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Research Paper | Engineering

Seismic Vulnerability of RC Buildings by Considering Plan Irregularities Using Pushover Analysis

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ABSTRACT

Many buildings in the present scenario have irregular configurations both in plan and elevation. This in future may subject to devastating earthquakes. In model, it is necessary to identify the performance of the structures to withstand against disaster for building structures. In Oder to identify the most vulnerable building among the models considered, the various analytical approaches are performed to identify the seismic demands in both linear and nonlinear way. It is also examined the effect of different lateral load patterns on the performance of various irregular buildings in pushover analysis.

In the present research work, a G+9 storey building situated in severe zone V is considered, having plan irregularities like, rectangular, diaphragm discontinuity, Y-shaped models. Nonlinear static analysis has been adopted for a project work, using FEM based analytical software ETABS 9.7.4 version. Various results such as base shear, point displacement, performance point, performance levels, and pushover curve.

KEYWORDS : Equivalent static, pushover, performance level, diaphragm discontinuity, performance point.

1.1 INTRODUCTION

Although there are so many studies about earthquakes but however it has not been possible to predict when and where earthquake will happen. The seismic zone governs the design earthquake forces and the performance level governs the permissible damage or the permissible values of members actions due to earthquake forces. The definition of these performance levels has been taken from Federal Emergency Management Agency (FEMA) and Applied Technology Council (ATC).

A desire to create an aesthetic and functionally efficient structure drives architects to conceive wonderful and imaginative structures. Sometimes the shape of the building catches the eye of the visitor, sometimes the structural system appeals, and in other occasions both shape and structural system work together to make the structure a marvel. However, each of these choices of shapes and structure has significant bearing on the performance of the building during strong earthquakes. The wide range of structural damages observed during past earthquakes across the world is very educative in identifying structural configurations that are desirable versus those which must be avoided (Fig 1.1).

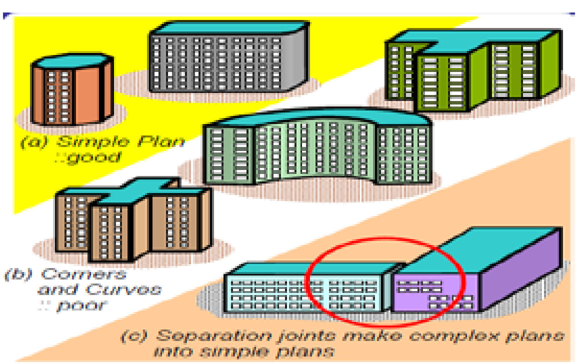


Fig 1.1: Simple Plan Shape Buildings Perform well during Earthquakes

1.2. METHODS OF SEISMIC EVALUATION

The different analytical methods are categorized below as follows:

1. Linear static analysis or equivalent static Analysis
2. Linear dynamic analysis by response spectrum Method
3. Nonlinear static analysis (pushover analysis)

1.2.1. Linear static analysis or equivalent static Analysis

Equivalent static method of analysis is a linear static procedure, in which the response of building is assumed as linearly elastic manner. The analysis is carried out as per IS: 1893- 2002 (Part 1) [5]. Here the total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure generally used for the equivalent static analysis is explained with the examples used for validation below in chapter-3

1.2.2. Nonlinear static analysis (pushover analysis)

Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral force is incrementally increased, maintaining the predefined distribution pattern along the height of the building. With the increase in the magnitude of the loads, weak links and failure modes of the building are found.

Pushover analysis can determine the behaviour of a building, including the ultimate load and the maximum inelastic deflection. Local Nonlinear effects are modelled and the structure is pushed until a collapse mechanism gets developed as shown in figure 1.2. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve. It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake.

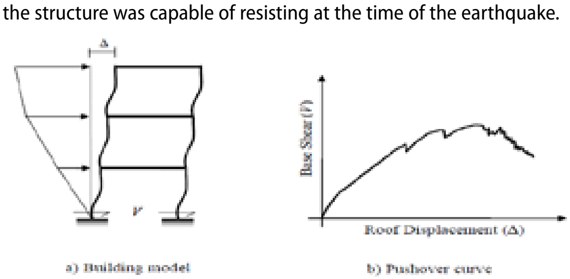
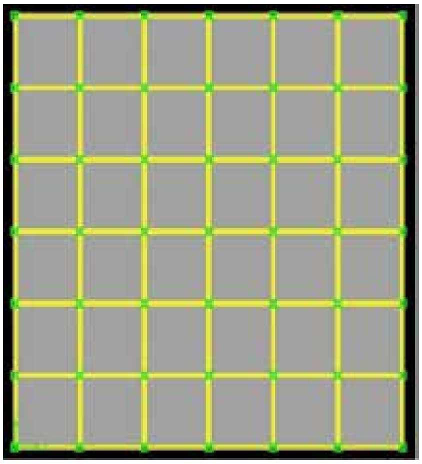


Fig 1.2: Pushover Analysis Procedure.

