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Estimation of Nonlinear Static Damage Index for Seismic Assessment

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Abstract: The main objective of this study is, evaluation damage index of reinforced concrete moment resisting frames by" NONLINEAR STATIC PROCEDURE" nonlinear static analysis includes the capacity spectrum method (CSM) that uses the intersection of the capacity (pushover) curve and a reduced response spectrum to estimate maximum displacement in terms of damage of building. Nonlinear static procedure is simple and practical method for static damage index. For this purpose, first some functions are derived to estimate damage to the structure using pushover analysis and then designed procedure is proposed. In this study damage function is estimated by using correlation between park-ang damage index (NLDD) and nonlinear static damage index (NLSD) which is based on the pushover analysis. For this purpose dynamic and static damage damage analysis are performed on several concrete frames subjected to various earthquake acceleration records. So the detail explanation is found in this study.

Keywords: pushover, FEMA-356, ATC-40, Static damage index, Dynamic damage index

I. INTRODUCTION

Experience learn from past earthquake and increase in design knowledge practicing designing engineers had moved towards predictive methods of design and evaluation. The main aim was to communicate safety related discussion which present seismic design does not clarify. one of such a design procedure is performance base seismic design. This method is generalized design process in which design parameter are expressed in terms of performance objective. These performance objective are statement of acceptable risk due to damage of structural component under specified seismic hazards level. Thought the performance of the structural is addressed but it does not quantify damage associated with performance level. For this damage state is associated with a damage value. The damage value is expressed with the help of damage index. Damage index is associated with physical measurable parameter known as engineering demand parameter (EDPs). The main ordinary parameter involve in damage assessment are permanent deformation, strength and stiffness degradation and number of hysteresis cycles involve. The damage index can be expressed by Nonlinear dynamic analysis as well as Nonlinear static analysis. The damage function was defined based on few Nonlinear responses which estimate plastic energy dissipated by rotation of beams and columns to verify the damage value it has been compared with Park-Ang damage value. Park-Ang expressed seismic seismic structural damage as a linear combination of the damage caused due to more deformation and the effect of repeated cyclic loading. Under elastics response the value of damage index is theoretically zero. And the damage index greater than one means the total collapse or total damage. Therefore the structural damage is a function of response of maximum deformation under earthquake and incremental absorbed hysteretic energy which is depend upon the loading. There are several different nonlinear dynamic analysis procedures are available but it is widely applicable due to its complexity and time consuming.

II. DAMAGE INDEX BASED ON NONLINEAR STATIC ANALYSIS

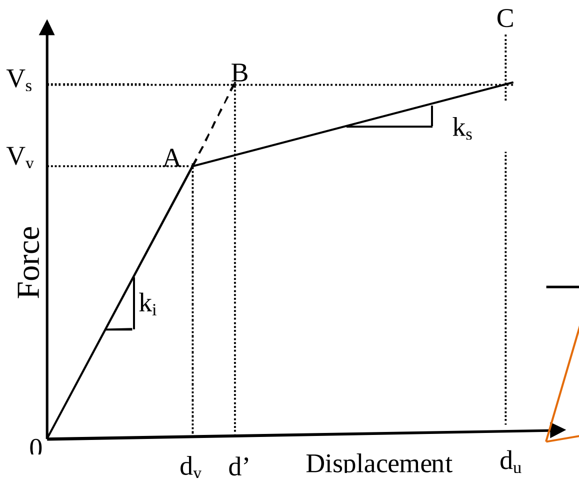

Figure 1 Bilinear SDOF system

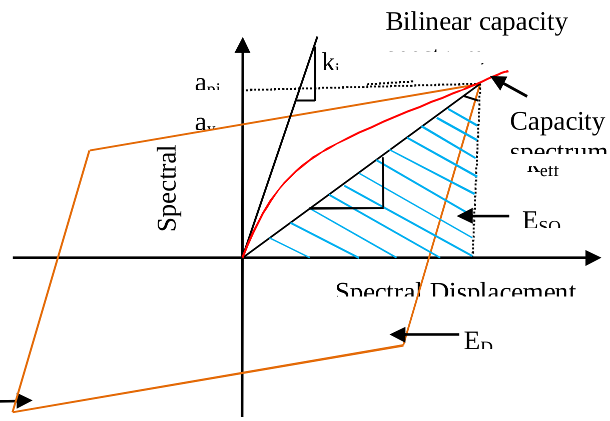

Figure 2 Damping for spectral reduction

The existence of plastic energy (PE) in the equation indicates the damage of the structural frame due to earthquake ground motion. It represents the energy that is consumed by the permanent plastic rotation in the beams and columns at the time't'. Larger the value of PE, the more significantly the frame has damaged. Therefore the damage index can be based on the energy stored in the permanent plastic rotation

