A. J. Kappos *et al.* [1] clarified the basic concepts involved in defining seismic damage indices for reinforced concrete buildings, and critically review the different schemes for classifying these indices. The available analytical procedures for the determination of damage indices are evaluated and the associated problems are discussed. Finally conclusions are drawn, focusing on the practical use of these indices, and some directions for future research efforts are identified.

Park and Ang [2] & [3] approached a method for evaluating structural damage of reinforced concrete buildings under random earthquake excitations. Based on these results, a simple relationship between destructiveness of the ground motions, expressed in terms of the "characteristic intensity," and the structural damage, expressed in terms of the "damage index," is established.

In 2010, Siddhartha Ghosh *et al.* [4] used Park–Ang damage index to estimate the damage demand on a MDOF system, by comparing the estimates from a nonlinear response history analysis (NLRH) of the SDOF model. These schemes are verified for both global and local damage indices. The expression is given in eq. 1.

$$D = \frac{d_m}{d_u} + \frac{\beta}{V_y d_u} \int dE_h \text{....................(1)}$$

Where d_u = ultimate deformation (capacity) under monotonic static loading, d_m = maximum deformation (demand) under dynamic loading, dE_h = incremental hysteretic energy (demand), V_y = yield strength,

β = a non-negative non-dimensional parameter.

Also $$d_u = \mu d_y \text{....................(2)}$$

Banon *et al.* [5] used the rotational ductility (μ_θ) at the end of a structural member as its damage index is expressed in eq. 3 & 4.

$$\mu_\theta = \frac{\theta_m}{\theta_y} \text{....................(3)}$$

$$\mu_\theta = 1 + \frac{\theta_m - \theta_y}{\theta_y} \text{....................(4)}$$

Where, θ_m = is the maximum rotation (including both elastic and plastic rotations) under an earthquake, θ_y = is the yield rotation.

2. DAMAGE INDEX

Although ductility demand and the amount of dissipated hysteretic energy are important parameters of the non-linear response. In order to assess the structural damage, it is necessary to know the available deformation capacity of the structure and the particular member. The degree of structural damage can be estimated through damage index DI, through comparison of specific structural response parameters demanded by the earthquake with available structural deformation capacity.

$$DI = D / C$$

where D is the maximum inelastic response quantity (e.g. displacement, curvature, etc.) during a ground excitation and C is the capacity of the structure. Damage index is a normalized quantity, whose numeric value varies between 0 and 1. Value of DI = zero denotes the non-damaged structure, i.e. linear elastic behaviour of the structure during an earthquake, while DI = 1 denotes the failure of the structure, i.e. local or general collapse of the structure. A classification of damage indices is provided in Table. 1 (Mohammad Reza Tabeshpour *et al.* 2004).

Table 1: Classification of damage indices

Damage model	Local damage Indices	Non-cumulative indices	i)Ductility ratio (DR)	
			ii)Interstorey drift (ID)	
			iii)Slope ratio (SR)	
			iv)Flexural design ratio (FDR)	
			v)Maximum permanent drift (MPD)	
			vi)Pushover-based damage index	
		Cumulative damage indices	i)Deformation-based models	i)Normalized cumulative rotation(NCR)
				ii)Cumulative displacement ductility
				iii)Normalised cumulative plastic deformation
				iv)Maximum deformation-based model
				v)Low-cycle fatigue model
			ii)Energy-based model	
			iii)Combined models	i)Parl-ang damage index
				ii)Bracci et al. . damage index
	Global damage Indices	Weighted average indices		
		Modal based indices	i)Roufaiel-meyer global model	
			ii)Maximum softening	
			iii)Final softening	
		Financial based indices	i)Ratio of the repair cost to the replacement cost	
			ii)Guntuni-shah financial index	

3. IDR

From decades, several researchers evaluated various types of damage indices of a structure. Among all inter storey drift ratio (IDR) is a damage indicator, which is one of the easiest way to find the damage index. In this study, IDR is determined for soft storey of all buildings with different earthquake data.

