

Push Over Analysis of Tall Building with Soft Stories at Different Levels

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ABSTRACT

Open first storey is a typical feature in the modern multistory constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. Though multistoried buildings with open (soft) ground floor are inherently vulnerable to collapse due to earthquake load, their construction is still widespread in the developing nations like India. Social and functional need to provide car parking space at ground level and for offices open stories at different level of structure far out-weighs the warning against such buildings from engineering community. With ground soft storey for office space open floor is required on different levels of building. In present thesis we are concentrating on finding the best place for soft stories in high rise buildings. With the availability of fast computers, so-called performance based seismic engineering (PBSE), where inelastic structural analysis is combined with seismic hazard assessment to calculate expected seismic performance of a structure, has become increasingly feasible. With the help of this tool, structural engineers too, although on a computer and not in a lab, can observe expected performance of any structure under large forces and modify design accordingly. PBSE usually involves nonlinear static analysis, also known as

seismic base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with soft first storey, the upper storey's being stiff undergo smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demand on the columns in the first storey is also large, as the shear in the first storey is maximum. For the upper storey's, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiff nesses have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. This has adverse effect on the performance of buildings during ground shaking. Such buildings are required to be analyzed by the dynamic analysis and designed carefully.

Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family residential uses in seismic-prone regions worldwide. Masonry infill typically consists of brick, clay tile or concrete block walls, constructed between columns and beams of a RC frame. These panels are generally not considered in the design process and treated as architectural (non-structural) components. Nevertheless, the presence of masonry walls has a significant impact on the seismic response of an RC frame building, increasing structural strength and stiffness (relative to a bare RC frame), but, at the same time, introducing brittle failure mechanisms associated with the wall failure and wall-frame interaction. If the infill's are properly distributed throughout the structure and properly considered in the design, then they usually have a beneficial effect on the seismic response of the structure. On the other hand, negative effects can be caused by irregular positioning of the infill's in plan.

The most commonly used technique to model infill panels is that of single or multiple compressive equivalent diagonal struts. The observation of the response of building structures, engineered or not engineered to resist major or moderate earthquakes, after the past earthquakes highlighted the significant contribution of the infill in the characterization of their seismic behavior.

PUSHOVER ANALYSIS.

I. INTRODUCTION

1.1 General

Many urban multistory buildings in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first stories. The upper stories have brick unfilled wall panels. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than 50% of the storey above or below [Draft IS: 1893, 1997]. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey." Whereas the total

Infill were usually classified as non structural elements, and their influence was neglected during the modeling phase of the structure leading to substantial inaccuracy in predicting the actual seismic response of framed structures. Masonry infill has several advantages like good sound and heat insulation properties, high lateral strength and stiffness. These help to increase the strength and stiffness of RC frame and hence to decrease lateral drift, higher energy dissipation capacity due cracking of infill and friction between infill and frame. This in turn increases redundancy in building and reduces bending moment in beams and columns. Masonry infill has disadvantages like very high initial stiffness and compressive strength. This also induces tensional effect in the structure if not symmetrically placed. For a proper design of masonry infilled reinforced concrete frames it is necessary to completely understand their behavior under repeated horizontal loading.

The only difference between the finished residential and office buildings are the type of materials used for partitions and building perimeter wall enclosures. Residential buildings commonly use masonry infills both internally and externally. However, office buildings require as much open internal space as possible due to varying tenancy requirements. This necessitates the building system to consist of columns with lightweight, non-structural, easily removable internal partition walls, and the façade walls to consist of full or part glazing. Despite having a similar structural frame, size and shape, office buildings exhibit much less loss of life, damage or collapse when compared to residential buildings of the same size. The reason for residential buildings having significantly more damage is because the masonry infills placed in framed structures, due to their stiffness, causes change in structural behavior of such structures. The observations and analysis results reveal that the use of masonry infill walls located in between the columns of reinforced concrete framed structures plays a major role in the damage and collapse of buildings during strong earthquakes.

Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based structures and is moving away from simplified linear elastic methods and towards a more non-linear technique. Recent interests in the development of performance based codes for the design or rehabilitation of buildings in seismic active areas show that an inelastic procedure commonly referred to as the pushover analysis is a viable method to assess damage vulnerability of buildings. Basically, a pushover analysis is a series of incremental static analysis carried out to develop a capacity curve for the building. Based on the capacity curve, a target displacement which is an

estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the structure at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground shaking. Many methods were presented to apply the nonlinear static pushover (NSP) to structures. These methods can be listed as:

- (1) Capacity Spectrum Method (CSM) (ATC)
- (2) Displacement Coefficient Method (DCM) (FEMA-356)
- (3) Modal Pushover Analysis (MPA).

