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Seismic Damage Assessment of irregular RC buildings with Re-Entrant Corner Plan Irregularities Using Drift-Based Criteria through Nonlinear Dynamic Analysis

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A B S T R A C T

An earthquake is a powerful natural disaster that can cause immense suffering to all living beings as well as non-living beings. Earthquakes are inherently unpredictable in both their occurrence and intensity. An earthquake becomes more dangerous when a building has a weak or poorly designed structure. Earthquakes can be even more hazardous for irregularly shaped buildings. There can be several types of structural irregularities, such as horizontal and elevation. If we look at the old earthquakes, the main reason for the damage to the structures was irregularities. One notable form of plan irregularity is the presence of re-entrant corners, which lead to stress concentrations due to abrupt changes in structural stiffness and amplified torsional effects within the building. In this study, a nonlinear time history analysis is conducted to evaluate the impact of plan configuration irregularities in reinforced concrete (RC) buildings, specifically focusing on variations in the A/L ratio of re-entrant corner-type structures. The primary objective is to propose and develop a drift-based damage index for estimating seismic damage in RC buildings with plan irregularities. To achieve this, several RC building models with different re-entrant corner configurations—namely +, L, C, H, and zig-zag shapes are analyzed using SAP2000. Each model is subjected to seven distinct earthquake ground motion records to compute displacement, inter-story drift, and damage, the latter quantified using the Park-Ang damage index. Subsequently, the irregularity index (A/L ratio) is used to modify the fundamental natural time period of each structure in accordance with IS 1893 (Part 1): 2016 provisions.

Keywords: Earthquake, Plan Irregularity, RC Structures, Re-entrant corners, Drift- based index

1. Introduction-

Earthquakes are natural hazards capable of causing extensive damage to property and posing serious risks to human life, primarily due to their erratic and unpredictable force patterns. The seismic response of a multi-story building is significantly influenced by the distribution of stiffness, mass, and strength across both horizontal and vertical planes. When subjected to strong ground motions, structural damage often concentrates in the most vulnerable components, typically within the lateral load-resisting frame, leading to progressive collapse. These structural deficiencies not only initiate failure but also tend to amplify and localize deterioration, thereby accelerating overall collapse mechanisms [1]. There are many factors on which the behavior of buildings depends at the time of earthquakes, such as the strength, ductility of the structure, the shape of the buildings. Buildings in a regular shape are much safer than an irregular shape. The possibility of structural detriment of structure is more in unequal shape RC structures [2]. Buildings are unsafe in the zone where the lateral load due to seismic is more due to lateral forces. The fault-finding effect may be produced due to structural Irregularities, the structural irregularities having different types of plan irregularities and vertical irregularities, torsion irregularities, and re-entrant corners, are also part of plan irregularities [3]. The seismic performance of a building is strongly influenced by its overall shape, size, and structural geometry, as well as the nature of ground motion during an earthquake. Therefore, architects and structural engineers must collaborate from the early planning stages to eliminate unfavorable design features and establish an optimal building configuration.[4] In contemporary construction, architectural expression often takes precedence, resulting in structures with complex and irregular geometries. Designing buildings with regular shapes has become increasingly challenging. However, such irregularities can significantly compromise structural integrity under dynamic loading conditions, including seismic events. Therefore, extensive research and advanced engineering strategies are essential to ensure optimal performance, even when the building configuration is inherently unfavorable [5]. A plan discontinuity typically occurs when a building's structural configuration includes a projection whose size exceeds 15% of the total plan dimension in the corresponding direction. Such geometric irregularities can significantly influence the building's seismic response and must be carefully addressed during the design phase. Re-entrant corners are a type of plan irregularity that is more common in the construction of modern multi-story buildings, mostly due to architectural factors like aesthetics. [6] Numerous prior studies have highlighted significant changes in ductility demands and substantial damage concentrations near structural irregularities. To mitigate the adverse effects caused by re-entrant corner configurations and to achieve the desired seismic performance, specific design strategies must be incorporated during the seismic design phase. One such emerging approach is drift-based seismic design, which focuses on predicting and controlling structural damage by directly considering inter-story drift demands. As this methodology continues to evolve, it offers promising potential for enhancing the resilience of buildings with irregular geometries under seismic loading.[7] The primary objective of this research is to establish drift-based relationships that quantify overall structural damage in reinforced concrete (RC) frame buildings. By performing nonlinear dynamic analysis, the damage induced by inter-story drift can be systematically evaluated. Furthermore, irregularity indices associated with re-entrant corner geometries are utilized to formulate drift-based damage functions, enabling a more accurate assessment of seismic vulnerability in irregular configurations.

2. Objectives of Study

Objectives: To evaluate the seismic performance of reinforced concrete (RC) buildings exhibiting plan irregularities specifically re-entrant corners under multiple earthquake ground motion records using nonlinear dynamic time history analysis. And quantify structural response parameters such as inter-story drift, displacement, base shear, and torsional effects in irregular RC frames subjected to seismic loading. To analyze the influence of plan irregularity geometry (e.g., A/L ratio of re-entrant corners) on seismic vulnerability and damage concentration across different story levels. To develop a drift-based damage index equation through nonlinear regression analysis of simulation data, enabling predictive estimation of structural damage in irregular RC buildings. To establish performance-based criteria for seismic damage assessment that can guide design improvements and retrofitting strategies for irregular RC structures in earthquake-prone regions.

3. Research Methodology-

From numbers of the literature, we can say that the effect of irregularities in seismic response of RC frames is significant and should not be ignored it. Whenever we talk about the different irregularities that generally come to our mind are opening, uneven column size, etc. The size, shape, and strength of that irregular structural element decide the performance of the overall structure under a given load. Thus, it must be studied the effect of size and shape of the structure on the overall performance of the frame and counter which resisting system will perform well.

3.1 Description of model

Considering Fixed supported 4, 8, 12-story building with Re-Entrant corners plan irregularity

- Model 1: Plus- shape (A/L ratio, X-0.333, Y-0.333)
- Model 2: plus -shape (A/L ratio, X-0.5, Y-0.667)
- Model 3: plus -shape (A/L ratio, X-0.667, Y-0.833)
- Model 4: plus -shape (A/L ratio, X-0.667, Y-0.667)
- Model 5: plus -shape (A/L ratio, X-0.833, Y-0.833)
- Model 6: H- shape (A/L ratio, X-0.333, Y-0.5)
- Model 7: H- shape (A/L ratio, X-0.5, Y-0.5)
- Model 8: H- shape (A/L ratio, X-0.667, Y-0.5)
- Model 9: H- shape (A/L ratio, X-0.667, Y-0.667)
- Model 10: H- shape (A/L ratio, X-0.667, Y-0.833)
- Model 11: C- shape (A/L ratio, X-0.167, Y-0.333)
- Model 12: C- shape (A/L ratio, X-0.167, Y-0.5)
- Model 13: C- shape (A/L ratio, X-0.667, Y-0.667)
- Model 14: C- shape (A/L ratio, X-0.5, Y-0.667)
- Model 15: C- shape (A/L ratio, X-0.833, Y-0.5)
- Model 16: C- shape (A/L ratio, X-0.833, Y-0.667)
- Model 17: L- shape (A/L ratio, X-0.167, Y-0.167)
- Model 18: L- shape (A/L ratio, X-0.5, Y-0.167)
- Model 19: L- shape (A/L ratio, X-0.5, Y-0.333)
- Model 20: L- shape (A/L ratio, X-0.5, Y-0.667)

- Model 21: L- shape (A/L ratio, X-0.333, Y-0.667)
- Model 22: L- shape (A/L ratio, X-0.833, Y-0.5)
- Model 23: L- shape (A/L ratio, X-0.833, Y-0.667)
- Model 24: L- shape (A/L ratio, X-0.833, Y-0.833)
- Model 25: zig-zag- shape (A/L ratio, X-0.333, Y-0.333)
- Model 26: zig-zag- shape (A/L ratio, X-0.5, Y-0.5)
- Model 27: zig-zag- shape (A/L ratio, X-0.667, Y-0.667)
- Model 28: zig-zag- shape (A/L ratio, X-0.833, Y-0.833)
- To analyze these Each model by applying 7-Time History data of earthquake loading
- Total 84 model have been prepared and performed 588 analyses.

