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Pushover Analaysis of Irregular Tall RCC Structures

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Abstract

The paper is based on the study of the Response of Irregular Plan Tall RCC structures by Pushover Analysis in order to find the Base Shear, Pushover Curve, Performance limit, Shear force Diagrams, Bending Moment of the structure. Nonlinear Static Analysis, is also called as "pushover analysis", and is also regarded as the most widely used analysis method for estimation of performance of Irregular tall RCC structures. Most of the significant Seismic Codes which proposes methods for seismic analysis of new or existing tall RCC Structures have been originally defined for simple regular structures.

Therefore the analysis of the seismic response of irregular Tall RCC Structures is difficult due to nonlinear and inelastic response of the structures and more difficult than that of regular structures. Most of the codes (IS 1893 (Part 1) 2016[1], ATC-40 1996[2], EC8-1 2004[3]) uses the concept of "regularity", taking into account distribution of mass, stiffness and strength in the structures, both in plan and in elevation. But real structures seldom act in accordance with these regularity requirements, resulting in a narrowly dependable application of the basic non-linear static analysis.

For the study we are considering two G+19 storey T shaped and U shaped irregular tall framed RCC structures having height of 68 meters each and storey height of 3.3 meters. Pushover Analysis is carried out using shear walls at different locations in the structure. The objective of this study is to finds out which irregular plan tall structure is the most efficacious in resisting lateral loads. The software used for modelling and analysis is ETABS 2017.

Keywords: Seismic performance, Pushover Analysis, Shear Walls, Nonlinear Static Analysis, Irregularity.

1. Introduction

The irregularities in the structures are one of the main causes of damage under seismic action or seismic vibrations. Irregular structures often have lower performance than regular structures. In other words, irregular structures yields during a low intensity earthquake and requires large ductility demands during the moderate seismic motion. Previous earthquakes have shown us that structures with misconfiguration of structural properties are prone to increased seismic demand, cause greater damage to structures.

The geometrical asymmetrical is only a geometrical irregularity whereas the structural irregularity means that, the centre of mass of structure does not coincide with centre of rigidity. The eccentricity between the centre of mass and centre of rigidity cause torsion and stress concentration. This torsion developed due to unequally loaded structure. Due to torsion of the structure building rotate about its centre of rigidity. The sources of structural irregularities in a structure can be many and of different types and are generally categorised into two: plan irregularities and elevation irregularities. The first type is associated with in plan irregular mass distribution, stiffness distribution, strength distributions, which results in a significant increase of the torsional effects when the structure is subjected to lateral structural forces. The second one involves differences in geometrical and/or structural properties which mostly happens in height of the structure and this generally increases the magnitude of the earthquake in a particular story.

Both these types of violations are often associated with the development of fragile collapse mechanisms due to the local increase in seismic demand for special elements that do not always have sufficient strength and flexibility. Most seismic laws provide standard criteria for classifying structures into regular and irregular categories, including changes in the planning and altitude of mass and lateral stiffness (and related eccentricity), planning configuration, setting, stiffness of the planning floor (rigid diaphragm conditions)-continuity of the structural systems from the foundation to the top of the structure. This list does not include all possible causes for irregularity, and there is no definitions related to the level of equilibrium in the entire three-dimensional system. Code definitions [4] fail to capture some irregularities, especially those generated from the right combination of both plan and elevation irregularities.

In addition, system irregularity depends not only on the geometrical and structural properties of the building, but also on the characteristics of the seismic excitation and

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progressive damage to the structure. Given this scenario, it is an urgent need to define and measure structural irregularities with more rational approach, to deeply understand its effect on the seismic behaviour and consequently upgrade seismic codes with specific and effective prescriptions for irregular structures. Between the two types of structural irregularity, planar irregularities seems to have the most detrimental effects on the applicability of the Classical Nonlinear Static Analysis (NSA)[5], correctly because such methods have been developed for the seismic assessment of structures whose behaviour is mainly translational. This is because, in recent years, there has been a great deal of scrutiny by experts in the field about NSA's plans to expand the scope of irregular structures.

The Non-Linear Static Procedures or Pushover Analysis, is described in FEMA-273[6] and its developments is described in FEMA-356[7] is now widely used by the Structural Engineers in their profession as a standard tool for calculating the seismic demands for the structures.

