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A Study & Pushover Analysis of RC Frame Buildings with Short leg shear wall

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Abstract*— Now-a-days, there is an incremental demand of high rise residential & commercial buildings because of under-supply of land. So, high rise buildings become first choice to developers & consumers looking for more tall & slender structures. In this case, designers are going to take lateral loads like wind loads & earthquake (trembling) loads etc., the increasing effect of creative loads are attaining importance & every designer was facing with a problem to provide adequate strength & stability to tall buildings. Attention is now being given to the judgment of the adequacy of strength in Reinforced Concrete (RC) framed structures to resist strapping ground motions. Further with more understanding of structural behaviour at micro level/element level the concept of "capacity design" was introduced & this enforced to decide the required recital of the structure right at the design stage itself. The NON LINEAR STAGNANT ANALYSIS (PUSHOVER ANALYSIS) is gaining recognition for this function. In the pushover examination, non linear finite element model of structure (eg: a building frame) subjected to gravity loads is tangentially loaded until either a predefined target disarticulation is met. The procedure for developing vulnerability or fragility curves and the damage probability indicates for buildings are discussed using probabilistic approach. For this purpose, RC FRAMES and SHORT LEG SHEAR WALLS are initially analysed and designed using ETABS v 13.2.2-FINITE ELEMENT SOFTWARE, under the combination of gravity loading and seismic loading for a particular seismic zone.

***Keywords*— ETABS v 13.2.2, Pushover methodology, short leg shear wall, comparison of pushover results with ESA &RSAmethods&models.**

I INTRODUCTION

T With the huge loss of existence & property witnessed in the last two of decades only in India due to failure of structures caused by earthquakes attention is now being given to the assessment of the adequacy of strength in framed Reinforced Concrete (RC) structures to resist strong ground movements. Hence the result of considering earthquake forces in the design process is realized & seismic resistant design became a practice. The short leg shear wall structure system eliminates material wasting caused by shear wall with too long wall limb and avoids potential safety hazard from shear wall with too short wall limb. This system will unitize and formulate the planar structure types. It makes the construction convenient and other basic components size uniform, forms the modular structure design and construction and enhances economic benefits of production. The exterior wall of shear wall's thickness is commonly 250mm or 200 mm the same as that of infill wall, the thickness of interior wall and fill wall are basically the same. The exterior wall of shear wall's thickness is commonly 250mm or 200 mm the same as that of infill wall, the thickness of interior wall and fill wall are basically the same. Shear wall has little extruding edges or corners that not only assurance the building function in order & perfect but also helps in architectural layout. Comparing with ordinary over long shear wall, it has both the excellent lateral rigidity of shear wall and the characteristic off frame flexible spatial arrangement and full space use .comparing with frame shear wall structure short leg shear wall structure overcame the negative effects to building layout of extruding edge. The primary advantage of pushover analysis is to obtain a measure of over strength and to obtain a sense of the general capacity of the structure to maintain in-elastic deformation. The loads acting on the structures are put in together from slabs, beams, columns, walls, ceilings & finishes. Then they are calculated by conventional methods according to IS 456 – 2000 & are applied as gravitational loads combination with live loads as per IS 875 (Part II) in the structural replica. The lateral loads & their vertical distribution on each floor level are determined as per IS 1893 – 2002.

II **ETABS v 13.2.2**

A As computers & computer interfaces evolved, ETABS added computationally complex analytical alternatives such as dynamic non-linear behavior & powerful CAD-like drawing tools in a graphical and object-based interface. The following topics describe some of the important areas in the modeling using ETABS.

Figure 2.1 shows one storey symmetrical frame with a span of 5m and storey height of 3.5m. The beam is subjected to a UDL of 50kN/m. The parameters considered in the analysis are as follows.

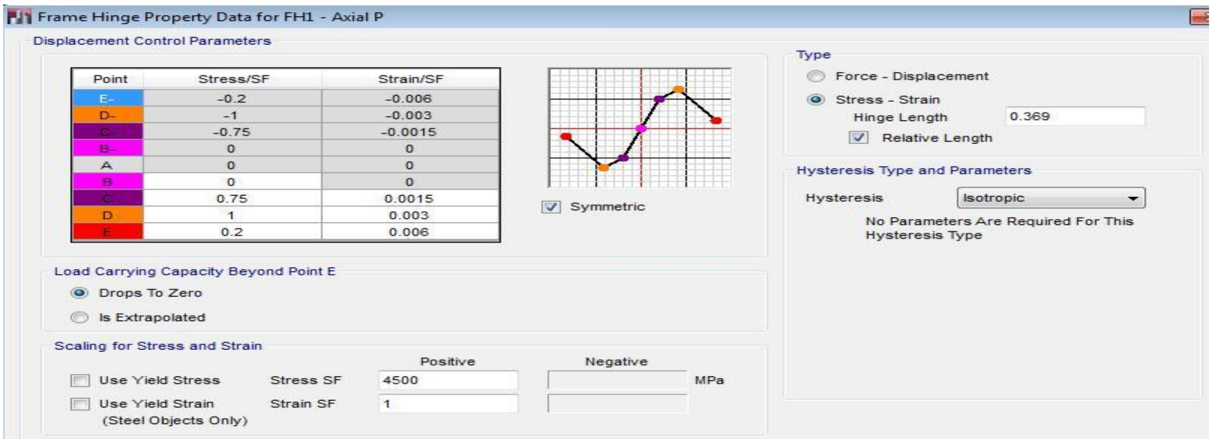
Size of beam – 230 mm x 450 mm
Grade of concrete – M-25
Size of columns – 400 mm x 400 mm
Grade of steel – Fe-415