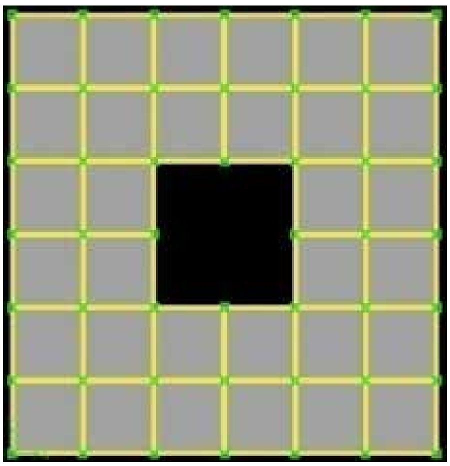
1.3 Performance point of the building using capacity spectrum method.

Performance point can be obtained by superimposing capacity spectrum curve and demand spectrum curve and the intersection point of these two curves is performance point. Fig 1.2 shows superimposing demand spectrum and capacity spectrum.

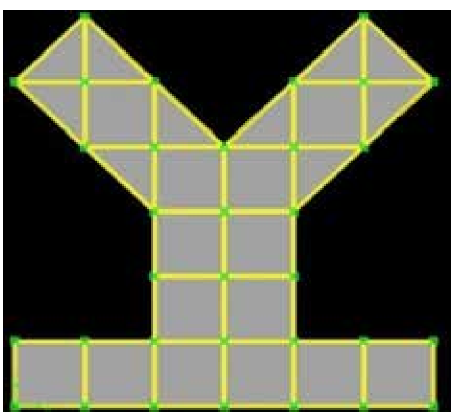
1.4. DESCRIPTION OF MODELS



1.3(a) Plan of rectangular shaped model



1.3(b) Plan of diaphragm discontinuity model



1.3(c) Plan of Y shaped model

The models shown in above fig.1.3 (a) to 1.3(c) have been considered for the analysis purpose, which is having G+9 storeys situated in severe seismic zone v with the response reduction factor of (R=5), and the loads have been assigned based on IS 875-2000. And all the factors are as per IS1893-2002 part-1 for earthquake. Then both linear static analysis and non-linear static analysis i.e. Pushover analysis is performed.

Various results such as base shear, point displacement, performance points, performance levels and pushover curve have been presented. The capacity of the building has been determined, and comparison of all the above mentioned results is made for the building models considered, and among these three considered models which is most vulnerable to seismic effect.

1.5 RESULTS & DISCUSSIONS

1.5.1 BASE SHEAR

Table no.1: Base shear comparison for considered G+9 storey models

SL NO.	MODELS	BASE SHARE(kN)
1	RECTANGLE	4250
2	DIAFRGM DICCONTINUITY	3950
3	Y SHAPE	1280

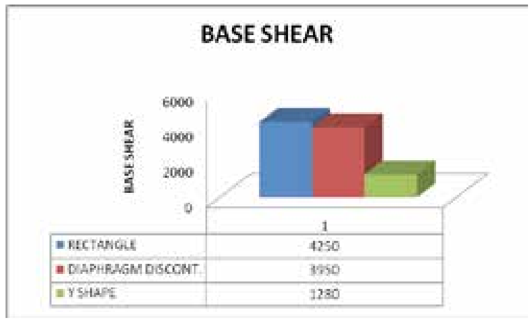


Fig: 1.4 Base shear comparison for all the three considered G+9 storey models

Discussion: The base shear as shown in fig no. 1.4 and table 1 has been plotted for all the models considered, the graph and tabular column shows that the base shear for rectangular model is much greater than the other two models.