The approach has been developed by many researchers with minor variation in computation procedure. Since the behavior of reinforced concrete structures may be highly inelastic under seismic loads, the global inelastic performance of RC structures will be dominated by plastic yielding effects and consequently the accuracy of the pushover analysis will be influenced by the ability of the analytical models to capture these effects. In general, analytical models for the pushover analysis of frame structures may be divided into two main types: (1) distributed plasticity (plastic zone) and (2) concentrated plasticity (plastic hinge). Although the plastic hinge approach is simpler than the plastic zone, this method is limited to its incapacity to capture the more complex member behavior that involve severe yielding under the combined actions of compression and bi-axial bending and buckling effects [1].

1.2 Seismic Design

RC frame building would become massive if they were to be designed to behave elastically without incurring damage, and hence the project may become economically unviable. On the contrary, the building must undergo damage necessarily to be able to dissipate the energy input to it during the earthquake. Thus, as per the seismic design philosophy, (a) under occasional strong shaking, structural damage is acceptable. Therefore, structures are designed philosophy, (a) under occasional strong shaking, structural damage is acceptable, but collapse is not, and (b) under semi occasional moderate shaking, structural damage is limited even though non-structural damage is not acceptable. Therefore, structures are designed only for a fraction of the force that they would experience if they were designed to remain elastic during the expected strong ground shaking and thereby permitting damage under minor shaking refer figure 2.1 Thus, seismic design balances reduced cost and acceptable damage, thereby making the project viable [2]

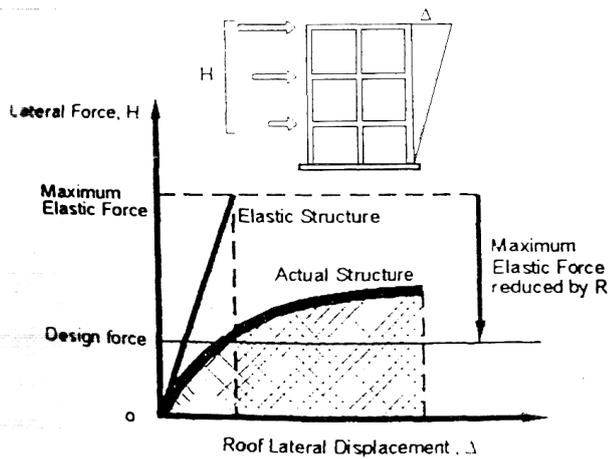


Fig. 1.1 Basic Strategy of Earthquake Design

II. OBJECTIVES OF THE PROJECT

RC frames buildings which are known to perform poorly during strong earthquake shaking, the presence of masonry infill wall influences the overall behavior of the structure when subjected to lateral forces, when masonry infill are considered to interact with their surrounding frames the lateral stiffness and lateral load carrying capacity of structure largely increase. In this paper the seismic vulnerability of building is shown with an Example of G+20. Earthquake analysis would be carried out on a RCC moment resisting framed tall building without Infill wall on different stories with the help of Software ETABS12.

So objective of project are

- Validation of earthquake analysis of G+20 RC building with the help of software ETABS
- 3D modeling of Tall RCC Building in ETABS12 for without infill walls at different stories. Analysis the following cases by Pushover method using ETABS12 software for ground motion 1) El Centro Earthquake
- To perform earthquake analysis of RC frames buildings with soft storey at GL
- To perform earthquake analysis of Rc frames building with soft storey at GL+1st
- To perform earthquake analysis of Rc frame building with soft storey at GL+2nd
- To perform earthquake analysis of Rc frames building with soft storey at GL+5rd
- To perform earthquake analysis of Rc frames building with soft storey at GL+10th
- To perform earthquake analysis of Rc frames building with soft storey at GL+15th
- To perform earthquake analysis of Rc frames building with soft storey at GL+20th

III. PUSHOVER ANALYSIS

Once the target performance of a structure has been determined by the engineer after having

met the requirements of the building and design codes. There are different methods of analysis which provides different degree of accuracy. Based on the type of external action and behavior of structure the seismic analysis methods are classified as

Table 1.1: Types of analysis methods

Static		Dynamic	
Linear	Nonlinear	Linear	Nonlinear
Seismic coefficient method	Pushover analysis method	Response spectrum method	Time history method

Nonlinear static analysis is an improvement over the linear static or dynamic analysis in the sense that it allows the inelastic behavior of the structure. The method assumes a set of static incremental lateral load over the height of the structure. The method is relatively simple to be implemented, and provides information of the strength, deformation and ductility of the structure and the distribution of demands.