The damping that occurs when earthquake ground motion drives a structure in to inelastic energy range is a combination of viscous damping that is inherent in the structure and hysteretic damping. Hysteretic damping is related to the area inside the loops that are formed when the earthquake forces (base shear) is plotted against the structure displacement. Hysteretic damping in the form of equivalent viscous damping as

$$\beta_{eq} = \beta_0 + 0.05 \quad (1)$$

Where;

$\beta_0 =$ Hysteretic damping represented as equivalent viscous damping

0.05 = 5% viscous damping inherent in the structure

$$\beta_0 = \frac{1}{4\pi}\frac{E_D}{E_{s0}} \quad (2)$$

Where;

$E_D =$ Energy dissipated by damping

$E_{SO} =$ Maximum strain energy

E_D is the energy dissipated by the structure in single cycle of motion that is the area enclosed by a single hysteretic loop. ESO is the maximum strain energy associated with that cycle of motion that is the area the hatched triangle in figure 4[11].

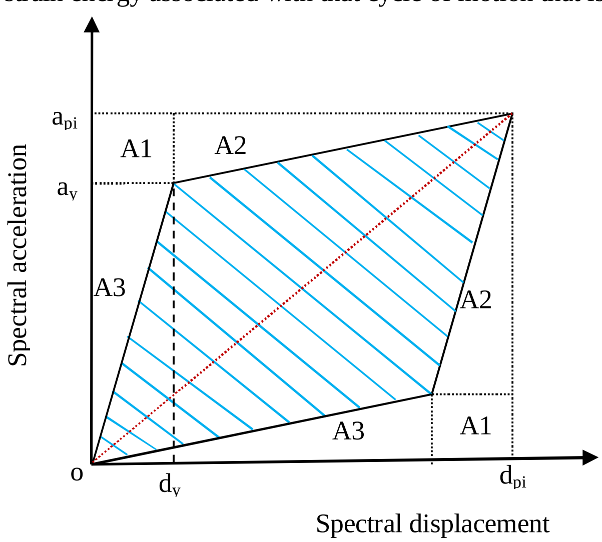

Figure No. 3

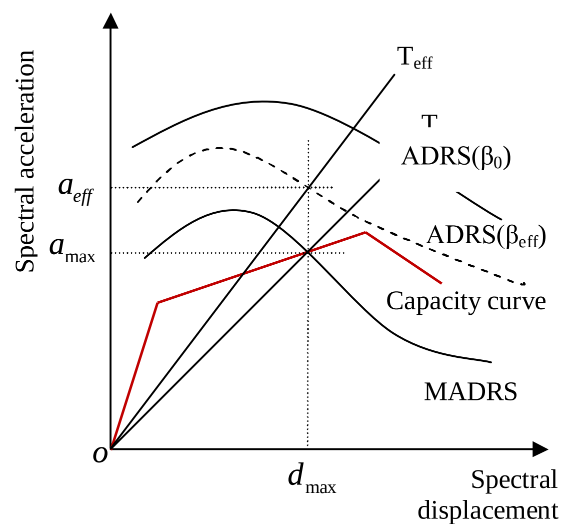

Figure No.4

$E_D = E_{PP} =$ (shaded area in figure 3)

$$E_{PP} = (a_{pi}d_{pi} - 2A_1 - 2A_2 - 2A_3)$$

$$E_{PP} = (a_{pi}d_{pi} - a_y d_y - (d_{pi} - d_y)(a_{pi} - a_y) - 2d_y(a_{pi} - a_y))$$

$$E_{PP} = (a_y d_{pi} - d_y a_{pi}) \quad (3)$$

and,

$$E_{SO} = \frac{a_{pi}d_{pi}}{2} \quad (4)$$

Plastic energy damage index to define structural damage can be formulated based on assumptions;

a) That capacity curve resulting from pushover analysis almost represents the envelopes of the hysteretic loops.