The present study is based on the Pushover Analysis of the Irregular Tall Structures using ETABS-2017 software. The study consists of two Irregular Plan Tall Structures of U shape and T shape. Both the structures have same height of 68 m and same plan area of 283.5 m^2. The irregular plan structures are purposely selected because very few researches are done on irregular plan structures using pushover analysis. Both the structures selected have same site conditions and same beam, column and floor dimensions. Since the structure is a tall structure and seismic zone selected is Zone–IV as per IS 1893(Part-1):2016, shear walls are also provided at different locations to resist the lateral loads.

2. Structural Model of Buildings

Both the structures are framed structures and are modelled and designed on ETABS software. Plan and 3D view of the structures are shown in the following figures:-

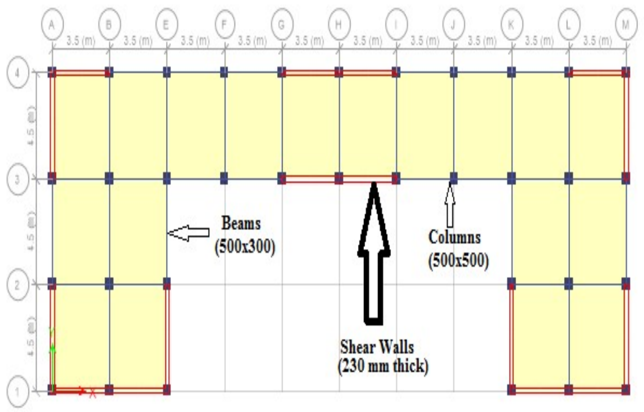

Fig.1. Plan of U Shape Structure

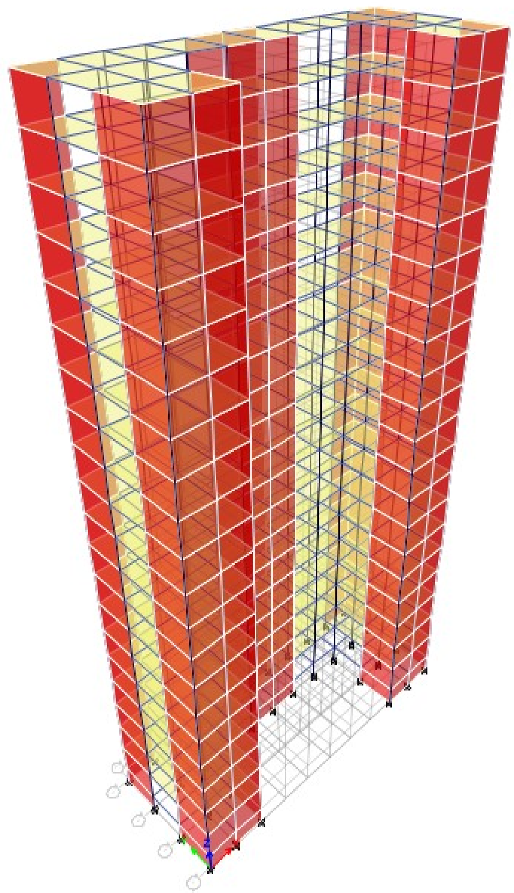

Fig.2. 3D View of U Shaped Structure

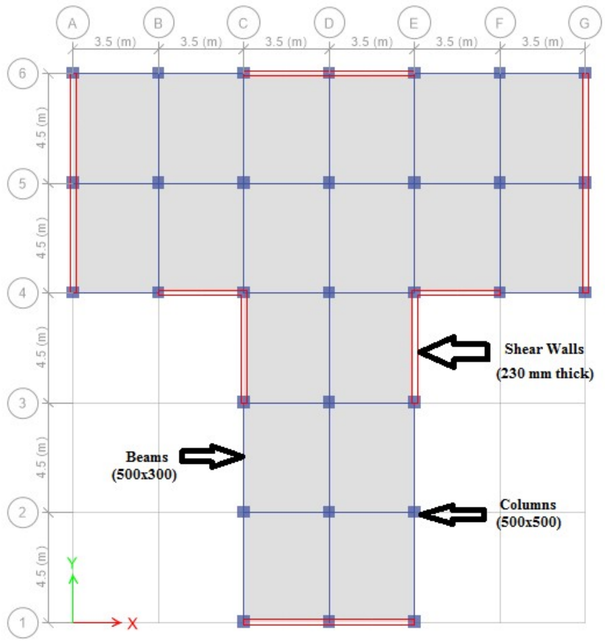

Fig.3. Plan of T Shape Structure

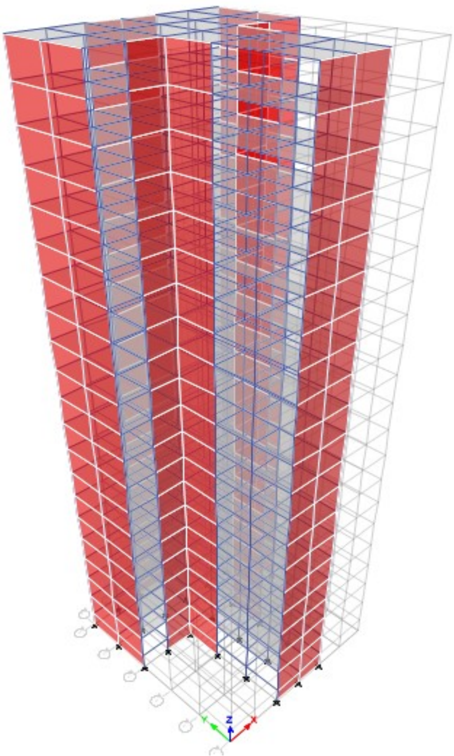

Fig.4. 3D View of T Shaped Structure

3. Results and Numerical Study

For numerical study variation in Storey lateral forces displacement and drift in both U & T shaped structure are presented due to pushover analysis.

Table1. Story Lateral Forces

Story	Elevation (m)	X & Y Direction (KN)	X & Y Direction (KN)
		U Shaped	T Shaped
Story19	68	394.6343	315.1496
Story18	64.7	436.7976	340.4525
Story17	61.4	393.3765	306.6088
Story16	58.1	352.2281	274.5366
Story15	54.8	313.3522	244.2356
Story14	51.5	276.7491	215.7061
Story13	48.2	242.4185	188.9479
Story12	44.9	210.3606	163.961