3.1 3D Pushover Analysis

In this analysis method, earthquake load is applied on the model in an incremental basis. Earthquake load distribution is selected for which analysis is required. For this load distribution an initial load step is selected 3 D static analysis is done for this initial load step and checking for plastic moment capacity of elements to reach. If no element reaches plastic moment capacity, then load applied increase and analysis is done for new load. When in any element, plastic moment capacity is reached, plastic hinge is introduced in that element now. New analysis is done on this structure with new earthquake distribution (since earthquake load distribution will depend on structural properties. We can also continue with same distribution of earthquake load).and checking plastic moment capacity in other elements. And when plastic moment capacity is reacted, plastic hinge is introduced in that element.

At each step, load required for each event to occurred is noted down (event is the formation of plastic hinge in any element) same procedure is repeated until plastic mechanism is formed in the entire structure that leads to collapse of structure. Now collapse load is calculated which's nothing but load required for final event to occur.

3.2 Advantages of Pushover Analysis

- It allows us to evaluate overall structural behaviors and performance characteristics.
- It enables us to investigate the sequential formation of plastic hinges in the individual structural elements constituting the entire structure.

- 3) When a structure is to be strengthened through a rehabilitation process, it allows us to selectively reinforce only the required members maximizing the cost efficiency
- 4) The pushover analysis provides good estimate of global and local inelastic deformation demands for structures that vibrate primarily in the fundamental mode.

3.3 Limitations of Pushover Analysis

- 1) Deformation estimates obtained from a pushover analysis may be grossly inaccurate for structures where higher mode effects are significant.
- 2) In most cases it will be necessary to perform the analysis with displacement rather than force control, since the target displacement may be associated with very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects.
- 3) Pushover analysis implicitly assures that damage is a function only of the lateral deformation of the structure, neglecting duration effects, number of stress reversals and cumulative energy dissipation demand
- 4) The procedure does not take into account for the progressive changes in modal properties that take place in a structure as it experiences cyclic non-linear yielding during earthquake.
- 5) Most critical is the concern that the pushover analysis may detect only the first local mechanism that will form in an earthquake mechanism that will form in an earthquake and may not expose other weakness that will be generated when the structures dynamic characteristics change after formation of first local mechanism.

IV. MODELING AND ANALYSIS OF BUILDING

4.1 Introduction to ETABS9

The software used for the present study is ETABS9. It is product of Computers and Structures, Berkeley, USA. ETABS9 is used for analyzing general structures including bridges, stadiums, towers, industrial plants, offshore structures, buildings, dam, silos, etc. It is a fully integrated program that allows model creation, modification, execution of analysis, design optimization, and results review from within a single interface. ETABS9 is a standalone finite element based structural program for analysis and design of civil structures. It offers an intuitive, yet powerful user interface with many tools to aid in quick and accurate construction of models, along with sophisticated technique needed to do most complex projects.

ETABS9 is objecting based, meaning that the models are created with members that represent physical reality. Results for analysis and design are reported for the overall object, providing information that is both easier to interpret and consistent with physical nature.

The ETABS9 structural analysis programme offers following features-

- Static and Dynamic Analysis
 - Linear and Nonlinear Analysis
 - Dynamic seismic analysis and Static push over analysis
 - Geometric Nonlinearity including P-Δ effect
 - Frame and shell structural elements
 - 2-D and 3-D plane and solid elements
- Nonlinear link and support analysis