Table I Comparison of SF & BM

S no.	Description	Node no.	Result from ETABS	Result from STAAD.PRO
1.	Moment (KN-m)	1	60.86	60.81
		2	126.59	126.32
		3	126.59	126.32
		4	60.86	60.81
2.	Shear force (KN)	2	197.20	196.65
		3	197.20	196.65

Table II Comparison of lateral force and storey shear distribution

Storey Level	Lateral force distribution (KN)		Storey shear distribution (KN)	
	Pankaj and Manish (2006)	Present study (ETABS)	Pankaj and Manish (2006)	Present study (ETABS)
4	39.65	39.46	39.65	39.27
3	38.75	38.70	78.40	77.85
2	17.22	17.13	95.62	94.99
1	4.31	4.34	99.93	99.28



Frame Hinge Property Data for FH1 - Axial P

Displacement Control Parameters

Point	Stress/SF	Strain/SF
E-	-0.2	-0.006
D-	-1	-0.003
C-	-0.75	-0.0015
B-	0	0
A	0	0
B	0	0
C	0.75	0.0015
D	1	0.003
E	0.2	0.006

☑ Symmetric

Load Carrying Capacity Beyond Point E
● Drops To Zero
○ Is Extrapolated

Scaling for Stress and Strain

		Positive	Negative	
☐ Use Yield Stress	Stress SF	4500		MPa
☐ Use Yield Strain (Steel Objects Only)	Strain SF	1		

Type
○ Force - Displacement
● Stress - Strain
Hinge Length 0.369
☑ Relative Length

Hysteresis Type and Parameters
Hysteresis Isotropic
No Parameters Are Required For This Hysteresis Type

Fig.1

III PUSHOVER METHODOLOGY

Necessity of Non-Linear Static Pushover Analysis (NLSA): The existing building will become seismically deficient because seismic design code requirements are continuously upgrading & advancement in engineering prospect. Further Indian buildings are built over last two decades which are seismically deficient for the reason that lack of awareness regarding on the seismic behaviour of structure. The extensive damage particularly to RC (Reinforced Concrete) buildings during earthquakes exposed. A graph for the total base shear versus top displacement in a structure is obtained by this analysis that may be indicating any premature failure. The analysis is administered up to the failure so it allows determination of collapse load & ductility capability. On a building frame & plastic rotation are monitored & lateral in-elastic forces versus displacement response for the complete structure is analytically computed. Idealized pushover curve with salient features In general, it is the method of analysis by applying nominative pattern of direct lateral loads on the structure, ranging from zero (0) to a value corresponding to a selected displacement level & identifying the attainable weak points & failure patterns of a structure. Under incrementally rising loads different structural elements may yield consecutively. Consequently at every event the structure experiences a loss in stiffness.

The techniques adopt the lumped plasticity advance, identifying the extent of inelasticity through the formation of nonlinear plastic hinges assigned at the ends of the frame rudiments while the increasing order loading is applied. In other words, determining a desired structural response that convinces both global level & local level (i.e. element level) response is needed.

Methodology of Performance Based Analysis:

Performance based seismic analysis requires that the engineer should complete the tasks indicated in the flowchart shown in Fig 2.

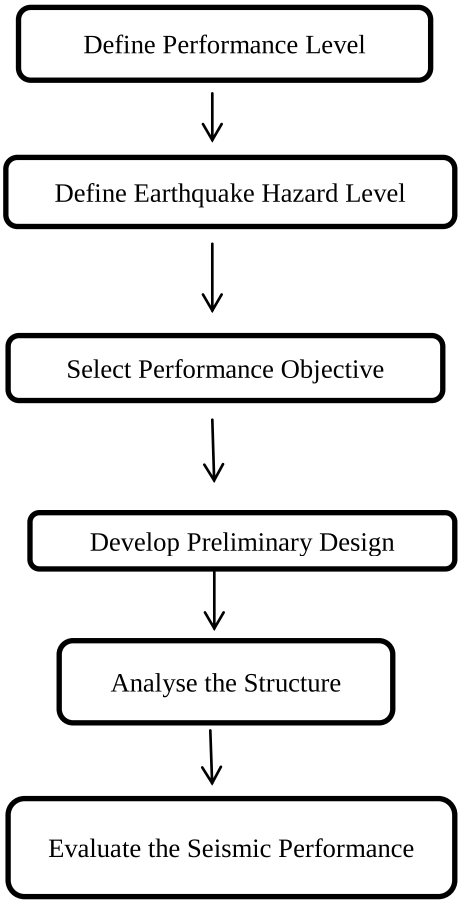


Fig 2

Performance Levels and Ranges

The building performance level is a function of the post-event conditions of the structural and non-structural components of the structure. The performance levels as per FEMA 356 are described below and are also shown in Fig 3

a) Immediate Occupancy (IO)

b) Life Safety (LS)

c) Collapse Prevention (CP)