4. ANALYTICAL APPROACH

An inelastic displacement of structure represents the damage sustained by the structure while dissipating the hysteretic energy during an earthquake. Thus, the evaluation of displacement parameters for a given structure can provide a realistic evaluation of structural damage during an earthquake. Nonlinear static pushover analysis and Time History analysis are the two essential tool for the analysis. Pushover analysis provides a ‘capacity curve’ of structure and relates the deformation parameters of the system (i.e. roof displacement) to the force parameter of the system (i.e. base shear). Time History provides the Dynamic response of the structure at every moment of time during the ground motion.

1. Calculate the total weight of individual structural elements like beam, column, slab and strut.

2. Lumped mass at each floor was calculated taking into account a constant cross sectional properties of columns and beams.

3. Overall stiffness at each floor was calculated considering the column at floor effectively held in position and restrained against rotation in both ends.

4. The natural frequency ω and Eigen vector Φ evaluated by using the characteristic eq. 5

$$[K]-\omega^2[M]=0..................(5)$$

Where $[K]$ = Stiffness of undamaged building

$[M]$ = Mass of the building

ω = Natural frequency of the building

ω^* = Natural frequency of damaged building

5. Change in time period at every stage of pushover analysis implies stiffness degradation occurred due to increase in base shear and it is noted in SAP2000.

6. The changed frequency/damaged frequency ω* is calculated.

7. After knowing the value of ω and ω*, storey stiffness and flexibility matrix before and after damage can be calculated.

5. METHODOLOGY

5.1 General

The main objective of performance based seismic design of buildings is to avoid total catastrophic damage and to minimize the structural damage of the building. For this purpose, Static Nonlinear pushover analysis Time History analysis was used to evaluate the capacity of the structure. These are the effective tools for performance based seismic design.

5.2 Description of structure

For the purpose of study, 2D regular four, seven and ten storey reinforced concrete buildings were considered. The storey height for each frame is 3.3m other than a soft storey and length of beam 4m. In each building 2.75m, 3.5m, 4.25m three different types of soft storey height was considered. Eccen back type strut member is applied as infill to increase the stiffness of the building. In X-direction each frame has three bays. The structure is designed as per Indian Standard plain and reinforced concrete code of practice (IS 456:2000). Details of structural members are given in table 2. Material properties are assumed to be 25Mpa for the concrete compressive strength and 415Mpa for the yield strength of longitudinal and shear reinforcement. The sectional Properties and percentage of reinforcement in beams and columns were fixed based on their nonlinear behavior, stress capacity, formation of plastic hinges under seismic excitation in both Pushover and Time History analysis.

Table 2: Dimension of structural members

Structural member	Dimension (mm)
Beam	550x500
Column	1100x1100
Strut	1728x250

5.3 Loading considered

In the present example considered for illustration, all the floors of the building structure to carry a triangular dead load 7.5 kN/m and a live load of 6.0kN/m and wall load was 14kN/m. In roof level, live load was 3.0kN/m and wall load was 5kN/m. The design lateral forces due to earthquake ware calculated as per I.S. 1893:2002 (Part1). Initially the seismic zone considered is Zone-V with a factor (Z) 0.36. The importance factor (I) is 1.0 and the response reduction factor initially assumed to be 5.0.

5.4 Pushover Analysis

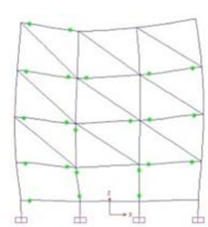
Pushover analysis is an effective way to the behavior & capacity of the structure, highlighting the sequence of member cracking and yielding as the base shear value increases. This information then can be used for the evaluation of the seismic performance of the structure, the locations with inelastic deformation and formation of plastic hinges. The purpose of pushover analysis is to obtain a measure of over strength and to obtain the capacity of the structure to sustain inelastic deformation under static loading. The loads acting on the structure are contributed from slabs, beams, columns, walls etc. They were calculated by conventional methods according to IS-456:2000 and are applied as gravity loads along with live loads as per IS 875 (Part II) on the beams as triangular & udl for wall load. For this analysis purpose appropriate Load combination ware considered.