Story11	41.6	180.5753	140.7455
Story10	38.3	153.0627	119.3014
Story9	35	127.8226	99.6286
Story8	31.7	104.8553	81.7272
Story7	28.4	84.1605	65.5971
Story6	25.1	65.7384	51.2384
Story5	21.8	49.5889	38.651
Story4	18.5	35.7121	27.835
Story3	15.2	24.1079	18.7904
Story2	11.9	14.7763	11.5171
Story1	8.6	7.7174	6.0151
Ground Floor	5.3	3.1325	2.456
Plinth Level	2	0.2555	0.1922
Base	0	0	0

Table 2. Maximum Story Displacement for X Direction (For PUSH X Load)

Story	Elevation (m)	U Shape (mm)	T Shape (mm)
		At Top	At Top
Story19	68	39.367	43.692
Story18	64.7	37.574	41.692
Story17	61.4	35.728	39.678
Story16	58.1	33.848	37.63
Story15	54.8	31.898	35.767
Story14	51.5	29.876	33.874
Story13	48.2	27.784	31.86
Story12	44.9	25.625	29.724
Story11	41.6	23.408	27.47
Story10	38.3	21.145	25.108
Story9	35	18.849	22.648
Story8	31.7	16.538	20.11
Story7	28.4	14.232	17.516
Story6	25.1	11.955	14.9
Story5	21.8	9.738	12.295
Story4	18.5	7.615	9.749
Story3	15.2	5.627	7.316
Story2	11.9	3.828	5.068
Story1	8.6	2.282	3.09
Ground Floor	5.3	1.064	1.494
Plinth Level	2	0.265	0.59
Base	0	0	0

Table 3. Maximum Story Displacement for Y Direction (For PUSH Y Load)

Story	Elevation (m)	U Shape (mm)	T Shape (mm)
		At Top	At Top
Story19	68	37.623	48.542
Story18	64.7	36.036	46.233
Story17	61.4	34.311	43.933
Story16	58.1	32.524	41.565
Story15	54.8	30.678	39.117
Story14	51.5	28.767	36.59
Story13	48.2	26.789	33.988
Story12	44.9	24.745	31.313
Story11	41.6	22.64	28.574
Story10	38.3	20.484	25.784
Story9	35	18.288	22.958
Story8	31.7	16.069	20.119
Story7	28.4	13.849	17.293
Story6	25.1	11.652	14.512
Story5	21.8	9.51	11.813
Story4	18.5	7.458	9.242
Story3	15.2	5.54	6.848
Story2	11.9	3.804	4.69
Story1	8.6	2.303	2.829
Ground Floor	5.3	1.11	1.367
Plinth Level	2	0.229	0.531
Base	0	0	0