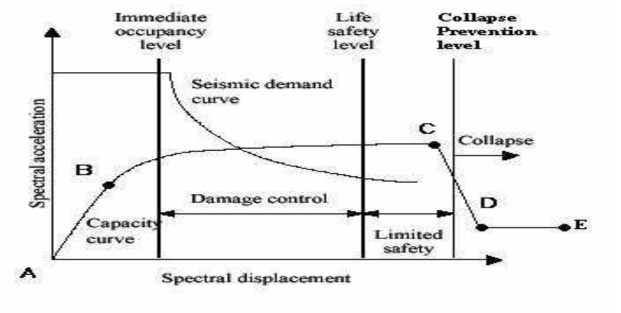
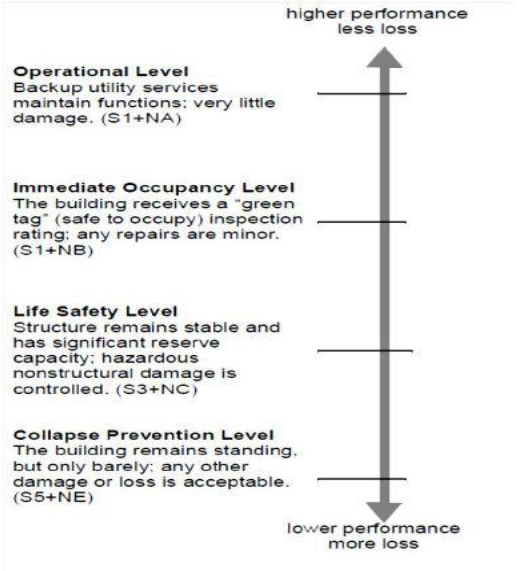


Fig. 3 Force-deformation relationship for a pushover hinge

Building performance level: The combination of a Structural Performance Level and a Nonstructural Performance Level to form a complete description of an overall damage level.



Operational Level
Backup utility services maintain functions; very little damage. (S1+NA)

Immediate Occupancy Level
The building receives a "green tag" (safe to occupy) inspection rating; any repairs are minor. (S1+NB)

Life Safety Level
Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled. (S3+NC)

Collapse Prevention Level
The building remains standing, but only barely; any other damage or loss is acceptable. (S5+NE)

Fig 4 Building Performance Levels (ATC, 1997a)

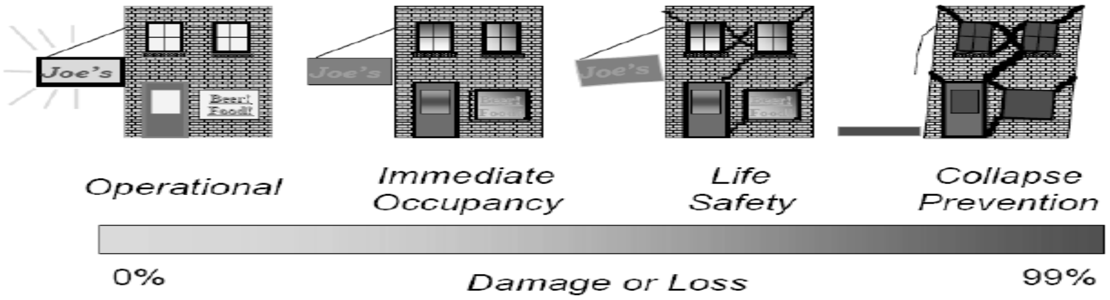


Fig. 5 Building Performance Levels

Table III Building Performance levels (FEMA 356)

Non-structural Performance Levels	**SP – 1 Immediate Occupancy**	**SP – 2 Damage Control**	**SP – 3 Life Safety**	**SP – 4 Limited Safety**	**SP – 5 Collapse Prevention**	**SP – 6 Not Considered**
N – A Operational	1 – A Operational	2 – A	NR	NR	NR	NR
N – B Immediate Occupancy	1 – B Immediate Occupancy	2 – B	3 – B	NR	NR	NR
N – C Life Safety	1 – C	2 – C	3 – C Life Safety	4 – C	5 – C	6 – C
N – D Hazards Reduced	NR	2 – D	3 – D	4 – D	5 – D	6 – D
N – E Not Considered	NR	NR	3 – E	4 – E	5 – E Collapse Prevention	No Rehabilitation