5.5 Time history Analysis

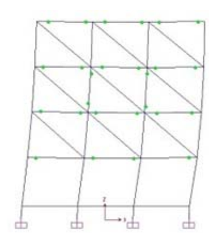
The purpose of Time History analysis is to obtain the Inter storey drift (As Damage Index), dissipated hysteretic energy under dynamic excitation.

6. RESULT

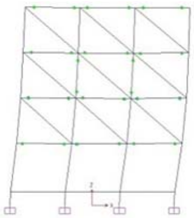
The performance of the structure is evaluated based on the results obtained from the Pushover and Time History analysis. Based on the Time History analysis performed for the buildings, the results are used to calculate the damage index in terms of Inter storey drift for different storied building and different height of soft storey (H_s). After pushover analysis, the behaviors of hinge formation for all nine models are shown in the following figures. For the purpose of analysis, modelings have been done using 'SAP-2000' software of Computers and Structures Inc. Following figures 1, 2, 3 indicate the hinge formation under Pushover analysis.



(a)

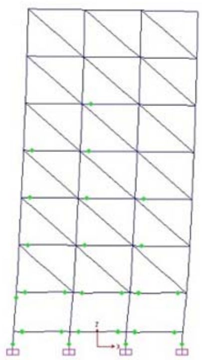


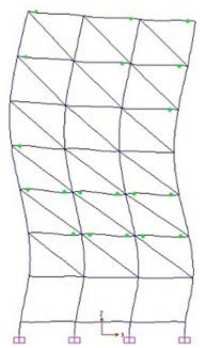
(b)



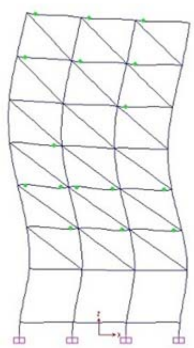
(c)

Fig. 1: Behavior of hinge formation for 4-storey building with soft storey height (a) 2.75m, (b) 3.5m, and (c) 4.25m



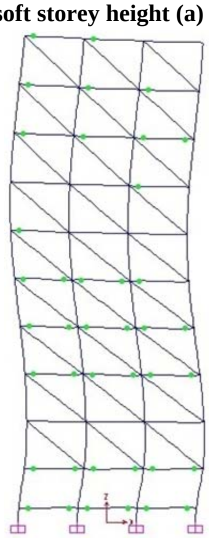


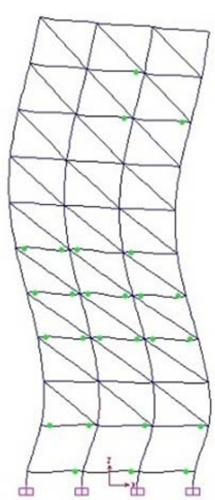
(a) **(b)**



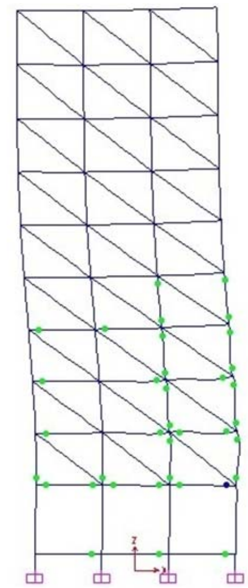
(c)

Fig. 2: Behavior of hinge formation for 7-storey building with soft storey height (a) 2.75m, (b) 3.5m, and (c) 4.25m





(a) **(b)**



(c)

Fig. 3: Behavior of hinge formation for 10-storey building with soft storey height (a) 2.75m, (b) 3.5m, and (c) 4.25m

Time History Analysis was done on all nine models with Kobe, Uttarkashi, Northridge and chi chi earthquake data. The calculated damage index is given in table no.3. IDR is a ratio of relative storey displacement to the storey height which is calculated with eq. 6.

$$IDR = \frac{\Delta_{i+1} - \Delta_i}{h_s} \text{.....................(6)}$$

Where Δ_i = Displacement at plinth level,

Δ_{i+1} = Displacement of immediately above floor

h_s = Soft storey height

The ground excitation pattern is shown in the following figures.