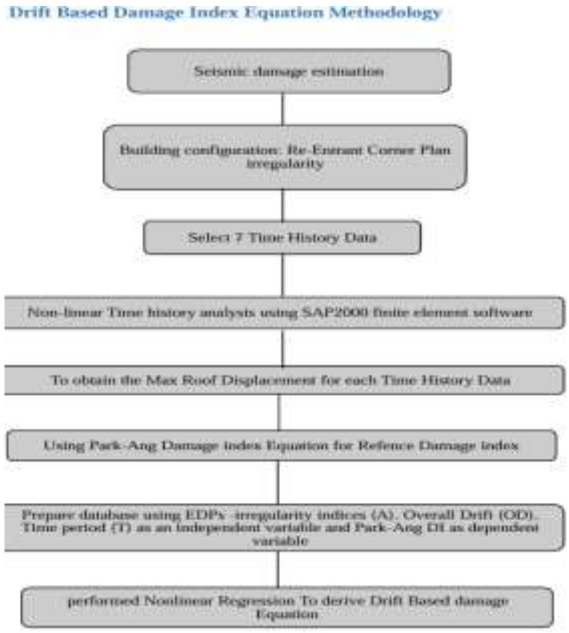


Fig. 1 - Flow chart of drift based damaged index equation methodology

3.2 Problem formulation

Prepare the model for study, having the following building configuration details:

Set units and standards as per Indian standard codes.

Define grid data, height, and diameter, & Define material property as mentioned in Table-Building Data.

Define section properties of beam, column as described in Table- building data.

Assign support condition as fixed.

Define dead load, Live load and earthquake load as per Table: -Loading data. Define plastic hinges.

Perform nonlinear time history analysis using earthquake data.

Follow the above steps for all models

Table 1 – Model properties and load description

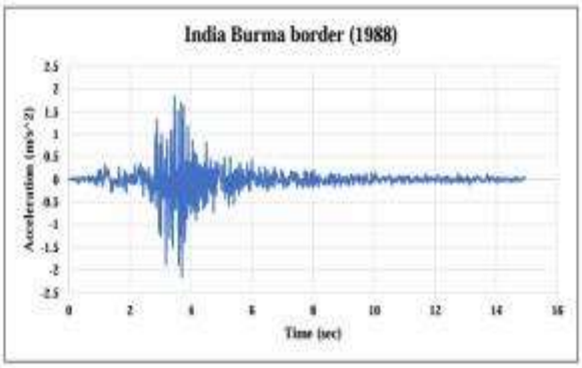
Design Code	IS 456:2000
Design Code	IS1893:2016 (part-1)
Design loads	IS 875-1987 (part-1,2)

Concrete Grade	M25
Brick masonry unit weight	20 KN\m3
Steel grade	FE500
Time history analysis	SAP2000 V24
Height of another storeys	3.5m
Ground floor height	4.5m
Length	30m
Width	30m
Size of beam	300 x 450mm
Size of column	350 x 600 mm
Floor load	1.5 kN/m^2
Live load on floor	2.5 KN/m^2
Live load on roof	1.5 KN/m^2
Exterior Wall load	14 KN/m
Interior Wall load	7 KN/m
Parapet Wall load	6 KN/m

Table 2 – Ground motion recorded data

Sr. No.	**Name of EQ**	**Magnitude**	**EQ stations**	**PGA**	**Hypo central dist. From station (km)**
1	India Burma border (1988)	6.9	Berlongfer	1.074	220.1
2	India–Burma border, (1990)	5.9	Laisong	1.121	233.5
3	India–Burma border, (1995)	6.4	Berlongfer	1.03	261.9
4	India Burma border, India(1988)	6.9	Diphu	1.386	210.1
5	India Burma border, India(1997)	5.5	jellalpur	1.182	41.9
6	NE India (1986)	4.5	Ummulong	1.455	44.9
7	Uttarkashi, India (1991)	5.7	Uttarkashi	1.005	21.7

(a)



(b)

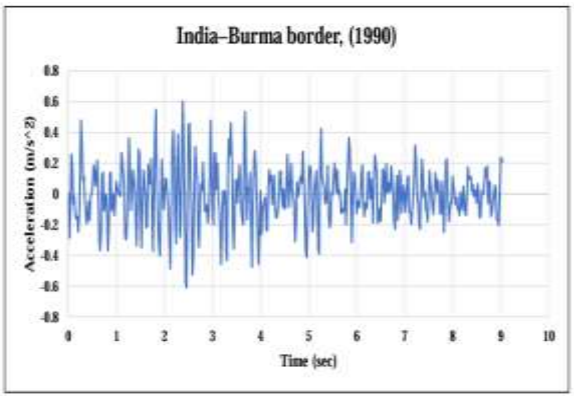


Fig. 2 - (a) Time history data: India Burma border (1988); (b) Time history data: India Burma border, (1990)

(a) **(b)**

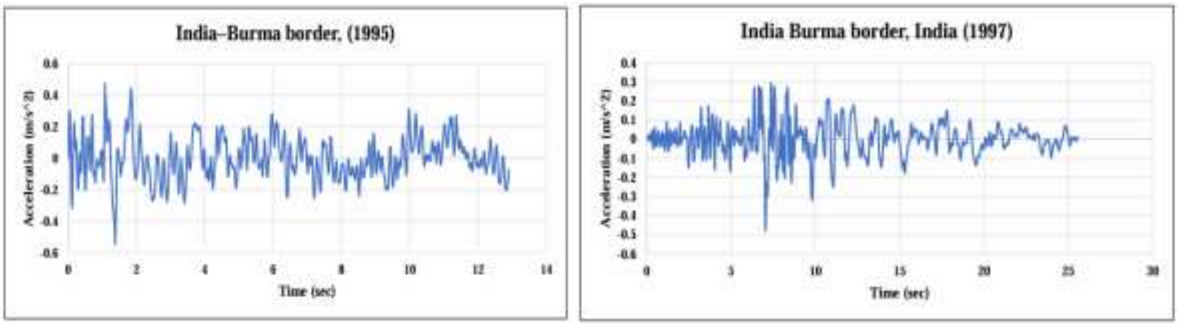


Fig. 3 - (a) Time history data: India Burma border (1988); (b) Time history data: India Burma border, (1990)