III **SHORT LEG SHEAR WALL**

It not only provides better economic benefits and competences but also easily realizes to save energy. At present, these advantages make this type of structure system popular in many countries. It is liked by the builder and possesses expansive prospect. Since the concept of short leg shear wall structure is relatively new, the method of planning and analysis of mechanical model for short-leg shear wall is not perfect and short of detailed documentation. These problems are being solved at present. The design of short-leg shear wall structure mainly refers to have bearing on stipulating of specially shaped columns. In recent years, the short leg shear wall structural system is being extensively applied in many structures. This structure is used in tall buildings, which need analyzing their response to seldom occurred earthquake by elasto plastic time-history analysis or nonlinear static analysis (or pushover analysis) method. To strengthen the structure integrity, form a whole space structure using structural component to resist lateral force, reinforce the connection of vertical component, try to make coupling beam between the combined shear walls and, in some cases, such as those influenced by structure layout, set proportion by the grade of anti-seismic. Increase in the depth–thickness ratio of wall limb can greatly improve the structure bearing capacity; greater stiffness coupling beams with small span-to-depth ratio have the higher capacity. One can form a tube using short-leg shear wall to strengthen structure rigidity, forming the short-leg shear wall–tube structure.

It should control axial compression ratio of short-leg shear wall, reinforcement ratio of longitudinal reinforcement and the volumetric percentage of stirrups ,to meet requirements of calculation and the standard. 5.5 COMPARISON OF SHORT LEG SHEARWALL WITH CONVENTIONAL SHEAR WALLS Its functional structure is more in line with construction needs compared with a frame structure.

COMPARISON OF SHORT LEG SHEARWALL WITH CONVENTIONAL SHEAR WALLS

1) Its functional structure is more in line with construction needs compared with a frame structure.
2) The wall is short, has flexible layout, can be adjusted, easy to satisfy the requirements of building plane.
3) The weight of the structure is reduced. Accordingly it reduces the overall stiffness of the structure, increasing the vibration cycle so that it reduces the seismic force.
4) Its lateral resistance ability meets the standards for use at higher altitudes better than a specially shaped column frame.

In addition, the short-leg shear wall structure is conducive to energy conservation; it can more easily handle changes in the layout than a general shear wall.

PERFORMANCE OF SHORT LEG SHEAR WALL IN PLAN SYMMETRICAL BUILDINGS

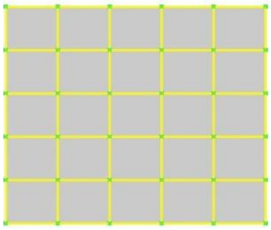
In this study eight models are considered. All the models have the same plan dimensions of 25m x 25m with 5 bays in each direction.Three different heights (five, ten and twenty stories) are considered in each model. These represent low-rise, medium-rise and high-rise structures.

Table IV Description of models

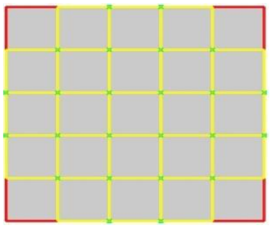
MODEL	MODEL DESCRIPTION
Model 1	*R.C. BARE FRAME*
Model 2	*R.C. FRAME WITH SHEAR WALL AT CORNERS*
Model 3	*R.C. FRAME WITH SHORT LEG SHEAR WALL AT CORNERS. THE COUPLING BEAM IS MODELLED AS FRAME ELEMENT (BEAM TYPE)*
Model 4	*R.C. FRAME WITH SHORT LEG SHEAR WALL AT CORNERS. THE COUPLING BEAM IS MODELLED AS SHELL ELEMENT (SPANRDEL TYPE)*
Model 5	*R.C. FRAME WITH OUTER PERIPHERY MASONRY WALL*
Model 6	*R.C. FRAME WITH SHEAR WALL AT CORNERS AND OUTER PERIPHERY MASONRY WALL*
Model 7	*R.C. FRAME WITH SHORT LEG SHEAR WALL AT CORNERS (**COUPLING BEAM-BEAM TYPE**) AND OUTER PERIPHERY MASONRY WALL*
Model 8	*R.C. FRAME WITH SHORT LEG SHEAR WALL AT CORNERS (**COUPLING BEAM - SPANRDEL TYPE**) AND OUTER PERIPHERY MASONRY WALL*