b) The area under the capacity spectrum at the performance point approximately demonstrates the stored energy at the biggest hysteretic loop in which a large portion of energy is dissipated when the structure is subjected to earthquake.

$$a_{\max} = a_{pi};\ d_{\max} = d_{pi}$$

$$DI_{pp} = \frac{A_p}{A_u} = \frac{E_{pp} - E_{ip}}{E_{fp} - E_{ip}} \quad (5)$$

Where,

A_p = net area of the capacity curve up to the performance point.

A_u = net area of the capacity curve up to the ultimate point

$$E_{pp} = a_y d_{pi} - d_y a_{pi}$$

$$E_{fp} = a_y d_u - d_y a_u$$

$$E_{ip} = 0.5 a_y d_y$$

III. EXAMPLES BUILDING FRAMES

In this study ten reinforced moment resisting frame buildings with 2,4,6,8,10,12,14,16,18,20 stories having three and four bays were designed using seismic force levels obtained from Indian seismic codes ie I.S 456:2000(rev) I.S. 1893:2001(part1) Table 1 and 2 describes the characteristics and preliminary data considered for analysis and design of the considered frames

Table 1: Characteristics of example building frames

Frame model	Height (m)	Time Period (sec)	Seismic Weight (W)	Base Shear (V)
S2b3	6	0.28752	972	87.48
S4b3	12	0.4835	2052	153.9
S6b4	18	0.6554	5565	308.382
S8b4	24	0.81328	7488	332.8
S10b4	30	0.9614	9408	352.8
S12b4	36	1.1022	11328	370.735
S14b4	42	1.2373	13248	387.746
S16b4	48	1.3677	15168	401.506
S18b4	54	1.49402	17088	412.864
S20b4	60	1.61687	19008	425.024

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Table 2: Preliminary data considered for analysis and design

Sr. No	Particulars	Value	Remarks
1	Bay width	4m	In both direction for all frames
2	Storey height	3.0m	In both direction for all frames
3	Concrete grade (M25)	25 Mpa	As per I.S 456:2000
4	Rebar's a. Main reinforcement b. Shear reinforcement	 415 Mpa 415 Mpa	
5	Type of exposure	Mild	
6	Type of soil	Hard soil	As per I.S 1893:2001(part) Z=0.36 Non-ductile Public building
7	Seismic zone	Zone IV	
8	Response reduction factor (R)	5.0	
9	Importance factor (I)	1.0	
10	Natural time period (T)	$0.075(h)^{0.75}$	
11	Lateral force (V)	$A_h W$	$A_h = \frac{ZIS_a}{2gR}$
12	Storey shear (Q_i)	$V\left(\frac{Wh_i^2}{\sum_{i=1} W_i h_i^2}\right)$	W = Seismic weight

The preliminary design is carried for various load combinations suggested in IS 1893:2000 (Part1) using FEM based software SAP 2000 V 17 for initial values of R =5.0. The gravity design output is tabulated in table No 3.and the result of damage index on the basis of pushovercurve is tabulated in table No 4.

Table No. 3: Gravity design results for example buildings

Model No.	Storey No.	Column design details					Beam design details				
		Cross section	Main reinf.	Shear reinf.	P_t main	P_t trans.	Cross section	Main reinf.	Shear reinf.	P_t main	P_t trans.
S2B3	1	400 x 400 mm	1280	65	0.8	Min.	300 x 300 mm	303	65	0.29	Min
S4B3	1-4	400 x 400 mm	1280	65	0.8	Min	400 x 400 mm	405	65	0.30	Min
S6B4	1-6	400 x 500 mm	1600	0.433	0.8	Min	400 x 400 mm	624	0.433	0.39	Min
S8B4	1-8	500 x 500 mm	2000	0.533	0.80	Min.	500x500 mm	723	0.533	0.40	Min.
S10B4	1-10	600 x 600 mm	2555	65	0.80	Min	600x600 mm	912	65	0.41	Min
S12B4	1-12	650 x 650 mm	2912	65	1.4	Min	650x650 mm	1114	65	0.4	Min
S14B4	1-14	700 x 700 Mm	3400	65	0.9	Min.	700x700 mm	1313	65	0.41	Min.
S16B4	1-16	800 x 800 mm	3600	65	0.8	Min	700x700 mm	1421	65	0.4	Min
S18B4	1-18	800 x 800 mm	4000	65	0.8	Min	800x800 mm	1622	65	0.4	Min
S20B4	1-20	900 x 900 mm	4600	65	1.2	Min	900x900 mm	1723	65	0.29	Min