4.2 Modeling and Analysis of Building

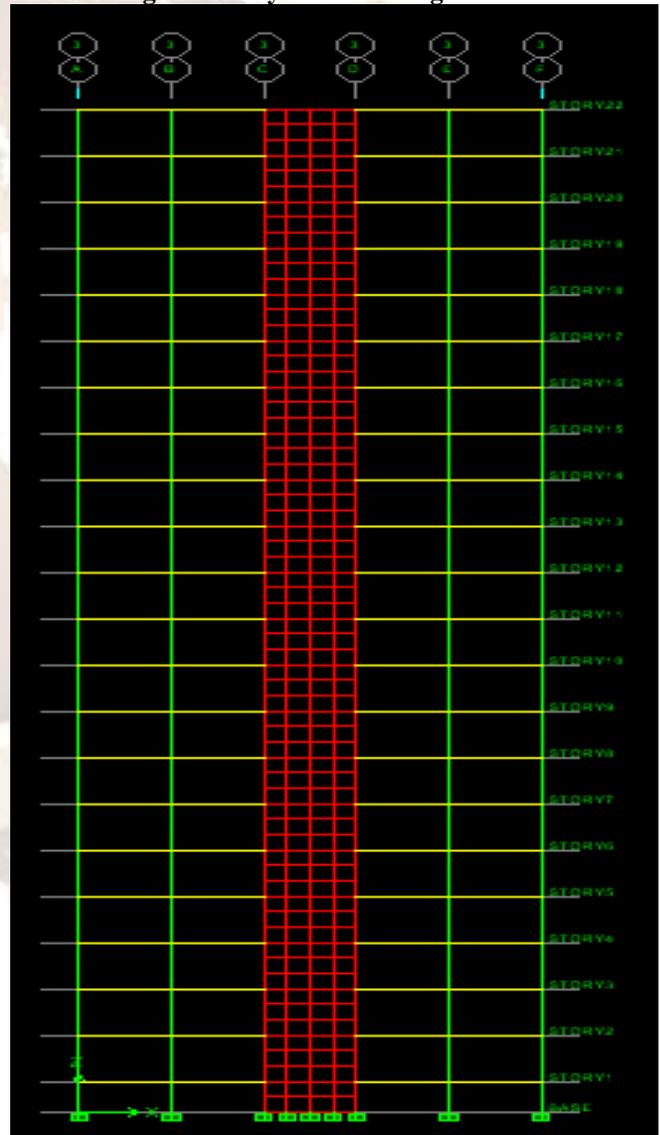


Fig. 4.1 Elevation of Building

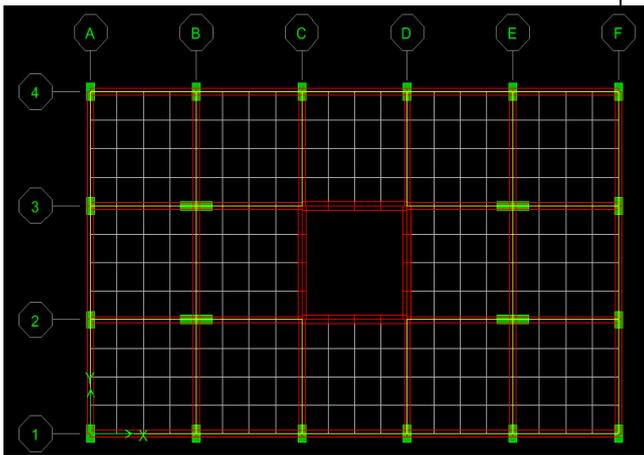


Fig 4.2 Plan of building

viii)	Imposed load	5.0 KN/m ²
V. RESULTS AND DISCUSSION		
5.1 General		
<p>In the present study, non-linear response of RC frame high rise building with soft storey at different levels in addition to one at ground floor using ETABS under the loading has been carried out. The objective of this study is to see the variation of load- displacement graph and check the maximum base shear and displacement of the frame with soft stories at different levels. After running the analysis, the pushover curve is obtained as shown in figures.</p>		
i)	Zone	V
ii)	Zone factor	0.36
iii)	Response reduction factor	5
iv)	Important factor	1
v)	Soil condition	Medium
vi)	Height of building	65 m
vii)	Wall thickness	
	External	230 mm
	Internal	230 mm
viii)	Weight density of Brick masonry	20 kN/m ³
ix)	Weight density of RC material	25 kN/m ³
x)	Thickness of slab	150 mm
xi)	Floor to floor height	3.0 m
xii)	Plinth height above ground level	2.0 m
xiii)	Size of columns	300 mm x 600 mm 300mm x 1200mm
xiv)	Size of beams	300 mm x 500 mm
xv)	Grade of steel	Fe-415
xvi)	Grade of concrete	M20
xvii)	Floor finish	2.0 KN/m ²