Table V Building parameters considered for models

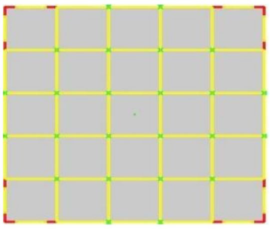
PARAMETER	TYPE / VALUE
Number of Stories	5- Storey, 10- Storey and 20-Storey
Typical Storey Height	3.2 m
Initial grid size	25 m x 25 m
Bay width in both directions	5 m
Grade of Concrete	M40 – for Beams, Walls and Columns M25 – for Roof Slabs
Grade of Reinforcing Steel	Fe–500-for Beams, Walls and Columns Fe–415- for Roof Slabs
Beam sizes	0.2 m x 0.45 m (5 - Storey) 0.3 m x 0.6 m (10 - and 20 - Stories)
Coupling Beam sizes	0.2 m x 0.6 m (5 - Storey) 0.2 m x 0.75 m (10 - and 20 - Stories)
Column sizes	0.4 m x 0.4 m (5 - Storey) 0.5 m x 0.5 m (10 - Storey) 0.7 m x 0.7 m (20 - Storey)
Thickness of Slab	0.150 m
Thickness of Shear Wall	0.2 m
Thickness of Brick Masonry Wall	0.23 m
Floor finishes	1 KN/m^2
Live Load on all Floors	3.5 KN/m^2
Live Load on Roof Slab	1.5 KN/m^2
Wall Load on Beams	13 KN/m
Parapet Wall Load	7 KN/m
Seismic Zone and Zone factor (Z)	a) Zone 2, Z= 0.10 b) Zone 3, Z= 0.16 c) Zone 4, Z= 0.24 d) Zone 5, Z= 0.36
Importance Factor "I"	1.0
Response Reduction Factor "R"	a) 3.0 (for Zone 2) b) 5.0 (for Zones 3,4 and 5)
Soil Type	a) Type I (Hard rock) b) Type II (Medium stiff) c) Type III (Soft soil)



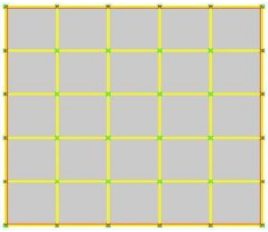
MODEL I



MODEL II



MODEL III



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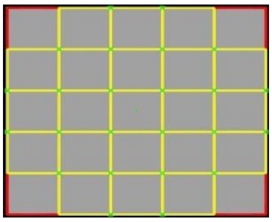
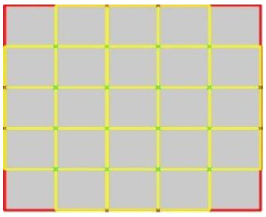
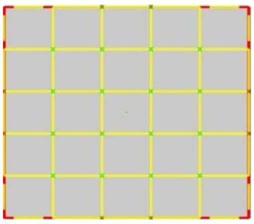


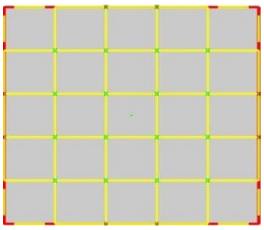
MODEL V



MODEL VI



MODEL VII



MODEL VIII

RESULTS:

Table VI Analysis results of base shear and performance point - Type 1 Soil for 5 storey models

Model No.	Base Shear (KN)				Ratio $\left(\frac{Vpo}{Ve}\right)$	Displacement at maximum Base Shear (mm)	Performance Point			
	ESA (V_e)	RSA (V_r)	Scale Factor	Pushover (V_{po})			V (KN)	D (mm)	Sa (g)	S_d (mm)
1	1613	648.02	4070	3725.56	2.309	278.79	2537.02	51.6	0.052	41.2
2	1655	1780.50	1635	6955.60	4.203	12.68	6952.61	12.3	0.152	8.7
3	1643	776.38	3455	3408.85	2.075	60.43	2813.87	36.9	0.062	26
4	1589	1300.30	1999	5242.16	3.299	25.31	4387.05	16.3	0.097	11.8
5	2550	886.09	4706	4993.49	1.958	60.51	3990.50	32.3	0.074	26.7
6	2562	1902.30	2203	8444.35	3.296	12.45	8217.60	11.3	0.172	8.1
7	2544	916.59	4538	4224.23	1.660	29.60	3885.57	25	0.079	18.5
8	2463	1491.08	2703	7331.82	2.977	20.69	6251.28	15.4	0.131	11.4

Table VII Analysis results of base shear and performance point - Type 2 Soil for 5 storey models