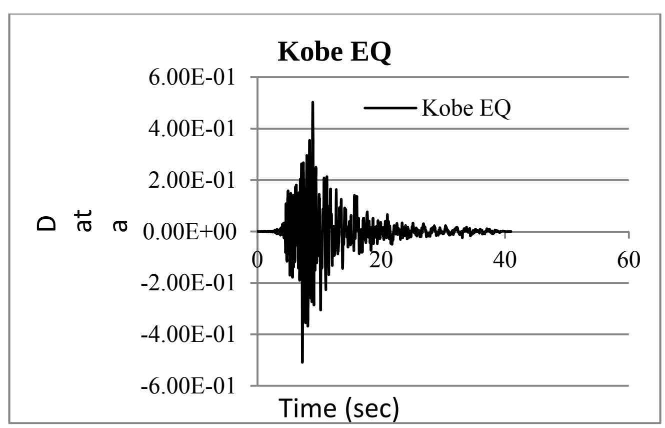


Fig. 4: Ground excitation of Kobe earthquake

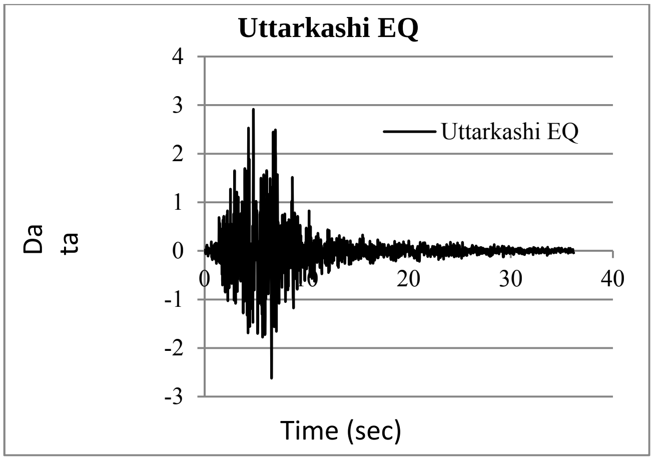


Fig.5 Ground excitation of Uttarkashi earthquake

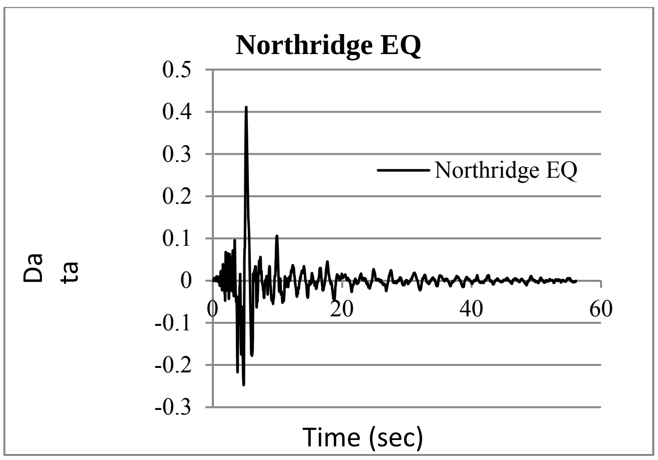


Fig. 6: Ground excitation of Northridge earthquake

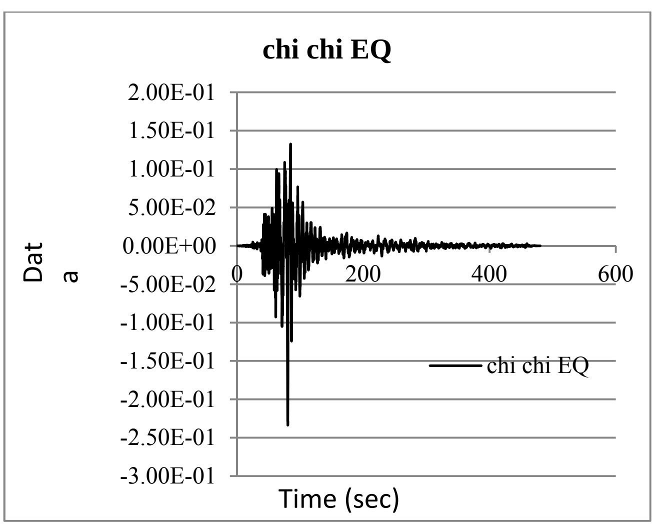


Fig. 7: Ground excitation of Chi chi earthquake

Table 3: Time History Analysis Results for four different Earthquake

No. of Storey	Name of EQ	Damage Index (in terms of IDR)		
		h_s = 2.75m	h_s = 3.5m	h_s = 4.25m
4- Storey	Kobe	0.59	0.69	0.79
	Uttarkashi	1.24	1.48	1.55
	Northridge	0.367	0.458	0.556
	Chi chi	0.17	0.19	0.22
7-Storey	Kobe	1.11	2.64	2.78
	Uttarkashi	0.6	0.63	0.66