Table 4. Maximum Story Drift for X Direction (For PUSH X Load)

Story	Elevation (m)	U Shape	T Shape
		At Top	At Top
Story19	68	0.000602	0.000607
Story18	64.7	0.000605	0.000611
Story17	61.4	0.000612	0.000621
Story16	58.1	0.000621	0.000637
Story15	54.8	0.000631	0.000658
Story14	51.5	0.000641	0.000681
Story13	48.2	0.000657	0.000706
Story12	44.9	0.000673	0.000729
Story11	41.6	0.000687	0.000751
Story10	38.3	0.000696	0.000769
Story9	35	0.0007	0.000781
Story8	31.7	0.000699	0.000786
Story7	28.4	0.00069	0.000794
Story6	25.1	0.000672	0.000791
Story5	21.8	0.000643	0.000773
Story4	18.5	0.000602	0.000739
Story3	15.2	0.000546	0.000684
Story2	11.9	0.000472	0.000603
Story1	8.6	0.000374	0.000486
Ground Floor	5.3	0.00025	0.000343
Plinth Level	2	0.000132	0.000295
Base	0	0	0

Table 5. Maximum Story Drift for Y Direction (For PUSH X Load)

Story	Elevation (m)	U Direction	T Shape
		At Top	At Top
Story19	68	0.000021	0.000038
Story18	64.7	0.000018	0.000036
Story17	61.4	0.000016	0.000037
Story16	58.1	0.000014	0.000036
Story15	54.8	0.000014	0.000034
Story14	51.5	0.000016	0.000031
Story13	48.2	0.000022	0.000027
Story12	44.9	0.000032	0.000022
Story11	41.6	0.000042	0.000016
Story10	38.3	0.000052	0.00001
Story9	35	0.000061	0.000004
Story8	31.7	0.00007	0.000004
Story7	28.4	0.000076	0.00001
Story6	25.1	0.000081	0.000015
Story5	21.8	0.000083	0.00002
Story4	18.5	0.000081	0.000023
Story3	15.2	0.000076	0.000025
Story2	11.9	0.000068	0.000024
Story1	8.6	0.000055	0.000021
Ground Floor	5.3	0.000042	0.00003
Plinth Level	2	0.000043	0.000027
Base	0	0	0

Table 6. Maximum Story Drift for X Direction (For PUSH Y Load)

Story	Elevation (m)	U Shape	T Shape
		At Top	At Top
Story19	68	0.000006	0.000012
Story18	64.7	0.000004	0.000008
Story17	61.4	0.000003	0.000002
Story16	58.1	0.000003	0.000001
Story15	54.8	0.000003	3.368E-07
Story14	51.5	0.000004	3.445E-07
Story13	48.2	0.000004	3.519E-07
Story12	44.9	0.000005	3.649E-07
Story11	41.6	0.000005	4.091E-07
Story10	38.3	0.000006	4.458E-07
Story9	35	0.000007	4.783E-07
Story8	31.7	0.000008	0.000001
Story7	28.4	0.000009	0.000001
Story6	25.1	0.00001	0.000001
Story5	21.8	0.000012	0.000001
Story4	18.5	0.000012	0.000001
Story3	15.2	0.000013	0.000003
Story2	11.9	0.000013	0.000004
Story1	8.6	0.000012	0.000004
Ground Floor	5.3	0.000011	0.000014
Plinth Level	2	0.000029	0.000026
Base	0	0	0

Table 7. Maximum Story Drift for Y Direction (For PUSH Y Load)

Story	Elevation (m)	U Shape	T Shape
		At Top	At Top
Story19	68	0.000516	0.000702
Story18	64.7	0.000525	0.00071
Story17	61.4	0.000542	0.000724
Story16	58.1	0.000559	0.000744
Story15	54.8	0.000579	0.000766
Story14	51.5	0.0006	0.000789
Story13	48.2	0.000619	0.000811
Story12	44.9	0.000638	0.000831
Story11	41.6	0.000654	0.000847
Story10	38.3	0.000665	0.000858
Story9	35	0.000672	0.000863
Story8	31.7	0.000673	0.000859
Story7	28.4	0.000666	0.000846
Story6	25.1	0.00065	0.000821
Story5	21.8	0.000623	0.000782
Story4	18.5	0.000582	0.000728
Story3	15.2	0.000527	0.000656
Story2	11.9	0.000455	0.000564
Story1	8.6	0.000361	0.000447
Ground Floor	5.3	0.000267	0.000309
Plinth Level	2	0.000114	0.000265
Base	0	0	0