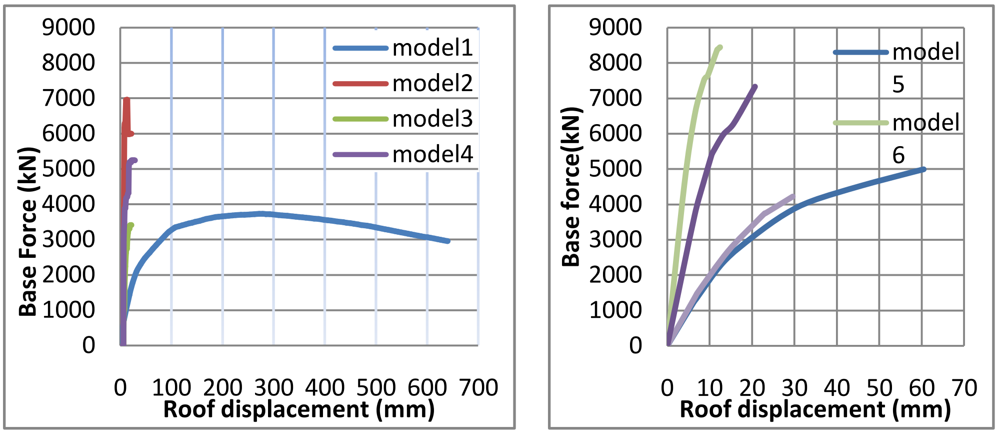
Model No.	Base Shear (KN)				Ratio $\left(\frac{Vpo}{Ve}\right)$	Displacement at max Base Shear (mm)	Performance Point			
	ESA (Ve)	RSA (Vr)	Scale factor	Pushover (Vpo)			V (kN)	D (mm)	Sa (g)	Sd (mm)
1	2193	849.44	4220	3738.13	1.705	281.46	2536.59	51.6	0.052	41.2
2	2251	1823.79	2019	6955.60	3.09	12.68	6952.61	12.3	0.152	8.7
3	2235	984.49	3714	3414.45	1.528	60.87	2813.87	36.9	0.062	26
4	2161	1751.95	2018	5242.16	2.426	25.31	4387.06	16.3	0.097	11.8
5	2550	1177.55	3543	4993.49	1.958	60.51	3990.55	32.3	0.075	26.7
6	2562	1902.32	2203	8444.36	3.296	12.45	8217.62	11.3	0.172	8.1
7	2544	1194.24	3484	4224.22	1.660	29.60	3885.57	25	0.079	18.5
8	2463	1919.15	2099	7331.82	2.98	20.69	6251.29	15.4	0.131	11.4

Table VIII Analysis results of base shear and performance point - Type 3 Soil for 5 storey models

Model No.	Base Shear (KN)				Ratio	Displacement at maximum Base Shear (mm)	Performance Point			
	ESA (Ve)	RSA (Vr)	Scale factor	Pushover (Vpo)	$\left(\frac{Vpo}{Ve}\right)$		V (KN)	D (mm)	Sa (g)	Sd (mm)
1	2419	1023.25	3866	3738.13	1.545	281.46	2536.59	51.6	0.052	41.2
2	2491	1829.85	2227	6942.43	2.787	12.58	6941.24	12.3	0.151	8.7
3	2466	1172.26	3441	3414.45	1.385	60.87	2813.87	36.9	0.062	26
4	2384	1828.46	2133	5241.93	2.199	25.31	4387.05	16.3	0.097	11.8
5	2550	1432.24	2912	4993.49	1.958	60.51	3990.55	32.3	0.074	26.7
6	2569	1908.36	2202	8428.64	3.281	12.45	8211.18	11.3	0.172	8.2
7	2544	1466.54	2838	4224.23	1.660	29.60	3885.57	25	0.079	18.5
8	2463	1919.15	2099	7331.82	2.977	20.69	6251.28	15.4	0.131	11.4

Pushover Curve Variation for 5 - Storey Models in Zone 2 Type1 Soil

The pushover curves obtained by plotting roof displacement v/s base shear for different models are shown in Figs. 5



a) Without Infill

b) With Infill

Fig. 5 Pushover curves for 5 - storey models

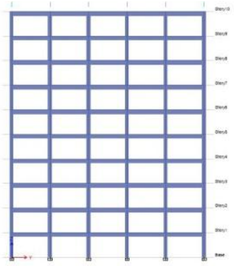
PUSHOVER ANALYSIS OF ELEVATION ASYMMETRIC BUILDINGS

Type-2 (medium stiff) soil is considered for the analysis. Different types of elevation asymmetric buildings are considered in the study. All the buildings are of 10 stories. The plan in the first four stories are symmetric and identical in all the models. The buildings are made asymmetric in elevation by changing the plans in two stages.

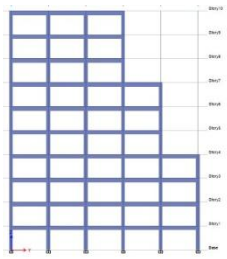
The first change in plan is made from fifth to seventh storey, and the second change in plan is made from eighth to tenth storey. The different plans used in this chapter include the overlapping square shape, L shape, U shape and T shape. These elevation asymmetric models are compared with RC frame model which constitute symmetry in both plan and elevation.