Table No. 4: Result of static damage index

FRAME	Dy	Ay	Dp	Ap	Du	Au	Eip	Epp	Efp	DI
S2B3	0.0078	0.1220	0.049	0.261	0.10149	0.26035	0.00048	-0.0103	-0.0103	0.0353
S4B3	0.0183	0.7903	0.018	0.767	0.086802	1.02082	0.00725	-0.0499	-0.0545	0.0758
S6B4	0.0192	0.4051	0.036	0.577	0.151189	0.65633	0.00391	-0.0486	-0.0501	0.0254
S8B4	0.0097	0.2354	0.045	0.464	0.119832	0.48448	0.00115	-0.0235	-0.0237	0.0239
S10B4	0.0126	0.2615	0.038	0.421	0.115815	0.42139	0.00165	-0.025	-0.025	0.0394
S12B4	0.0152	0.2424	0.043	0.366	0.139597	0.36426	0.00185	-0.0283	-0.0283	0.0352
S14B4	0.0184	0.2381	0.047	0.34	0.137463	0.33796	0.0022	-0.0265	-0.0265	0.0542
S16B4	0.0186	0.0628	0.135	0.092	0.171468	0.09179	0.00059	-0.0091	-0.009	0.0551
S18B4	0.0264	0.0749	0.131	0.095	0.154805	0.09449	0.00099	-0.0091	-0.0091	0.09896
S20B4	0.0267	0.0716	0.126	0.1	0.18418	0.09905	0.00096	-0.0105	-0.0105	0.0797

Table No. 5: Acceptance Criteria for performance levels [FEMA 356:2000]

Type of structure	Performance level	Acceptance criteria (Drift)
Moment resisting concrete frame	Collapse prevention (S-5)	4% transient or permanent
	Life safety (S-3)	2% transient ; 1% permanent
	Immediate occupancy (S-1)	1 % transient; negligible permanent

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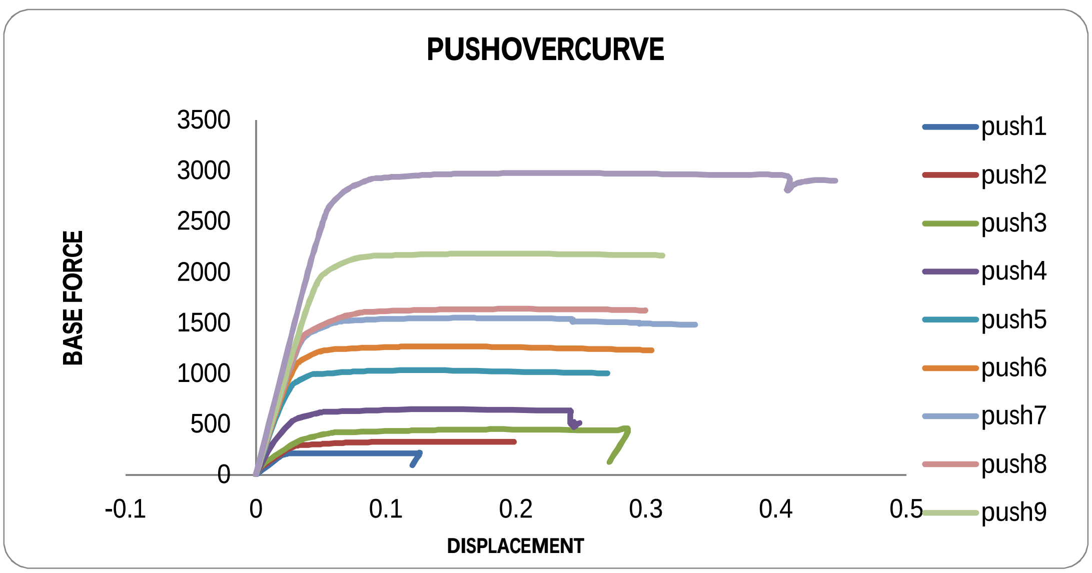
IV. RESULT AND DISCUSSION