	Northridge	0.524	1.164	1.477
	Chi chi	0.23	0.42	0.53
10-Storey	Kobe	1.99	2.054	2.065
	Uttarkashi	0.392	0.397	0.425
	Northridge	1.26	1.28	1.32
	Chi chi	0.53	0.58	0.53

Damage index is compared among different storey of buildings with varrying soft storey height for four different earthquake is shown in the following figures.

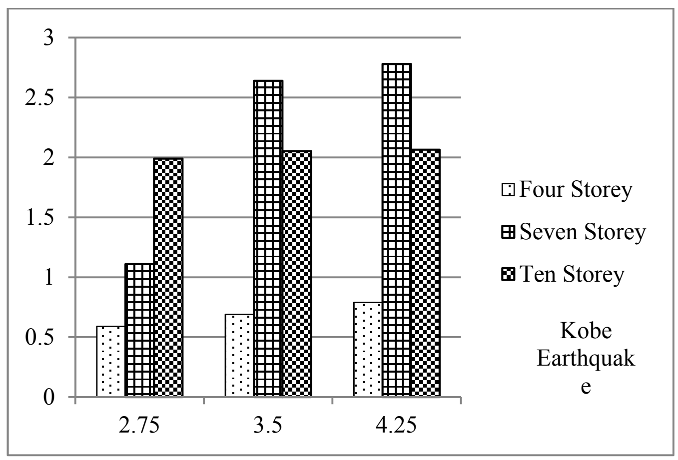


Fig. 8: Damage Index for different soft storey height of building for Kobe EQ

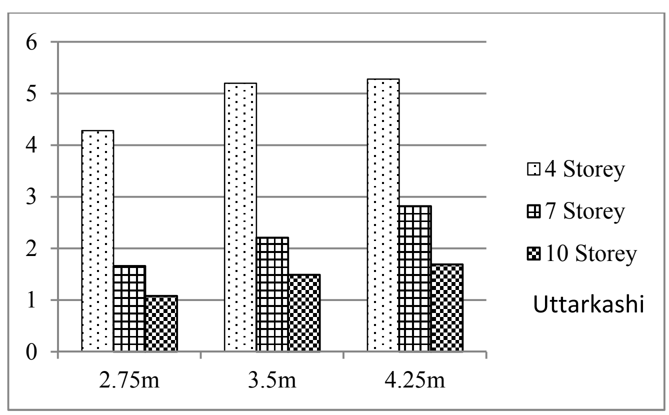


Fig. 9: Damage Index for different soft storey height of building for Uttarkashi EQ

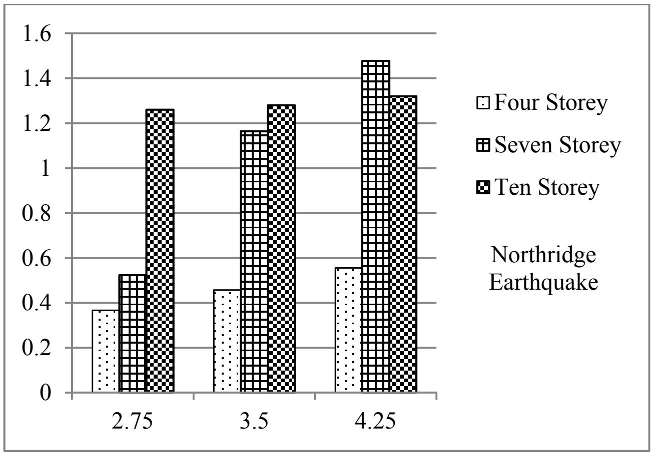


Fig. 10: Damage Index for different soft storey height of building for Northridge EQ