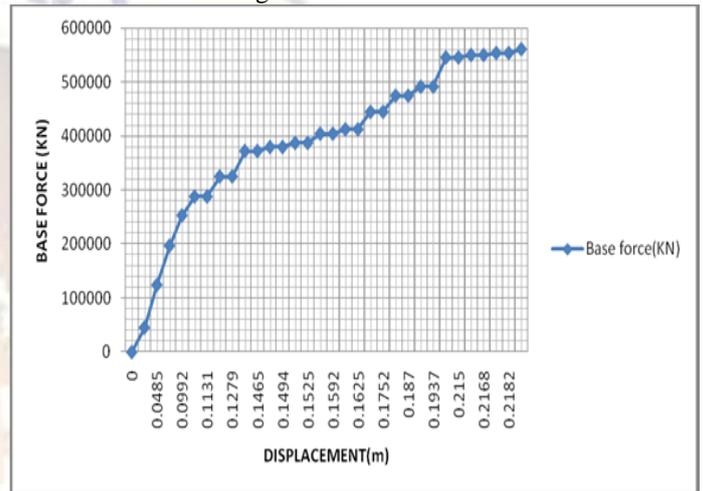


Fig. 5.1 Pushover Curve of tall Building with ground soft story.

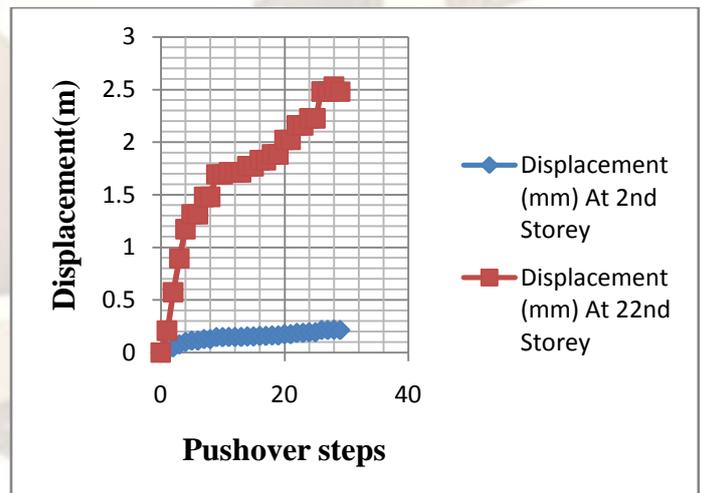


Fig. 5.2 Stepwise displacement curve for Soft Storey at Ground & 20th floor

5.2 Capacity Spectrum Curves

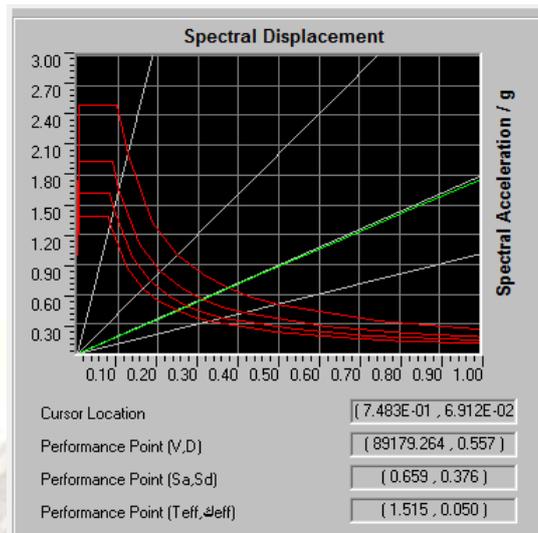


Fig. 5.3 Capacity Spectrum Curve Of Building With Soft Storey At Ground and Third floor

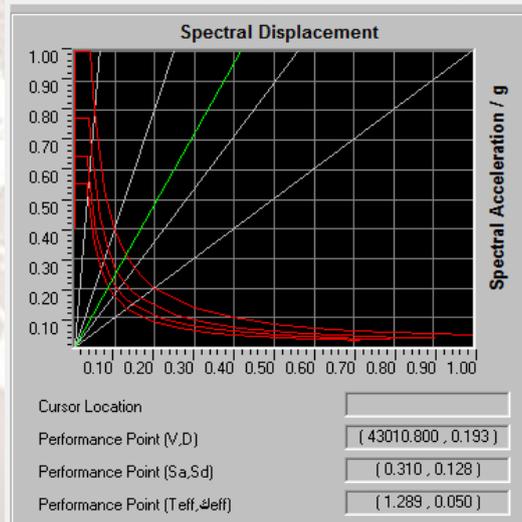


Fig. 5.4 Capacity Spectrum Curve Of Building With Soft Storey At Ground and Twentieth floor