1.5.2. POINT DISPLACEMENT

Table no. 2 Point displacement comparison for considered G+9 storey models

POINT DISPLACEMENT FOR G+9 STOREYS in meters			
STOREYS	Rectangle	Diaphragm Discontinuity	Y SHAPE
STORY10	0.0339	0.3315	0.0191
STORY9	0.0325	0.3175	0.0182
STORY8	0.0303	0.2957	0.0168
STORY7	0.0273	0.2666	0.0151
STORY6	0.0238	0.2318	0.0131
STORY5	0.0198	0.1926	0.0108
STORY4	0.0155	0.1505	0.0084
STORY3	0.011	0.1068	0.0059
STORY2	0.0065	0.0632	0.0035
STORY1	0.0024	0.0234	0.0012
BASE	0	0	0

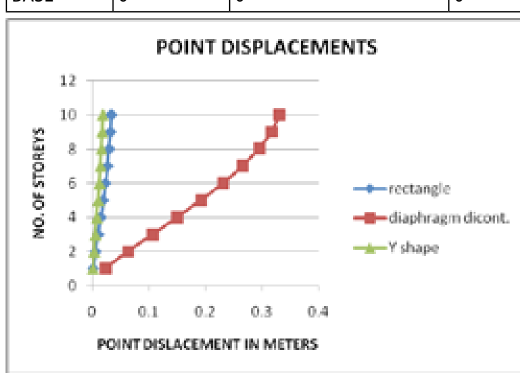


Fig no 1.5 Point Displacement comparisons for the three considered G+9 storey models

Diaphragm Discontinuity:
Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next.

Discussion: The Point displacement as shown in fig no. 1.5 and table 2 has been plotted for all the models considered, the graph and tabular column shows that the point displacement for Diaphragm Discontinuity model is having greater displacement than the other two models.

1.5.3. PERFORMENCE POINT

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curves is performance point. Fig 1.6 shows

Superimposing demand spectrum and capacity spectrum. The Table 4 shows the Data for Performance point in longitudinal direction (PUSH X) for G+ 9 storeys and shapes are rectangle, diaphragm discontinuity models.

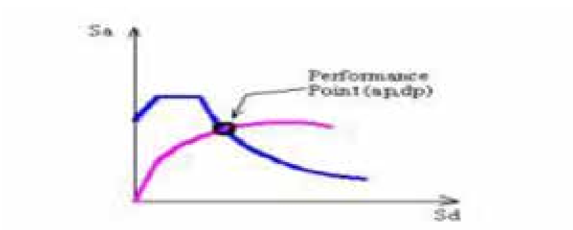


Fig no 1.6 Performance point

1.5.4. Pushover curve using excel:

Table no: 3 Performance points for rectangular model

STEP	Teff	βeff	Sd(C)	Sa(C)	Sd(D)	Sa(D)
0	1.476	0.050	0.000	0.000	0.147	0.271
1	1.476	0.050	0.045	0.084	0.147	0.271
2	1.476	0.050	0.046	0.085	0.147	0.271
3	1.566	0.093	0.057	0.093	0.131	0.216
4	1.621	0.117	0.062	0.095	0.127	0.194
5	2.341	0.249	0.150	0.110	0.140	0.103
6	2.636	0.262	0.201	0.116	0.154	0.089
7	3.136	0.286	0.284	0.116	0.177	0.072
8	3.537	0.300	0.365	0.118	0.197	0.063

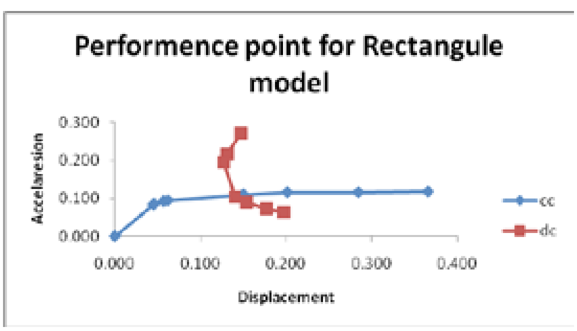


Fig no. 1.7(a) Performance points for rectangular model

Table no.4 Performance points for Diaphragm discontinuity

Step	Teff	βeff	sd(C)	Sa(C)	Sd(D)	Sa(D)
0	5.355	0.050	0.000	0.000	0.532	0.075
1	5.355	0.050	0.093	0.013	0.532	0.075
2	5.359	0.050	0.185	0.026	0.532	0.075
3	5.36	0.050	0.278	0.039	0.532	0.075
4	5.361	0.050	0.371	0.052	0.532	0.075
5	5.361	0.050	0.419	0.059	0.532	0.075
6	5.54	0.076	0.475	0.062	0.494	0.065
7	5.654	0.091	0.500	0.063	0.478	0.06
8	5.734	0.102	0.515	0.063	0.469	0.057
9	5.773	0.107	0.522	0.063	0.466	0.056
10	5.829	0.114	0.531	0.063	0.461	0.055
11	5.878	0.120	0.54	0.063	0.457	0.053
12	6.013	0.137	0.562	0.063	0.448	0.05
13	6.324	0.169	0.615	0.062	0.438	0.044