Table IX Description of Models

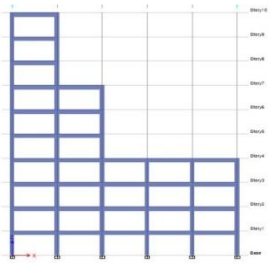
MODEL	MODEL DESCRIPTION
Model 1	*R.C. FRAME HAVING SYMMETRY IN BOTH PLAN AND ELEVATION*
Model 13	*R.C. FRAME HAVING ASYMMETRY IN ELEVATION WITH OVERLAPPING SQUARE SHAPE AT TOP*
Model 14	*R.C. FRAME HAVING ASYMMETRY IN ELEVATION WITH L SHAPE AT TOP*
Model 15	*R.C. FRAME HAVING ASYMMETRY IN ELEVATION WITH U SHAPE AT TOP*
Model 16	*R.C. FRAME HAVING ASYMMETRY IN ELEVATION WITH T SHAPE AT TOP*



MODEL 1



MODEL 13



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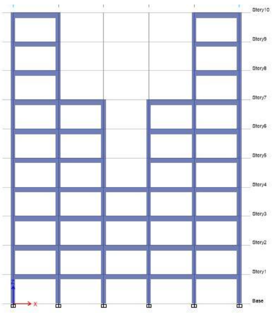
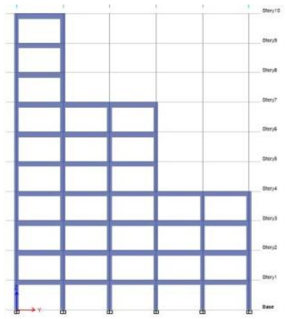


MODEL 15



MODEL 16

RESULTS:

Base Shears and Performance Points

The base shears obtained from Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and the Pushover Analysis of all the models are stated in Table IX. The analysis is performed considering the seismic zone 4 and soil type 2 are represented in a tabular form in Table X.

Table X Base shears and performance points of RC bare frame models with elevation asymmetry

Model No.	Base Shear (KN)				Ratio (Vpo) (Ve)	Displacement at max Base Shear(mm)	Performance Point			
	ESA (Ve)	RSA (Vr)	Scale factor	Pushover (Vpo)			V (KN)	D (mm)	Sa (g)	Sd (mm)
1	4438	4437	1948	6824	1.53	354	6771	384	0.057	327
13	3878	3876	1810	7003	1.80	372	7001	370	0.069	304
14	3328	3310	1948	7158	2.15	360	7104	329	0.084	255
15	3650	3544	1834	7066	1.93	381	7055	361	0.075	292
16	3323	3322	1890	7145	2.15	356	7127	340	0.084	262

Pushover curves of RC frame models with asymmetry in elevation

The pushover curves are obtained by plotting the roof displacement of the models along X- axis and the base shear along Y- axis .Figure.6 corresponds to the pushover curves of RC frame models with symmetric and asymmetric elevations.

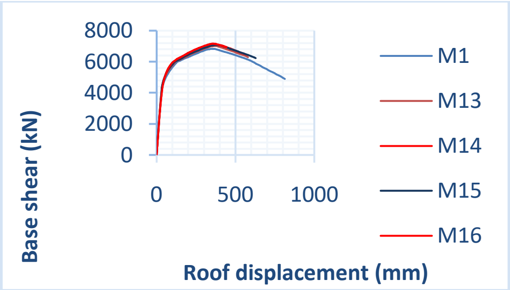
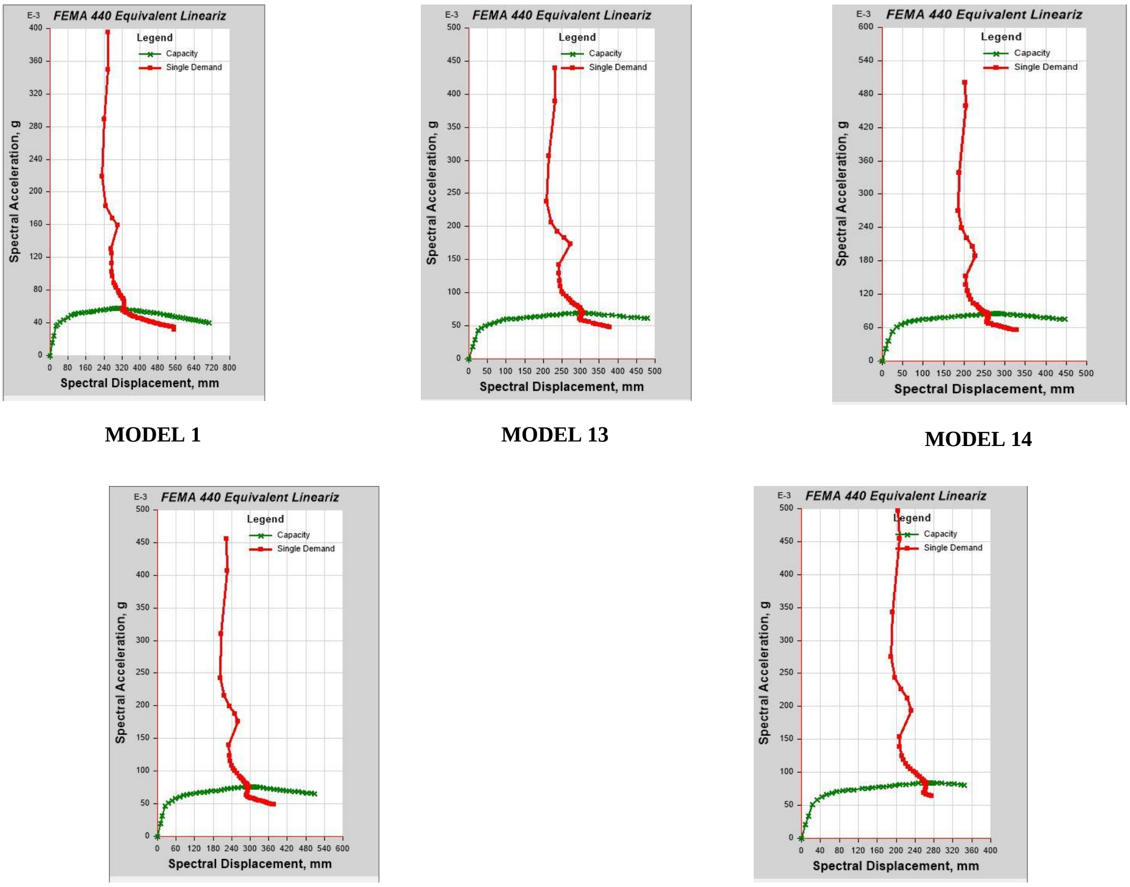