As per IS 1893, Part I, 2002, Clause No. 7.6.1, Page No. 24 Natural period of vibration is given as

$$T = 0.075 \times H^{0.75}$$

Here for our structure $H = 65 \text{ m}$

So,

$$T = 0.075 \times 65^{0.75}$$

$$T = 1.71 \text{ Sec.}$$

From pushover analysis and capacity spectrum curve we are getting T_{eff} . **1.289 Sec** to **1.515 Sec**. for different cases of soft stories which is within specified limit.

Table 5.1 Stepwise displacement and base force for Soft Storey at ground and 3rd floor

Pushover Steps	At 2nd Storey		At 5th Storey	
	Displacement	Base Force	Displacement	Base Force
0	0	0	0	0
1	0.02	41201	0.05	35852
2	0.02	45199	0.05	39332
3	0.04	108274	0.13	94218
4	0.06	151806	0.18	132099
5	0.08	193506	0.23	168386
6	0.09	234574	0.27	204122
7	0.11	275641	0.32	239857
8	0.11	283633	0.33	246812
9	0.11	283599	0.33	246783
10	0.13	319584	0.37	278096
11	0.13	319582	0.37	278095
12	0.15	366898	0.43	319268
13	0.15	366899	0.43	319269
14	0.15	370455	0.43	322364
15	0.15	370446	0.43	322355
16	0.15	370448	0.43	322357
17	0.15	384253	0.45	334370
18	0.15	384227	0.45	334348
19	0.15	387104	0.45	336850
20	0.15	387077	0.45	336827
21	0.16	390993	0.46	340235
22	0.16	390982	0.46	340226
23	0.16	396389	0.47	344931
24	0.14	361195	0.42	314305

Table 5.2 Stepwise displacement and base force for Soft Storey at ground and 20th floor

Pushover Steps	At 2nd Storey		At 22nd Storey	
	Displacement	Base Force	Displacement	Base Force
0	0.00	0	0.00	0
1	0.02	45598	0.21	1175
2	0.05	125769	0.57	3240

3	0.08	196688	0.90	5067
4	0.10	257488	1.17	6634
5	0.11	288593	1.32	7435
6	0.11	288547	1.32	7434
7	0.13	324735	1.48	8366
8	0.13	324733	1.48	8366
9	0.15	371693	1.69	9576
10	0.15	371695	1.69	9576
11	0.15	376022	1.71	9687
12	0.15	376009	1.71	9687
13	0.15	376012	1.71	9687
14	0.15	388627	1.77	10012
15	0.15	388613	1.77	10012
16	0.16	401365	1.83	10340
17	0.16	401368	1.83	10340
18	0.16	413293	1.88	10648
19	0.16	413287	1.88	10647
20	0.17	443627	2.02	11429
21	0.17	443632	2.02	11429
22	0.19	473860	2.16	12208
23	0.19	473865	2.16	12208
24	0.19	488602	2.23	12588
25	0.19	488604	2.23	12588
26	0.21	544523	2.48	14028
27	0.21	544527	2.48	14028
28	0.22	554726	2.53	14291
29	0.21	543987	2.48	14015

5.3 Plastic Hinges Mechanism

Plastic hinge formation for ground floor soft storey and ground plus different level soft storey have been obtained at different displacements levels. The hinging patterns are plotted in figures 5.13, 5.14 and 5.15. From figure 5.13 it can be seen that the plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories.

Comparison of the figures 5.13, 5.14 and 5.15 reveals that the patterns of plastic hinge formation for the different level soft storey is quite different, as we shift soft storey to higher level the intensity of hinge formation becomes lower and lower in soft storey.