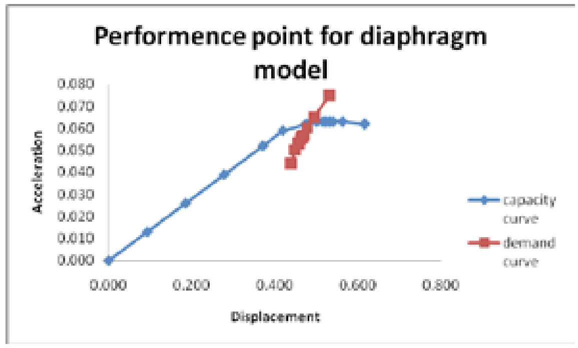


Fig no. 1.7(b) Performance points for diaphragm discontinuity

Table no.5 Performance points for Y-shape model

Step	Teff	βeff	Sd(C)	Sa(C)	Sd(D)	Sa(D)
0	1.040	0.050	0.000	0.000	0.103	0.385
1	1.040	0.050	0.029	0.106	0.103	0.385
2	1.088	0.079	0.040	0.135	0.096	0.326
3	1.178	0.128	0.051	0.147	0.090	0.260
4	1.434	0.221	0.082	0.160	0.090	0.176
5	1.789	0.263	0.136	0.171	0.104	0.131
6	2.004	0.275	0.175	0.176	0.115	0.115
7	2.026	0.276	0.179	0.176	0.116	0.114
8	2.097	0.280	0.192	0.176	0.119	0.109
9	2.104	0.281	0.193	0.176	0.119	0.109
10	2.112	0.281	0.195	0.176	0.120	0.108
11	2.125	0.282	0.197	0.176	0.120	0.107
12	2.138	0.283	0.199	0.175	0.121	0.107
13	2.784	0.334	0.298	0.155	0.155	0.080

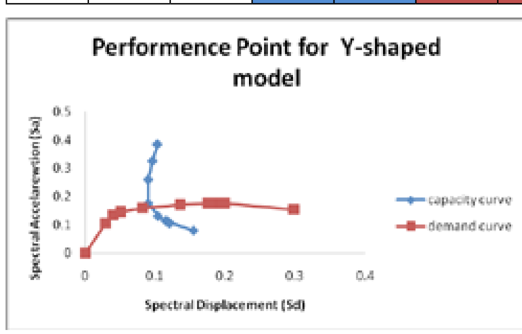


Fig no. 1.7(c) Performance points for Y-shape model

Discussion: The Performance points have been plotted for all the models considered as shown in fig no. 1.7(a) to fig no.1.8(c) and table 3 to 5 using both excel and ETABS. The intersection point of both demand curve and capacity curve is the performance point.

The Performance point for rectangular model i.e,. V=9286.247kN and D=0.182m
The Performance point for diaphragm discontinuity model i.e, V=5326.853kN and D=0.627m
The Performance point for Y-shaped model i.e,. V=4354.397kN and D=0.122m
Where V- base shear and D – displacement