Fig.6 Pushover curves of RC bare frame models with symmetric and elevation Asymmetry

Capacity and demand curves of RC bare frame models with elevation asymmetry

The capacity and demand curves are plotted by considering the spectral displacement along X-axis and spectral acceleration along Y-axis. These spectrums for RC frame with elevation symmetric and asymmetric models are plotted in Fig 7.



MODEL 1 **MODEL 13** **MODEL 14**

MODEL 15 **MODEL 16**

Fig.7 **Capacity and demand curves for RC bare frame Models with symmetric and asymmetric elevation**

IV **CONCLUSION**

In the present study attempts are made to evaluate the seismic performance by observing pushover curve, performance point, hinge formation, fragility curves and calculation of vulnerability indices. Following are some of the conclusions drawn from the present study.

1. In each zone the base shear increases from Type-1 soil to Type-3 soil for all models. As the number of storey increases the base shear obtained from equivalent static analysis and response spectrum analysis increases. The base shear obtained from equivalent static analysis is greater than that obtained from response spectrum analysis for all models.
2. There is a prominent decrease in pushover base shear in case of models with infill from 10-storey to 20-storey.
3. In case of 5-storey models the large ratio of non linear static analysis base shear to elastic base shear for shear wall model indicates that large amount of stored strength is not-utilized. Thus a shear wall model fails earlier than that of a short leg shear wall owing to its lesser ductility than a short leg shear wall. However, these ratios decrease as the number of storey increases. Also as the soil type changes from Type 1 to Type 3, the Vpo/Ve ratio decreases.
4. The pushover curves indicate that the behavior of short leg shear wall models are in between that of shear wall model & bare frame model for 5 (five) -storey models. This indicates that SLSW models having higher stiffness than that of bare frame model but smaller value than that shear wall model. Also SLSW models have more ductility than shear wall model but less than bare frame model. But for 10 (ten) & 20 (twenty) stories models of SLSW-beam type model has the least stiffness among all the models.

5. The modeling of the coupling beam in case of short leg shear wall plays a significant role in determining the performance of the building. If the shell element is used for modeling the coupling beam behavior of the model tends to be similar to that of a general shear wall having higher stiffness and lesser ductility. If the coupling beam is assigned as a frame element (beam type), then the behavior of the model tends to be similar to that of a general bare frame having lesser stiffness and higher ductility.

Effect of Elevation Asymmetry on RC Frame Buildings

1. The value of base shear obtained from ESA of symmetric model is greater than all elevation asymmetric models. Pushover base shear is highest for model 14 and lowest for model 13 among the elevation asymmetric models. The pushover base shear of all asymmetric models is greater than the symmetric model.
2. The value of base shear at performance point of all elevation asymmetric models is greater than the symmetric model.
3. The roof displacement corresponding to maximum base shear is highest for model 15(U shape) and least for model 16 (T shape) among elevation asymmetric models. The roof displacement corresponding to maximum base shear of all elevation asymmetric models is greater than the symmetric model. The nature of pushover curves remains similar for both elevation symmetric and asymmetric models of different shapes.
4. The intersection point of demand curves with the capacity curves of models for both symmetric and elevation asymmetric falls in the nonlinear region. This means that the performance point lies in between immediate occupancy level and life safety level.
5. The percentage of hinges reaching collapse stage in symmetric model is less than all asymmetric models. The percentage of hinges in immediate occupancy level lies between 71 to 73% in elevation asymmetric models of different shapes and it is 76% for symmetric model. The percentage of hinges reaching collapse stage lies between 9 to 11% in elevation asymmetric models and it is 9.2% for symmetric model.

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