Table No. 6 Result of park-ang damage index and nonlinear static damage index

STOREY NO	Park-ang damage index DI(IDARC)	Energy base damage index DI(NLSD)
S2B2	0.000	0.03535
S4B3	0.001	0.07583
S6B4	0.009	0.02541
S8B4	0.003	0.02395
S10B4	0.007	0.0394
S12B4	0.011	0.03525
S14B4	0.058	0.05427
S16B4	0.077	0.05516
S18B4	0.078	0.09896
S20B4	0.041	0.0797

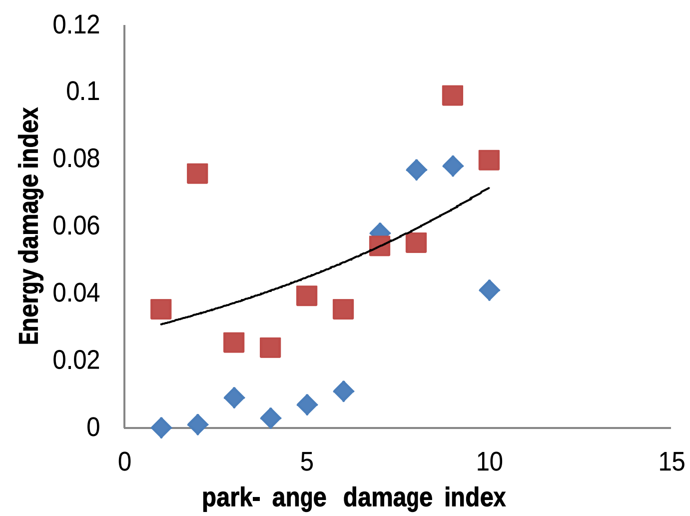
Table no. 6 shows the NLDD and the NLSD ie park ang damage index and energy base damage index, the park-ang damage index is non linear damage index evaluated by using software IDARC. And static damage index is evaluated using pushover curve by sap2000v17.



Graph No. 1

A. Correlation Between The Static And Dynamic Damage Index

Correlation between the energy damage index (static damage index)and the Park–Ang damage index (dynamic Damage index) is determined by comparing damage results of two sets (static and dynamic criteria). Scatter points on graph no. 2 specify this correlation. As seen in graph no. 2 the energy damage index (static) proposed in this research possesses proper dispersal with the Park–Ang damage index (dynamic). Considering this outstanding feature, its simplicity of calculation and the fact that the energy criterion is a global damage index, this static damage index can be introduced as a simple and effective criterion. To develop a relation for estimating the damage index using pushover results, by fitting a curve, according to graph no. 2



Graph no. 2

Table No. 7 Damage state

Degree of damage	Damage index	State of building
collapse	>1.0	Loss of building
Severe	0.4-1	Beyond repair
Moderate	0.25-0.4	Repairable
Minor	0.1-0.25	Repairable
Slight	<0.1	Repairable

V. SUMMARY AND CONCLUTION

A. In this study damage function is estimated by using correlation between park-ang damage index (NLDD) and nonlinear static damage index (NLSD) which is very simple practical method for nonlinear analysis.

B. The nonlinear static damage index ie (Energy damage index) is proposed and implanted to estimate the damage value using nonlinear responses resulting from pushover analysis. The use of dissipated energy by a structure has been implemented to determine damage index

C. The ultimate deformation capacity of the structure is found by using nonlinear static pushover analysis and for that deformation the energy capacity of the structure is calculated.

Abbreviations	
ATC	Applied Technical Council
FEMA	Federal Emergency Management Authority
DI	Damage index
NLSD	Nonlinear Static Damage index
NLDD	Nonlinear Dynamic Damage index

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