(a) **(b)**

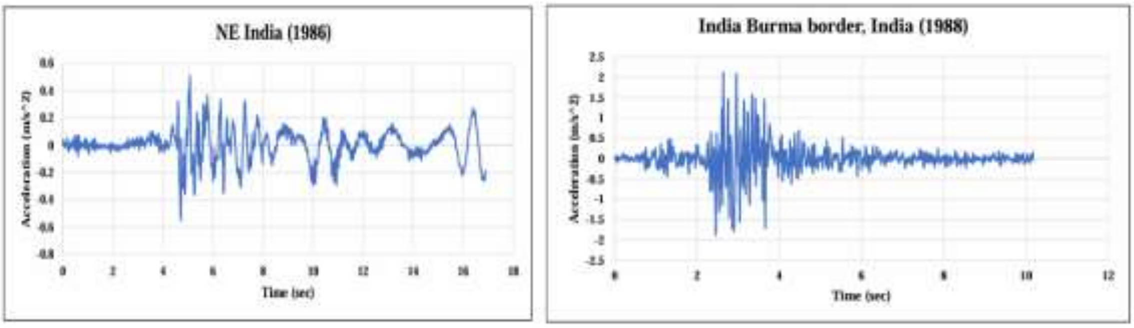


Fig. 4 - (a) Time history data: NE India (1986); (b) Time history data: India Burma border (1988)

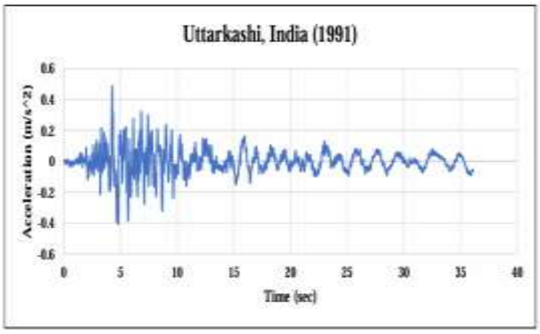


Fig. 5 - time history data: Uttarkashi, India (1991)

3.3 RC frame model with different shape

PLUS- Shape model

(a) **(b)**

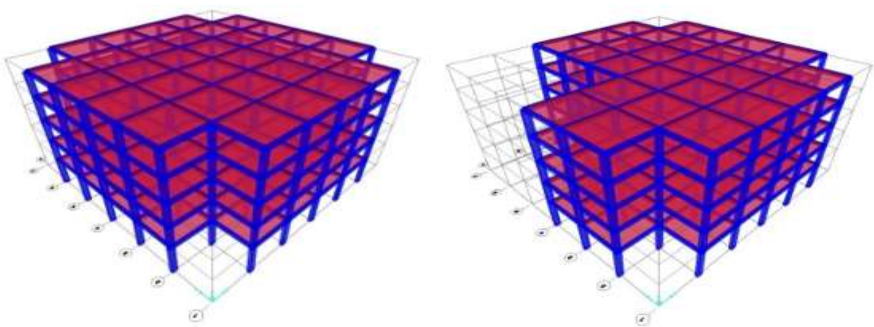


Fig. 6 - (a) Model-1: (A/L ratio:X-0.333, Y-0.333); (b) Model-2: (A/L ratio: X-0.5, Y-0.667)

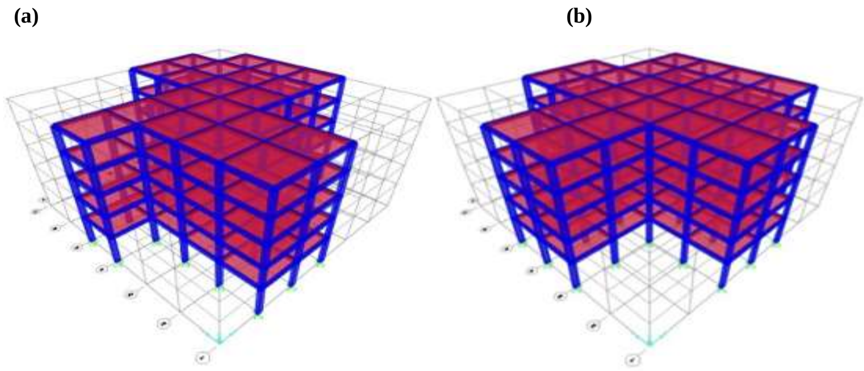


Fig. 7 - (a) Model-3: (A/L ratio:x-0.667, Y-0.833); (b) Model-4: (A/L ratio:X-0.667, Y-0.667)

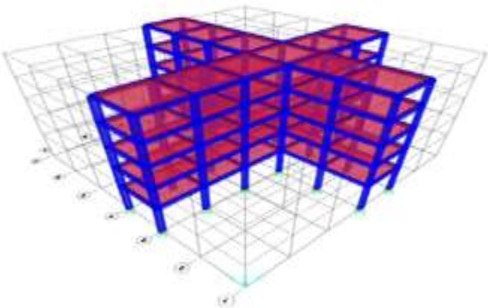


Fig. 8- Model-5: (A/L ratio:X-0.833, Y-0.833)

H- Shape models

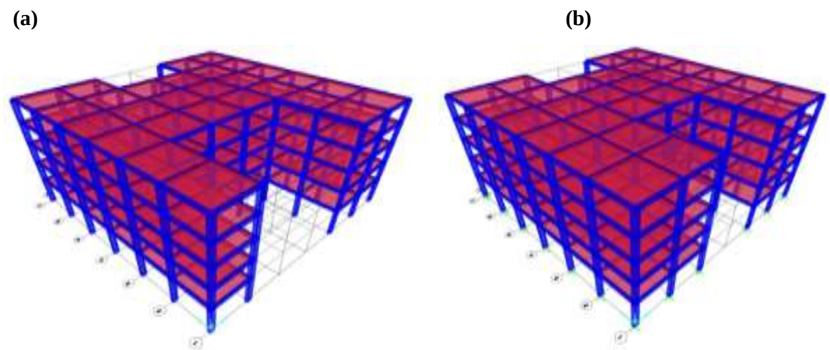


Fig. 9 - (a) Model-6: (A/L ratio:X-0.333, Y-0.5); (b) Model-7: (A/L ratio:X-0.5, Y-0.5)

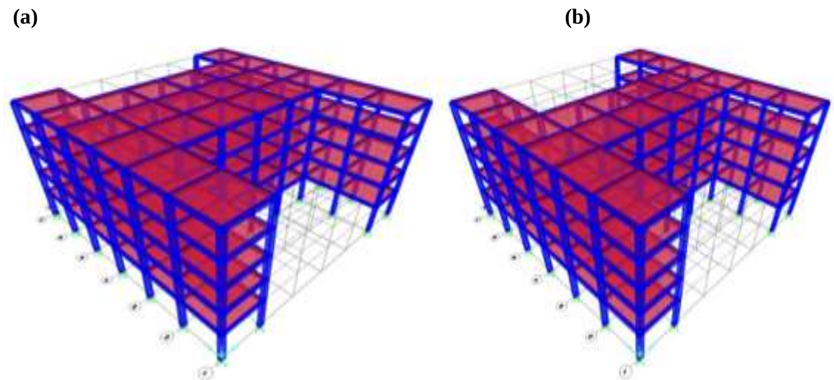


Fig. 10 - (a) Model-8: (A/L ratio:X-0.667, Y-0.5); (b) Model-9: (A/L ratio:X-0.667, Y-0.667)