Fig.5 Graph Showing Pushover Curve-Base Shear vs Monitored Displacement for U Shaped Structure For PUSH X Load in X-direction

Table 8. Hinges Position after the PUSH X Load in the X-direction for U Shaped Structure

Step	Displacement (mm)	Base Force(KN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
0	0	0	5796	0	0	0	0	5796	0	0	0	5796
1	32.267	4541.3675	5788	8	0	0	0	5796	0	0	0	5796
2	37.625	5290.4872	5764	28	4	0	0	5792	0	0	4	5796

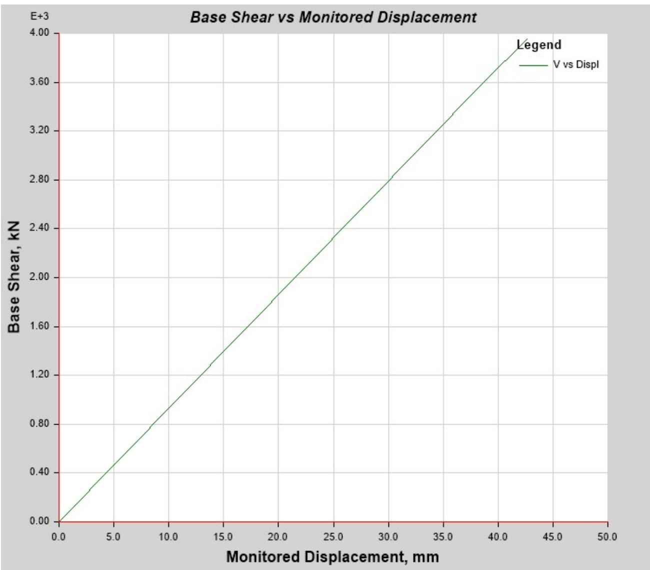

Fig.6 Graph Showing Pushover Curve-Base Shear vs Monitored Displacement for T Shaped Structure For PUSH X Load in X-direction

Table 9. Hinges Position after the PUSH X Load in the X-direction for T Shaped Structure

Step	Displacement (mm)	Base Force (KN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
0	0	0	5460	0	0	0	0	5460	0	0	0	5460
1	38.676	3594.1634	5456	4	0	0	0	5460	0	0	0	5460
2	42.601	3955.5328	5448	12	0	0	0	5460	0	0	0	5460

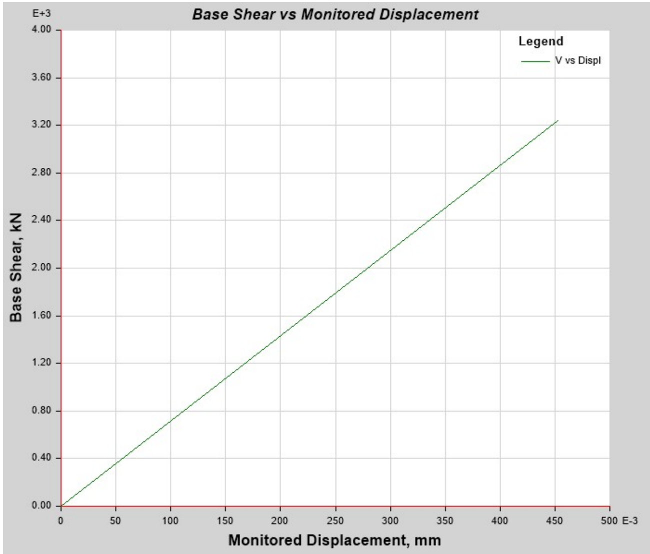

Fig.7 Graph Showing Pushover Curve-Base Shear vs Monitored Displacement for U Shaped Structure For PUSH Y Load in Y-direction

Fig.8 Graph Showing Pushover Curve-Base Shear vs Monitored Displacement for T Shaped Structure For PUSH Y Load in Y-direction

Table 10. Hinges Position after the PUSH Y Load in the Y-direction for U Shaped Structure

Step	Displacement (mm)	Base Force (KN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
0	0	0	5796	0	0	0	0	5796	0	0	0	5796
1	0.453	3240.8155	5788	8	0	0	0	5796	0	0	0	5796
2	0.453	3240.8871	5788	0	8	0	0	5788	0	0	8	5796