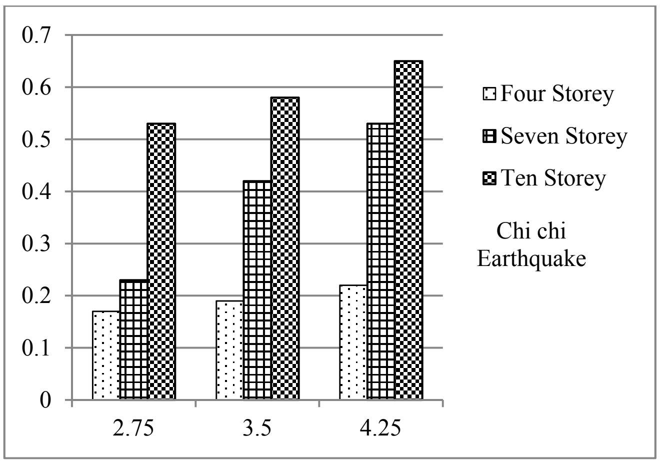


Fig. 11: Damage Index for different soft storey height of building for Chi chi EQ

7. CONCLUSION

After analyzing different storey of a building and different soft storey height damage index was calculated. From table no. 3, we can draw the following conclusion,

i) Damage index increases with increasing number of storey of a building.

ii) Damage index also increases with increasing of height of a soft storey of a building.

iii) Damage index in terms of IDR may be more than unity.

iv) Pushover analysis gives the capacity of the building under monotonic loading.

v) Time History Analysis provides the maximum IDR in each node under seismic excitation.

REFERENCES

[1]. A J Kappos in 1997 "Seismic damage indices for RC buildings: evaluation of concepts and procedures" *In construction research communication limited* Vol I (I): 78-87.

[2]. Park and Ang in 1985 "MECHANISTIC SEISMIC DAMAGE MODEL FOR REINFORCED CONCRETE", *Journal of Structural Engineering*, Vol. Ill, No. 4, April, 19, page no. -722-739.

[3]. Park and Ang in 1985 "SEISMIC DAMAGE ANALYSIS OF REINFORCED GONCRETE BUILDINGS", *Journal of Structural Engineering*, Vol. Ill, No. 4, April, 19, page no. -740-757.

[4] Siddhartha Ghosh in ‘’ Estimation of the Park–Ang damage index for planar multi-storey frames using equivalent single-degree systems’’ In Enginerring Structures 33 (2011) 2509-2524, June 2011.

[5] Banon in ‘’SEIMIC MODEL IN REINFORCED CONCRETE FRAME’’ In J. Struct. Eng., 1983, 109(1): 286-287.

[6] A.S. Moghadam et al. ‘’Damage assessment of eccentric multi-storey building using 3-D pushover analysis’’, WCEE, in 1196, paper no. 997, ISSN: 0 08 042822 3

[7] H. Estekanchi in 2007 ‘’ COMPARISON OF DAMAGE INDEXES IN NONLINEAR TIME HISTORY OF STEEL MOMENT FRAME’’ VOL. 8 NO.6

[8]. Đorđe Lađinović et al. . "SEISMIC PERFORMANCE ASSESMENT BASED ON DAMAGE OF STRUCTURES" in *Architecture and Civil Engineering,* Vol. 9, No 1, 2011, pp. 77 - 88.

[9]. R. Sinha & S. R. Shiradhonkar in 2012 "Seismic Damage Index for Classification of Structural Damage – Closing the Loop", in *WCEE*.

[10] Dr. Sudhir K Jain & Dr. C V R Murty in ‘’ Proposed provision and Commentary on Indian Seismic code IS1893 (part 1)’’ in 2007.

[11] Prasad Prahlad et al. in 2012 ‘’ Damage Indices using Energy Criterion for Seismic Evaluation of Steel Frame Buildings’’ in 12th WCEE.