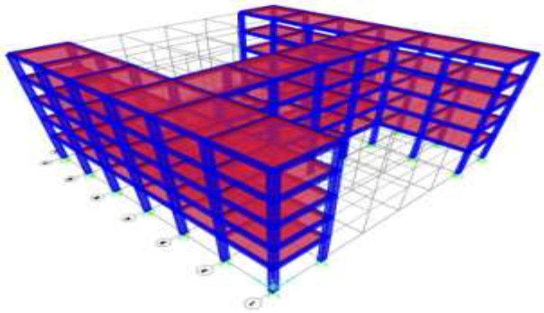


Fig. 11 - Model-10: (A/L ratio:X-0.667, Y-0.833)

C- Shape models

(a) (b)

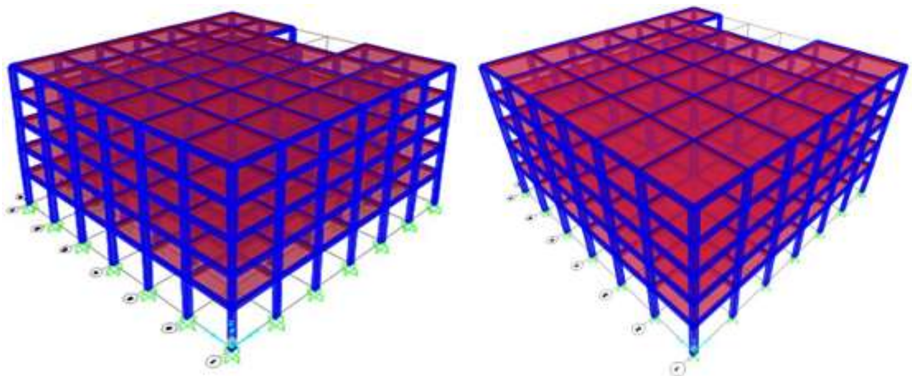


Fig. 12 - (a) Model-11: (A/L ratio:X-0.167, Y-0.833); (b) Model-12: (A/L ratio:X-0.167, Y-0.5)

(a) (b)

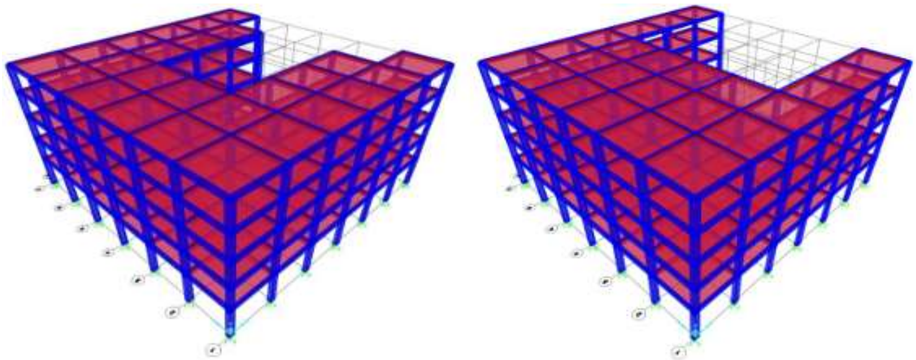


Fig. 13 - (a) Model-13: (A/L ratio:X-0.667, Y-0.667); (b) Model-14: (A/L ratio:X-0.5, Y-0.667)

(a) (b)

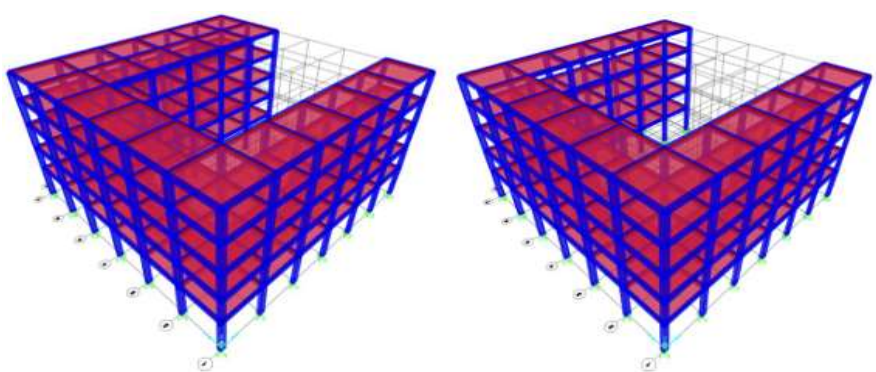


Fig. 14 - (a) Model-15: (A/L ratio:X-0.833, Y-0.5); (b) Model-16: (A/L ratio:X-0.833, Y-0.667)

L & Z - Shape models

(a) **(b)**

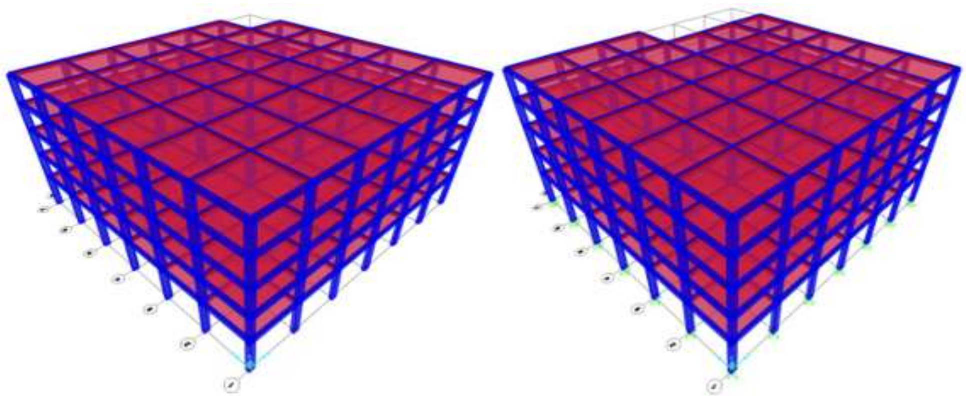


Fig. 15 - (a) Model-17: (A/L ratio:X-0.167, Y-0.167); (b) Model-18: (A/L ratio:X-0.5, Y-0.167)

(a) **(b)**

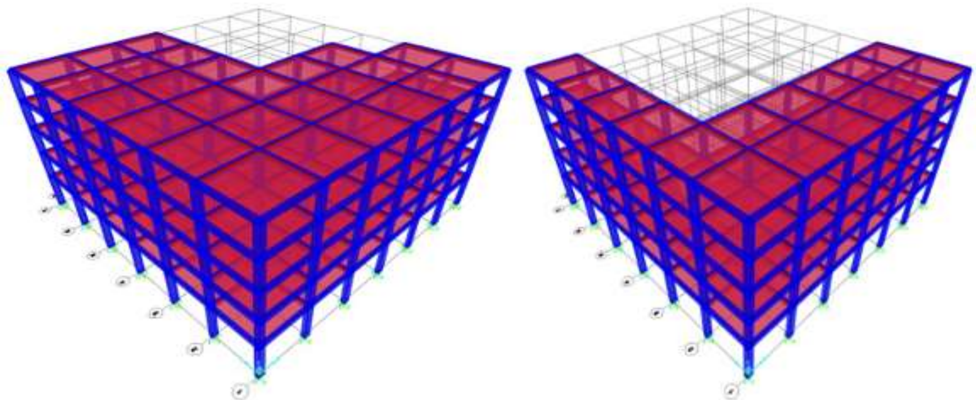


Fig. 16 - (a) Model-20: (A/L ratio:X-0.5, Y-0.667); (b) Model-22: (A/L ratio:X-0.833, Y-0.5)