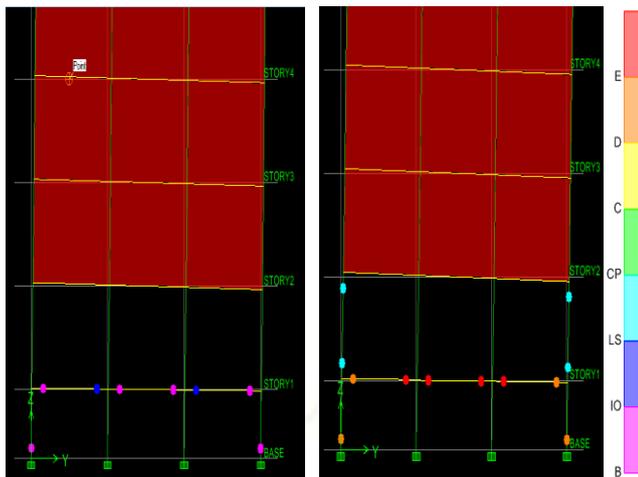


Fig. 5.5 Hinges Pattern of tall Building at Different Pushover Steps

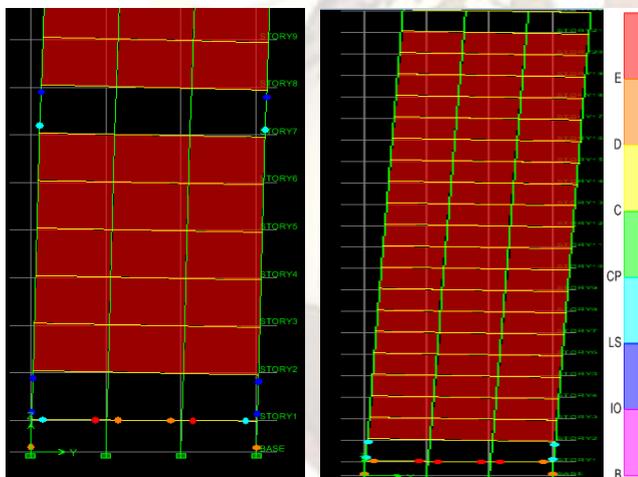


Fig. 5.6 Hinges Pattern of tall Building with soft stories at Different Pushover Steps

From figure 5.13 to figure 5.15 it can be seen that as we shift the soft storey to higher level the intensity of hinge formation becomes lower and lower and at the same time displacement increases and base shear also. Maximum yielding occurs at the base storey, because of soft stories maximum plastic hinges are forming though the base force is increasing. As we go higher soft stories yielding is less than ground soft storey and lower intensity hinges are forming after maximum number of pushover steps.

5.4 Base Shear

The maximum base shears at the base for soft stories at different levels

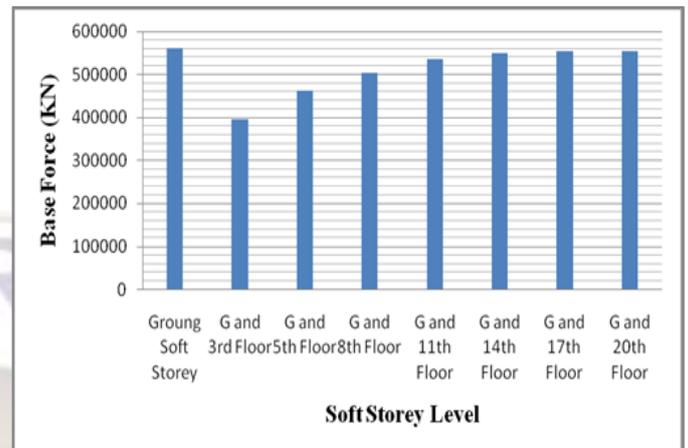


Fig. 5.7 Base Shear in Ground Soft Storey

It has been observed from above graph of base force for different level soft stories that, if we use soft storey at ground floor base shear is more, but as we shift the soft storey to higher level with ground floor soft storey combination, base shear goes on increasing and displacement also.

VI. CONCLUSION

From present analysis model in ETABS it can be concluded that,

As we shift the soft storey to higher level the intensity of hinge formation becomes lower and lower and at the same time displacement increases and base shear also.

Maximum yielding occurs at the base storey, because of soft stories maximum plastic hinges are forming though the base force is increasing.

As we shifted soft storey to higher level yielding is less than lower level soft storey and lower intensity hinges are forming after maximum number of pushover steps.

As we shift soft storey to higher level it can be seen from pushover and capacity spectrum curve that T_{eff} goes on reducing from 1.52 Sec. for 3rd floor soft storey to 1.29 Sec. at 20th floor soft storey. Which means soft storey is safer at higher level in high rise building

The behavior of properly detailed reinforced concrete frame building is adequate as Indicated by the intersection of the demand and capacity curves and the distribution of Hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns.

The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behavior of structures.

It is advisable to provide soft storey at higher levels in addition to ground soft storey

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