Table 11. Hinges Position after the PUSH Y Load in the Y-direction for T Shaped Structure

Step	Displacement (mm)	Base Force (KN)	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
0	0	0	5460	0	0	0	0	5460	0	0	0	5460
1	-0.005	3910.7116	5456	4	0	0	0	5460	0	0	0	5460
2	-0.007	4973.9939	5420	40	0	0	0	5460	0	0	0	5460
3	-0.007	4973.9939	5420	40	0	0	0	5460	0	0	0	5460
4	-0.007	4973.9939	5420	40	0	0	0	5460	0	0	0	5460

3.1 Discussions about tables

1. The Table 1 shows Story Lateral forces i.e. with the increase in the height of the structure lateral forces which are acting on the structures is also increasing .On comparing the story lateral forces of both the structures, value of lateral forces acting on the U shaped structure is more than T Shaped structure, instead of the same plan area, same site and building conditions.
2. The Table 2 shows Maximum Story Displacement for the X-Direction for the PUSH X load case for both U & T shaped structure. This PUSH X load case is considered for the maximum displacement in the X-Direction. For this case U Shaped structure shows less displacement for each story than the T Shaped structure.
3. The Table 3 shows Maximum Story Displacement for the Y-Direction for the PUSH Y load case for both U & T shaped structure. This PUSH Y load case is considered for the maximum displacement in the Y-Direction. For this case U Shaped structure shows less displacement for each story than the T Shaped structure.
4. The Table 4 shows Maximum Story Drift for the U & T Shaped structure. The Story Drift is shown for the PUSH X load case in the X direction. This PUSH X load case is considered for the maximum story drift in the X-Direction. On comparing the results we found that maximum story drift for the U Shaped structure is less than the T Shaped structure.
5. The Table 5 shows Maximum Story Drift for the U & T Shaped structure. The Story Drift is shown for the PUSH X load case in the Y direction. This PUSH X load case is considered for the maximum story drift in the X-Direction. On comparing the results we found that maximum story drift for the T Shaped structure is more in the X-Direction as compared to the U Shaped structure. Whereas for the Y-Direction the story drift for the T shaped structure is more up to story 13, after that its value decreases in comparison to U Shaped structure.
6. The Table 6 shows Maximum Story Drift for the U & T Shaped structure. The Story Drift is shown for the PUSH Y load case in the X direction. This PUSH Y load case is considered for the maximum story drift in the X-Direction. On comparing the results we found that maximum story drift for the U Shaped structure is more than the T Shaped structure except for Story 19 & 18.
7. The Table 7 shows Maximum Story Drift for U & T Shaped structure. The Story Drift is shown for the PUSH Y load case in the X direction. This PUSH Y load case is considered for the maximum story drift in the X-Direction. On comparing the results we found that maximum story drift for the T Shaped structure is more than the U Shaped structure.
8. Pushover analysis was carried out separately in the X and Y directions for both the structures. The resulting pushover curves, in terms of Base Shear-Monitored Displacement, given for X and Y separately in both the PUSH X and PUSH Y zones.
9. From the results obtained in the PUSH X and PUSH Y case of the U Shaped structure there are elements exceeding the limit levels between life safety (LS) and collapse prevention (CP) due to more load carrying capacity and more lateral loads. This means that building requires retrofitting at extreme failure. This condition is not found in the T Shaped structure as no elements of the T Shaped structure not exceed the limit levels of LS-CP due to low values of lateral loads to the structure.

4. Conclusions

The Pushover Analysis is being carried out and the results and data obtained from it is evaluated for the Irregular Tall Structures of T& U Shaped structure with the help of ETABS 2017 software for Building Analysis and Design. The seismic performance in terms of responses of Irregular Structures is studied with the help of two U & T shaped structures. The seismic performance of both the structures is studied by comparing results story lateral forces, maximum story displacements and maximum story drift of both U & T shaped structure in X & Y direction for both PUSH X and PUSH Y load case. On comparing the story lateral forces U Shape structure is carrying more load than the T Shaped structure. So U Shaped structure is better in load carrying capacity. For the maximum story displacement U Shaped structure performs well than the T Shaped structure. For the maximum story drift U Shaped structure shows less value than T Shaped structure in the both X & Y direction. In the PUSH X and PUSH Y load case U Shaped structure fails in the extreme condition and will not fail if retrofitted. Hence, U Shaped Irregular Tall Structure performs well in performance parameters using Pushover Analysis than the T Shaped Irregular Tall Structure.

Disclosures

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