(a) **(b)**

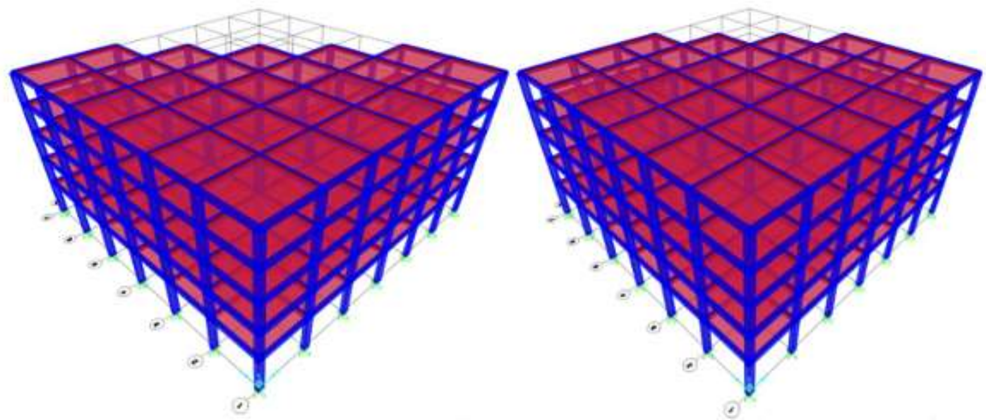


Fig. 17 - (a) Model-27: (A/L ratio:X-0.667, Y-0.667); (b) Model-26: (A/L ratio:X-0.5, Y-0.5)

(a) **(b)**

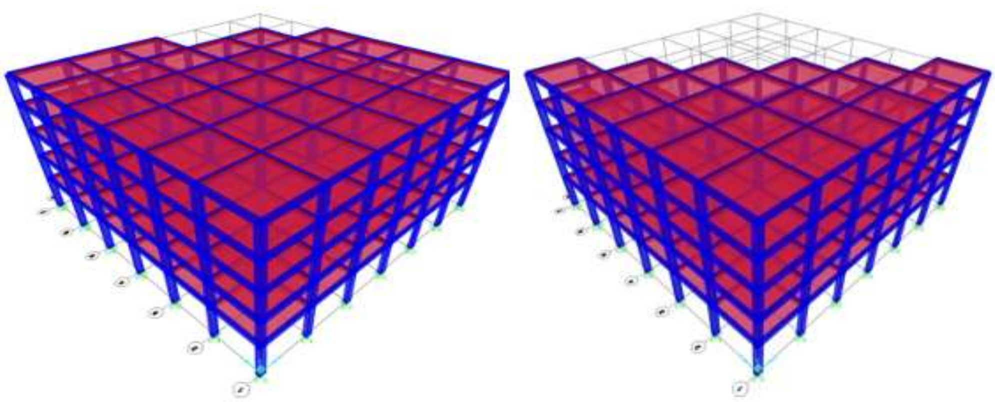


Fig. 18 - (a) Model-19: (A/L ratio:X-0.5, Y-0.167); (b) Model-28: (A/L ratio:X-0.833, Y-0.833)

(a) **(b)**

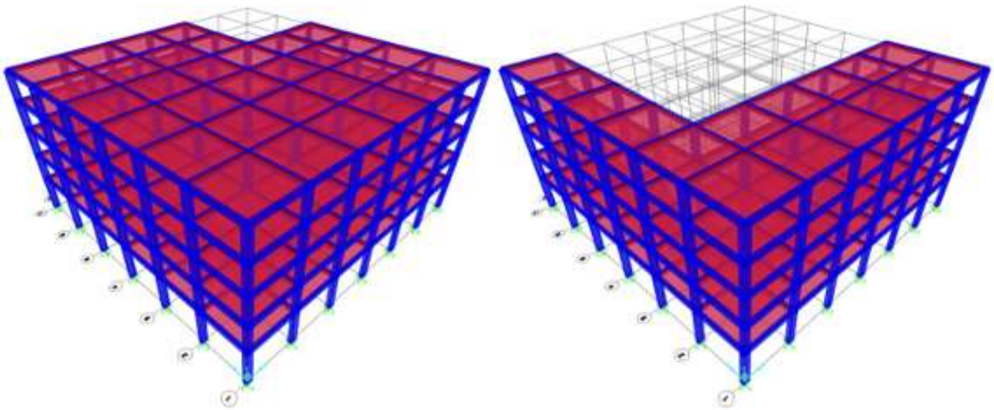


Fig. 19 - (a) Model-25: (A/L ratio:X-0.333, Y-0.333); (b) Model-23: (A/L ratio:X-0.833, Y-0.667)

(a) **(b)**

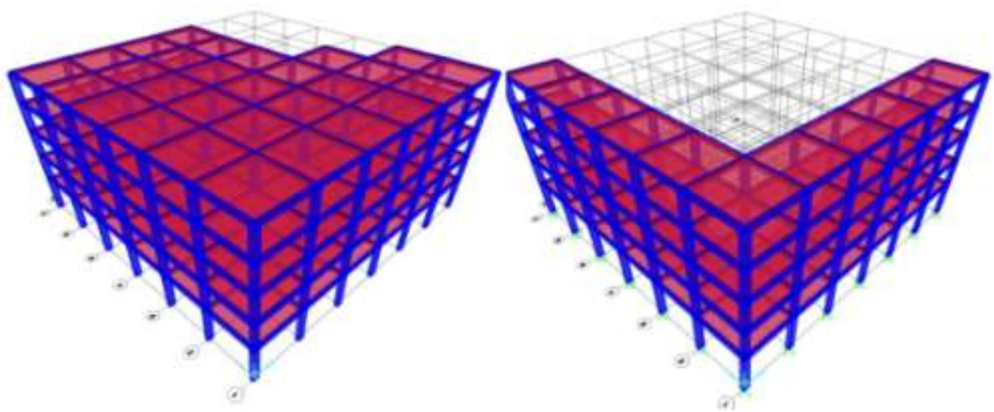


Fig. 20 - (a) Model-21: (A/L ratio:X-0.167, Y-0.5); (b) Model-24: (A/L ratio:X-0.833, Y-0.833)