1.5.4. Pushover curve using ETABS:

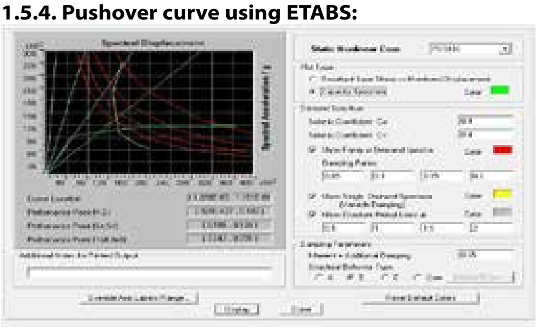


Fig no. 1.8(a) Performance points for rectangular model

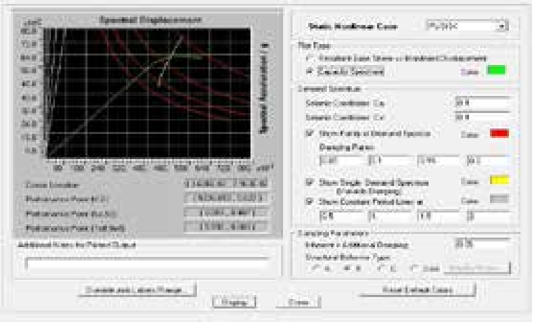


Fig no. 1.8(b) Performance points for diaphragm discontinuity model

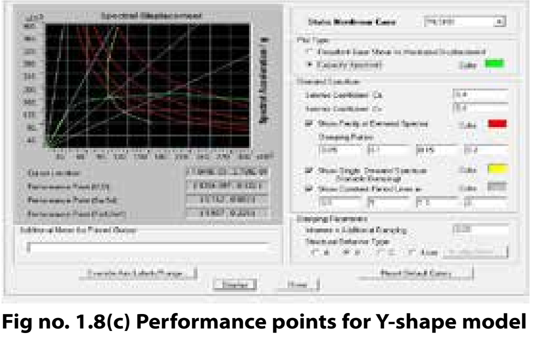


Fig no. 1.8(c) Performance points for Y-shape model

1.5.4. Pushover curve using excel:

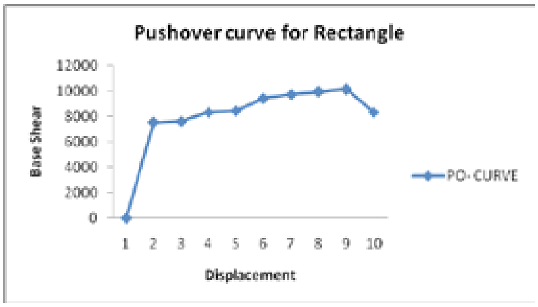


Fig no. 1.9(a) Pushover curve for G+9 storey rectangle building model

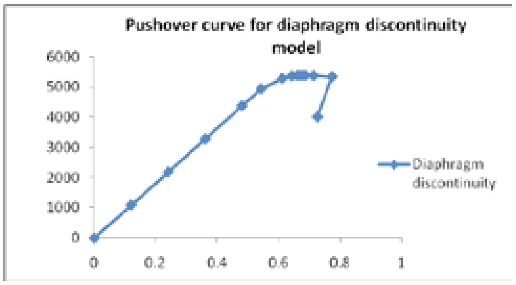


Fig no. 1.9(b) curve for G+9 storey diaphragm discontinuity building model

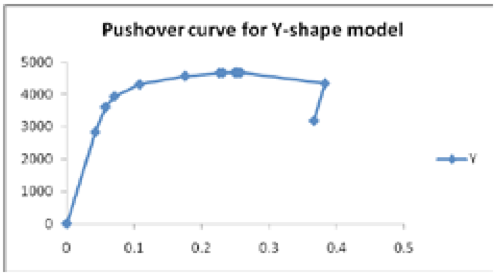


Fig no. 1.9(c) curve for G+9 storey Y-shape building model

1.5.5. Pushover curve using ETABS:

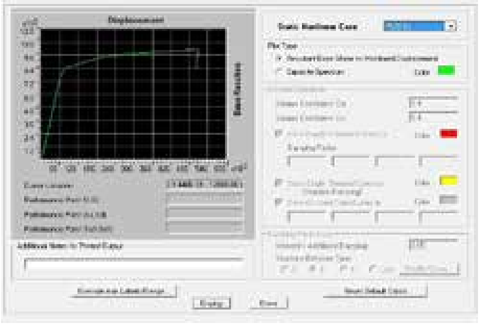


Fig no 1.10(a) curve for G+9 storey rectangular building model

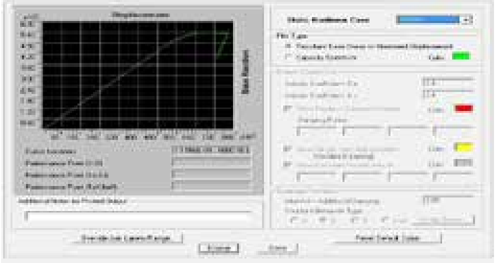


Fig no 1.10(b) curve for G+9 storey diaphragm discontinuity building model

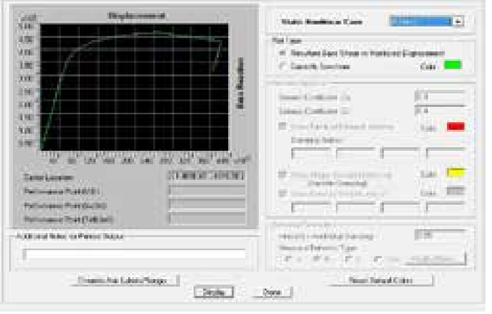


Fig no 1.10(c) curve for G+9 storey Y-shape building model

1.5.5. Performance points

Table no6: performance level for Rectangle shaped building in longitudinal direction push X