3.4 Drift (Displacement) based damage index based on nonlinear Dynamic analysis

In the domain of structural engineering and architecture, the concept of an irregularity index is employed to quantify the geometric irregularity introduced by re-entrant corners in building plans. This study utilizes drift-based criteria to assess structural damage in irregular reinforced concrete (RC) buildings, based on the results of nonlinear Time History Analysis. The influence of re-entrant corners is initially evaluated using a geometrical irregularity index denoted as A, which represents the area of the re-entrant corner. To further characterize this irregularity, a normalized parameter—A/L ratio—is introduced, where L denotes the length of the adjoining walls forming the re-entrant corner. The plan irregularity is first quantified in accordance with IS 1893 (Part 2): 2016 provisions using the index A, and subsequently, dynamic analysis is conducted to evaluate the seismic response and damage potential of the structure. In the development of a drift-based damage index, the Park–Ang damage indexes are computed using the formulation provided in Equation (a). Utilizing the curated database and applying multivariable nonlinear regression analysis, a predictive model has been proposed to estimate the extent of seismic damage in irregular buildings characterized by re-entrant corners. This formulation enables a quantitative assessment of damage severity, linking geometric irregularity with dynamic response parameters derived from Time History analysis. To predict potential seismic damage in irregular RC buildings, a mathematical model is developed using nonlinear regression analysis. This approach underscores the versatility of nonlinear regression, particularly in contexts where linear models fall short in capturing complex interdependencies among variables. Through nonlinear regression, researchers can identify intricate patterns, estimate model parameters, generate predictive insights, and gain a deeper understanding of underlying structural behaviors. This was accomplished by using the results of the study. The database was utilized in order to carry out this nonlinear regression study. There are 168 observations displayed in this table. It is possible to derive and evaluate the quadratic polynomial equation, which is distinct damage measures. Equation (b) respectively show the final mathematical expression of the suggested damage index.

DBDI = -13.557+103.954 x T+ 2.786 x A – 136.204 x OD -122.778 x T^2 – 0.765 x A^2 + 134.348 x OD^2 - 0.120 x T x A -11.209 x A x OD + 342.337 x T x OD ……. (b)

Were,

DBDI: Drift based Damage Index

A: Re- Entrant corner plan irregularity indices (A/L Ratio)

T: Fundamental Natural time period as per IS:1893 (Part-1):2016 [cl.7.6.2, pg-21]

- OD: Overall Drift [$OD = \frac{\Delta}{H}$]

where, Δ is Maximum roof displacement and H is a total height of the building

The coefficient of determination of regression, or R^2, is a statistical measure that can be used to determine how well the data fit the fitted regression model. In this case, the R^2 value is 0.93223. This demonstrates that the regression equation, when compared to the data, produces accurate results.

Table 3 – Database of RC irregular buildings to develop a drift-based damage index

Park-Ang DI	**T (sec)**	**A**	**OD (%)**	**T2**	**A2**	**OD^2**	**T*A**	**A*OD**	**T*OD**
5.151	0.304	0.333	0.1228	0.09242	0.11089	0.01508	0.10123	0.04089	0.03733
5.398	0.304	0.333	0.1684	0.09242	0.11089	0.02836	0.10123	0.05608	0.05119
5.281	0.304	0.5	0.1228	0.09242	0.25	0.01508	0.152	0.0614	0.03733
3.844	0.304	0.667	0.1684	0.09242	0.44489	0.02836	0.20277	0.11232	0.05119
5.232	0.304	0.667	0.1228	0.09242	0.44489	0.01508	0.20277	0.08191	0.03733
5.335	0.304	0.833	0.1684	0.09242	0.69389	0.02836	0.25323	0.14028	0.05119
5.131	0.304	0.667	0.1228	0.09242	0.44489	0.01508	0.20277	0.08191	0.03733
5.393	0.304	0.667	0.1684	0.09242	0.44489	0.02836	0.20277	0.11232	0.05119
5.125	0.304	0.833	0.1228	0.09242	0.69389	0.01508	0.25323	0.10229	0.03733
5.09	0.304	0.833	0.1684	0.09242	0.69389	0.02836	0.25323	0.14028	0.05119
5.156	0.304	0.333	0.1228	0.09242	0.11089	0.01508	0.10123	0.04089	0.03733
5.31	0.304	0.5	0.1684	0.09242	0.25	0.02836	0.152	0.0842	0.05119
5.245	0.304	0.5	0.1226	0.09242	0.25	0.01503	0.152	0.0613	0.03727
5.335	0.304	0.5	0.1638	0.09242	0.25	0.02683	0.152	0.0819	0.0498

4. Result-

The results shown here are the measured damage index using the Park-Ang Equation & estimated damage using the Drift-based damaged equation, and the percentage of error present between them.

Table 4 - Results of Measured DI and Estimated DI

Sr No.	Model Designation	Load Type	Measured DI (%) Park-Ang Equation (a)	Estimated DI (%) DBDI Equation (b)	Error (%)
1	S4-Plus-1-X	TH	5.151	5.151	0.002
2	S4-Plus-1-Y	TH	5.398	5.300	-1.823
3	S4-Plus-2-X	TH	5.281	5.274	-0.132
4	S4-Plus-2-Y	TH	3.844	5.332	38.712
5	S4-Plus-3-X	TH	5.232	5.354	2.337
6	S4-Plus-3-Y	TH	5.335	5.285	-0.942
7	S4-Plus-4-X	TH	5.131	5.354	4.352
8	S4-Plus-4-Y	TH	5.393	5.332	-1.130
9	S4-Plus-5-X	TH	5.125	5.392	5.206
10	S4-Plus-5-Y	TH	5.090	5.285	3.826
11	S4-H-1-X	TH	5.156	5.151	-0.095
12	S4-H-1-Y	TH	5.310	5.337	0.512
13	S4-H-2-X	TH	5.245	5.275	0.572
14	S4-H-2-Y	TH	5.335	5.305	-0.554
15	S4-H-3-X	TH	5.257	5.350	1.776
16	S4-H-3-Y	TH	5.289	5.300	0.206
17	S4-H-4-X	TH	5.248	5.338	1.715
18	S4-H-4-Y	TH	5.257	5.294	0.701
19	S4-H-5-X	TH	5.628	5.354	-4.875
20	S4-H-5-Y	TH	5.207	5.259	0.994
21	S4-C-1-X	TH	4.124	4.986	20.914
22	S4-C-1-Y	TH	4.333	5.206	20.155
23	S4-C-2-X	TH	5.331	4.994	-6.328
24	S4-C-2-Y	TH	5.850	5.280	-9.745
25	S4-C-3-X	TH	5.115	5.394	5.453
26	S4-C-3-Y	TH	5.547	5.320	-4.087
27	S4-C-4-X	TH	5.106	5.296	3.727
28	S4-C-4-Y	TH	6.097	5.293	-13.195
29	S4-C-5-X	TH	5.415	5.491	1.405
30	S4-C-5-Y	TH	6.073	5.298	-12.769
31	S4-C-6-X	TH	5.092	5.490	7.816
32	S4-C-6-Y	TH	6.258	5.308	-15.186
33	S4-L-1-X	TH	5.173	5.010	-3.149
34	S4-L-1-Y	TH	5.405	5.168	-4.384

Sr No.	Model Designation	Load Type	Measured DI (%) Park-Ang Equation (a)	Estimated DI (%) DBDI Equation (b)	Error (%)
35	S4-L-2-X	TH	5.188	5.269	1.561
36	S4-L-2-Y	TH	5.459	5.250	-3.827
37	S4-L-3-X	TH	5.242	5.271	0.549
38	S4-L-3-Y	TH	5.458	5.316	-2.603
39	S4-L-4-X	TH	5.317	5.289	-0.528
40	S4-L-4-Y	TH	5.526	5.339	-3.383
41	S4-L-5-X	TH	5.180	5.155	-0.488
42	S4-L-5-Y	TH	5.343	5.346	0.052
43	S4-L-6-X	TH	5.294	5.446	2.880
44	S4-L-6-Y	TH	5.349	5.472	2.300
45	S4-L-7-X	TH	5.638	5.403	-4.167
46	S4-L-7-Y	TH	4.870	5.420	11.293
47	S4-L-8-X	TH	6.125	5.371	-12.316
48	S4-L-8-Y	TH	4.499	5.435	20.801
49	S4-Z-1-X	TH	5.253	5.149	-1.977
50	S4-Z-1-Y	TH	5.475	5.316	-2.906
51	S4-Z-2-X	TH	5.305	5.278	-0.511
52	S4-Z-2-Y	TH	5.476	5.348	-2.339
53	S4-Z-3-X	TH	5.300	5.394	1.772
54	S4-Z-3-Y	TH	5.701	5.295	-7.118
55	S4-Z-4-X	TH	4.967	5.401	8.742
56	S4-Z-4-Y	TH	5.982	5.260	-12.075
57	S8-Plus-1-X	TH	13.947	14.377	3.081
58	S8-Plus-1-Y	TH	16.280	16.097	-1.125
59	S8-Plus-2-X	TH	13.971	14.512	3.873
60	S8-Plus-2-Y	TH	15.837	16.263	2.692
61	S8-Plus-3-X	TH	13.814	14.591	5.624
62	S8-Plus-3-Y	TH	16.199	16.175	-0.149
63	S8-Plus-4-X	TH	13.971	14.584	4.387
64	S8-Plus-4-Y	TH	16.254	16.180	-0.455
65	S8-Plus-5-X	TH	14.509	14.513	0.026
66	S8-Plus-5-Y	TH	15.971	16.028	0.358
67	S8-H-1-X	TH	14.118	14.762	4.563
68	S8-H-1-Y	TH	15.767	15.958	1.214
69	S8-H-2-X	TH	16.598	13.449	-18.973

Sr No.	Model Designation	Load Type	Measured DI (%) Park-Ang Equation (a)	Estimated DI (%) DBDI Equation (b)	Error (%)
70	S8-H-2-Y	TH	16.098	15.958	-0.867
71	S8-H-3-X	TH	14.877	15.063	1.253
72	S8-H-3-Y	TH	16.061	15.851	-1.306
73	S8-H-4-X	TH	14.258	15.056	5.599
74	S8-H-4-Y	TH	15.788	15.806	0.114
75	S8-H-5-X	TH	14.715	15.221	3.440
76	S8-H-5-Y	TH	15.264	15.724	3.012
77	S8-C-1-X	TH	14.070	14.013	-0.408
78	S8-C-1-Y	TH	16.187	16.336	0.923
79	S8-C-2-X	TH	14.265	13.998	-1.874
80	S8-C-2-Y	TH	16.258	16.408	0.925
81	S8-C-3-X	TH	14.171	14.029	-1.002
82	S8-C-3-Y	TH	16.674	17.035	2.164
83	S8-C-4-X	TH	14.067	14.053	-0.101
84	S8-C-4-Y	TH	17.116	16.584	-3.108
85	S8-C-5-X	TH	14.211	14.029	-1.280
86	S8-C-5-Y	TH	16.209	17.352	7.049
87	S8-C-6-X	TH	13.778	14.003	1.633
88	S8-C-6-Y	TH	16.520	17.866	8.146
89	S8-L-1-X	TH	14.103	14.177	0.527
90	S8-L-1-Y	TH	16.333	15.954	-2.322
91	S8-L-2-X	TH	14.313	14.505	1.341
92	S8-L-2-Y	TH	15.985	16.084	0.620
93	S8-L-3-X	TH	13.986	14.462	3.404
94	S8-L-3-Y	TH	16.170	16.105	-0.404
95	S8-L-4-X	TH	14.370	14.627	1.788
96	S8-L-4-Y	TH	16.279	16.135	-0.885
97	S8-L-5-X	TH	14.188	14.414	1.589
98	S8-L-5-Y	TH	16.311	16.097	-1.311
99	S8-L-6-X	TH	14.397	14.587	1.320
100	S8-L-6-Y	TH	16.583	16.330	-1.525
101	S8-L-7-X	TH	14.762	14.332	-2.911
102	S8-L-7-Y	TH	17.309	16.271	-5.997
103	S8-L-8-X	TH	13.997	14.379	2.728
104	S8-L-8-Y	TH	18.699	16.197	-13.381

Sr No.	Model Designation	Load Type	Measured DI (%) Park-Ang Equation (a)	Estimated DI (%) DBDI Equation (b)	Error (%)
105	S8-Z-1-X	TH	14.031	14.391	2.569
106	S8-Z-1-Y	TH	16.413	16.041	-2.265
107	S8-Z-2-X	TH	14.221	14.377	1.095
108	S8-Z-2-Y	TH	16.339	16.128	-1.291
109	S8-Z-3-X	TH	14.238	14.260	0.153
110	S8-Z-3-Y	TH	15.785	16.347	3.560
111	S8-Z-4-X	TH	13.971	14.381	2.937
112	S8-Z-4-Y	TH	17.732	15.883	-10.430
113	S12-Plus-1-X	TH	12.366	14.938	20.796
114	S12-Plus-1-Y	TH	17.176	15.210	-11.449
115	S12-Plus-2-X	TH	12.450	15.048	20.864
116	S12-Plus-2-Y	TH	17.143	15.114	-11.835
117	S12-Plus-3-X	TH	12.371	15.317	23.815
118	S12-Plus-3-Y	TH	16.721	15.632	-6.511
119	S12-Plus-4-X	TH	12.281	15.114	23.069
120	S12-Plus-4-Y	TH	17.169	15.052	-12.332
121	S12-Plus-5-X	TH	11.552	15.354	32.908
122	S12-Plus-5-Y	TH	16.587	15.276	-7.902
123	S12-H-1-X	TH	13.078	14.922	14.098
124	S12-H-1-Y	TH	15.737	15.237	-3.176
125	S12-H-2-X	TH	13.397	14.827	10.672
126	S12-H-2-Y	TH	16.118	15.221	-5.563
127	S12-H-3-X	TH	13.667	14.725	7.739
128	S12-H-3-Y	TH	15.985	15.111	-5.469
129	S12-H-4-X	TH	13.558	15.192	12.053
130	S12-H-4-Y	TH	15.356	14.337	-6.636
131	S12-H-5-X	TH	13.968	14.787	5.862
132	S12-H-5-Y	TH	15.014	14.860	-1.025
133	S12-C-1-X	TH	13.336	12.708	-4.709
134	S12-C-1-Y	TH	15.081	14.222	-5.698
135	S12-C-2-X	TH	13.295	12.755	-4.058
136	S12-C-2-Y	TH	15.001	14.387	-4.095
137	S12-C-3-X	TH	13.280	12.197	-8.155
138	S12-C-3-Y	TH	16.601	14.663	-11.677
139	S12-C-4-X	TH	13.144	12.556	-4.477