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	3.25E-05	0.0000	4297	43	0	0	0	0	0	0	4340
1	0.599	7497.4873	4072	268	0	0	0	0	0	0	4340
2	0.607	7588.2451	3833	507	0	0	0	0	0	0	4340
3	0.0745	8328.8193	3700	640	0	0	0	0	0	0	4340
4	0.0809	8445.6484	3496	387	457	0	0	0	0	0	4340
5	0.1978	9419.0352	3451	187	561	141	0	0	0	0	4340
6	0.2732	9703.5313	3451	0	224	665	0	0	0	0	4340
7	0.3936	9917.6240	3451	0	32	822	0	35	0	0	4340
8	0.5102	10124.8750	3451	0	32	790	0	0	67	0	4340
9	0.5023	8316.0156	4340	0	0	0	0	0	0	0	4340

Table no7 performance level for Diaphragm discontinuity shaped building in longitudinal Direction push X

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	3.25E-04	0.0000	4160	0	0	0	0	0	0	0	4160
1	0.1207	1095.0198	4160	0	0	0	0	0	0	0	4160
2	0.2411	2190.0396	4160	0	0	0	0	0	0	0	4160
3	0.3615	3285.0596	4160	0	0	0	0	0	0	0	4160
4	0.4819	4380.0796	4120	40	0	0	0	0	0	0	4160
5	0.5437	4942.0928	3939	141	80	0	0	0	0	0	4160
6	0.613	5292.4043	3869	171	120	0	0	0	0	0	4160
7	0.643	5367.5684	3845	160	131	24	0	0	0	0	4160
8	0.6599	5383.3159	3826	174	102	58	0	0	0	0	4160
9	0.6679	5386.7935	3820	174	86	80	0	0	0	0	4160
10	0.6787	5387.8091	3792	169	119	80	0	0	0	0	4160
11	0.6881	5387.9941	3758	168	133	101	0	0	0	0	4160
12	0.7139	5379.6504	3746	68	117	214	0	15	0	0	4160
13	0.7746	5346.6685	3746	68	116	180	0	4	0	46	4160
14	0.7265	4019.9426	4160	0	0	0	0	0	0	0	4160

Table no8 performance level for Y- shaped building in longitudinal direction push X

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	8.65E-05	0.0000	2893	7	0	0	0	0	0	0	2900
1	0.0424	2824.1929	2693	207	0	0	0	0	0	0	2900
2	0.0575	3599.1711	2574	326	0	0	0	0	0	0	2900
3	0.0708	3933.6577	2452	448	0	0	0	0	0	0	2900
4	0.1081	4301.6426	2357	295	248	0	0	0	0	0	2900
5	0.1756	4557.5435	2292	259	237	112	0	0	0	0	2900
6	0.2261	4654.7695	2283	259	231	127	0	0	0	0	2900
7	0.2315	4660.5894	2270	236	238	156	0	0	0	0	2900
8	0.2489	4669.2339	2266	240	233	161	0	0	0	0	2900
9	0.2506	4669.7524	2265	237	231	167	0	0	0	0	2900
10	0.2525	4669.8169	2258	240	228	174	0	0	0	0	2900
11	0.2554	4669.4995	2256	242	219	183	0	0	0	0	2900
12	0.2580	4665.3369	2239	147	143	365	0	6	0	0	2900
13	0.3828	4330.4067	2239	147	142	364	0	0	8	0	2900
14	0.3663	3178.1221	2900	0	0	0	0	0	0	0	2900

1.5.6. CONCLUSIONS:

1. The results obtained in terms of pushover demand, capacity spectrum and plastic hinges gave an insight into the real behaviour of structures.
2. The overall performance level for G+9 storey rectangular, diaphragm discontinuity and Y-shaped building models were found between LS-CP (life safety to collapse prevention). The hinge status and location has been determined and it is noted that most of the hinges begin to form in A-B range onwards.
3. The performance point is determined for G+9 storey rectangular,

diaphragm discontinuity and Y-shaped building models in PUSH X direction.

4. Base shear for rectangular model is greater than diaphragm discontinuity and Y-shaped models. Increase in mass of rectangular building tends to increase in base shear.
5. Point displacement is greater for diaphragm discontinuity model as there is an opening in the centre for that model.
6. Thus finally we can conclude that among the considered three models rectangular model is most vulnerable to seismic effect rather than other two models.

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