Sr No.	Model Designation	Load Type	Measured DI (%) Park-Ang Equation (a)	Estimated DI (%) DBDI Equation (b)	Error (%)
140	S12-C-4-Y	TH	16.596	14.818	-10.714
141	S12-C-5-X	TH	12.836	12.106	-5.691
142	S12-C-5-Y	TH	17.325	14.748	-14.874
143	S12-C-6-X	TH	12.888	12.106	-6.071
144	S12-C-6-Y	TH	17.917	15.442	-13.811
145	S12-L-1-X	TH	11.932	14.801	24.047
146	S12-L-1-Y	TH	16.501	15.012	-9.026
147	S12-L-2-X	TH	12.357	14.969	21.135
148	S12-L-2-Y	TH	17.007	15.141	-10.971
149	S12-L-3-X	TH	12.418	14.780	19.017
150	S12-L-3-Y	TH	17.447	14.826	-15.023
151	S12-L-4-X	TH	12.467	14.544	16.657
152	S12-L-4-Y	TH	17.370	15.474	-10.917
153	S12-L-5-X	TH	12.292	14.730	19.836
154	S12-L-5-Y	TH	17.560	15.036	-14.373
155	S12-L-6-X	TH	11.839	14.860	25.518
156	S12-L-6-Y	TH	17.170	16.255	-5.327
157	S12-L-7-X	TH	11.728	14.814	26.313
158	S12-L-7-Y	TH	17.248	17.054	-1.124
159	S12-L-8-X	TH	11.796	14.354	21.685
160	S12-L-8-Y	TH	19.285	16.161	-16.197
161	S12-Z-1-X	TH	12.146	14.842	22.195
162	S12-Z-1-Y	TH	17.056	15.338	-10.074
163	S12-Z-2-X	TH	12.343	14.512	17.575
164	S12-Z-2-Y	TH	17.656	14.717	-16.648
165	S12-Z-3-X	TH	12.408	14.198	14.425
166	S12-Z-3-Y	TH	17.571	15.177	-13.628
167	S12-Z-4-X	TH	12.434	13.800	10.982
168	S12-Z-4-Y	TH	17.840	15.493	-13.157

Comparison results of DBDI using NLDA for 4-storey

(a) **(b)**

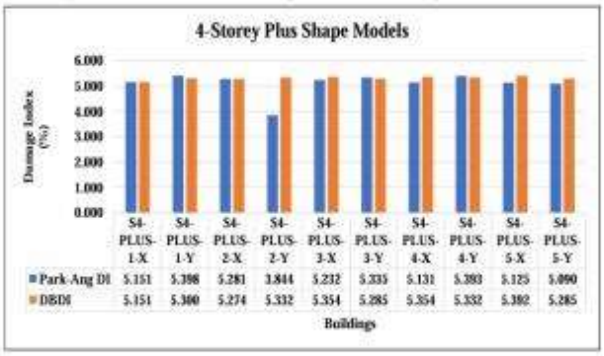
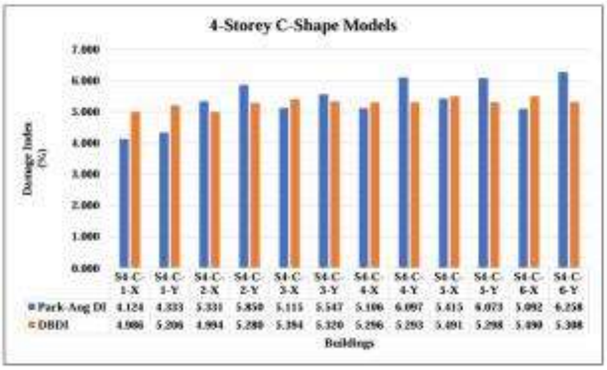


Fig. 21- (a) Comparison results of DBDI using NLDA for 4-storey (model no. 1 to 5);

(b) Comparison results of DBDI using NLDA for 4-storey (model no. 6 to 10)

(a) **(b)**



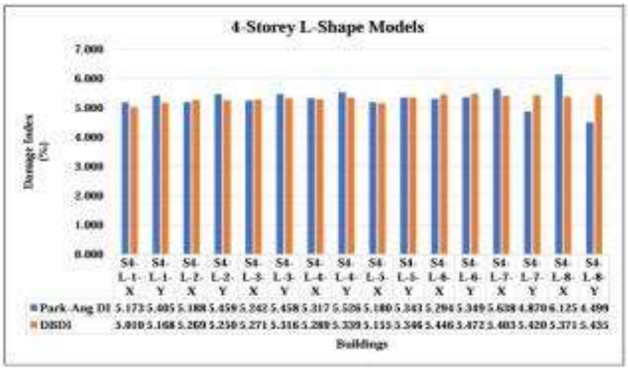


Fig. 22- (a) Comparison results of DBDI using NLDA for 4-storey (model no. 11 to 16);

(b) Comparison results of DBDI using NLDA for 4-storey (model no. 17 to 24)

(a) **(b)**

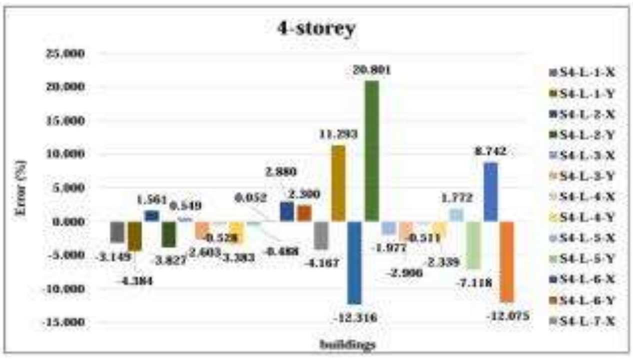


Fig. 22- (a) Comparison results of DBDI using NLDA for 4-storey (model no. 25 to 28);

(b) Error % of DBDI using NLDA for 8-storey (model no.17 to 28)

5. Conclusion-

In the present study, results for the behavior of the Re-Entrant corners plan Irregular building with different shapes are presented. Nonlinear time history analysis was performed for different time history data. Based on irregularity indices (A), Overall drift (OD), time period (T) performed nonlinear regression analysis and developed and proposed Drift based damage index equation.

From the results, the following conclusion is listed below:

1. It was demonstrated that the proposed function is able to predict the damage to the re-entrant corner plan of irregular buildings with reasonable accuracy.

2. The proposed function is a simple and applicable relation that is able to estimate the damage value by knowing the values of overall drift (OD), fundamental period (T), and irregularity indices (A) for a Re-Entrant corner Building, without needing the intensive computational and modelling effort of a dynamic damage analysis.

3. The proposed expression simplifies the method of Park-Ang DI which significantly reduces computation time and effort. Therefore, this method is suitable for rapid evaluation of low to medium -scale damage assessment of buildings efficiently.

4. The results of the error percentage increase with building story increase show that the proposed DBDI is applicable to low- to medium-rise buildings

5. The analysis of 3D Plan irregular buildings are provided acceptable outcomes and DI method have been proven to be capable of properly estimating the damage to 3D irregular buildings using various engineering demand parameters.

6. Based on the result of analyses, the multi-variable nonlinear regression concept was performed to derive effective function including Polynomial quadratic equation in terms of overall drift, fundamental period and irregularity indices

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