# Non-Linear Pushover Analysis of Flatslab Building by using SAP2000

K. Soni Priya, T. Durgabhavani, K. Mounika, M.Nageswari, P.Poluraju

***Abstract*: Recent earthquakes in which many concrete structures have been severely damaged or collapsed, have indicated the need for evaluating the seismic adequacy of existing buildings. About 60% of the land area of our country is susceptible to damaging levels of seismic hazard. We can't avoid future earthquakes, but preparedness and safe building construction practices can certainly reduce the extent of damage and loss. In order to strengthen and resist the buildings for future earthquakes, some procedures have to be adopted. One of the procedures is the static pushover analysis which is becoming a popular tool for seismic performance evaluation of existing and new structures. By conducting this push over analysis, we can know the weak zones in the structure and then we will decide whether the particular part is retrofitted or rehabilitated according to the requirement. In this paper we are performing the push over analysis on flat slabs by using most common software SAP2000.Many existing flat slab buildings may not have been designed for seismic forces. Hence it is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. But when compared to beam-column connections, flat slabs are becoming popular and gaining importance as they are economical.***

***Index Terms*: Pushover analysis, Retrofitting, Rehabilitation, Column jacketing, Response Spectrum, Demand curve, Capacity curve, Plastic hinge.***

## I. INTRODUCTION

The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest.

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**Types of analysis**

Different types of analysis are as follows:

1. Linear Static Analysis.
2. Linear Dynamic Modal Response Spectrum Analysis.
3. Linear Dynamic Modal Response History Analysis.
4. Linear Dynamic Explicit Response History Analysis

Among all the analyses, deformation can be predicted in nonlinear static and dynamic analysis.Two-dimensional nonlinear push-over analysis is carried out on a typical flat slab building.

Flat slab is an American development, originated by Turner in 1906. It is a concrete slab reinforced in two or more directions so as to bring its load to supporting columns, generally without the help of any beams or girders. Failure of RC flat slab farming systems during severe earthquakes have led to widespread rejection of flat slab as a viable system in regions of high seismicity. Many existing buildings do not have been designed for seismic forces. It is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. By conducting this push over analysis we can know the weak zones in the flat slab then the particular part is retrofitted. The retrofitting can be done by:

a) Column jacketing
b) Addition of beams at floor
c) Column jacketing and addition of beams

The retrofitting of ground storey by column jacketing is a good cost effective technique but is adequate only when seismic deficiency is small.

The beam retrofitting reduces the sagging hinging significantly. Increasing the number of storey of retrofitting by either column retrofitting alone or beam retrofitting alone does not improve the behavior significantly.

When column jacketing and addition of beam are adopted simultaneously on more number of stories, large increase in lateral strength and stiffness can be achieved.

## Push over analysis

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out upto failure, thus it enables determination of collapse load and ductility capacity. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies.

**Necessity of non-linear static pushover analysis**

The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures.

The widespread damage especially to RC buildings during earthquakes exposed the construction practices being adopted around the world, and generated a great demand for seismic evaluation and retrofitting of existing building stocks.

**Purpose of non-linear static push-over analysis**

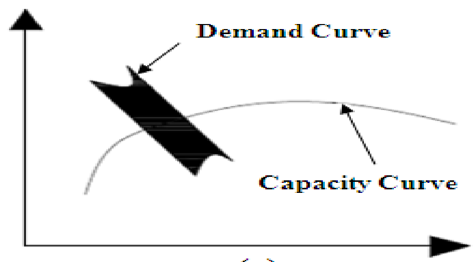
The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter story drift, inelastic element deformations (either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations), The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behavior.

**Pushover methodology**

A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking.
Under incrementally increasing loads various structural elements may yield sequentially.
Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic non linear force displacement relationship can be determined.
Main steps involved in pushover methodology

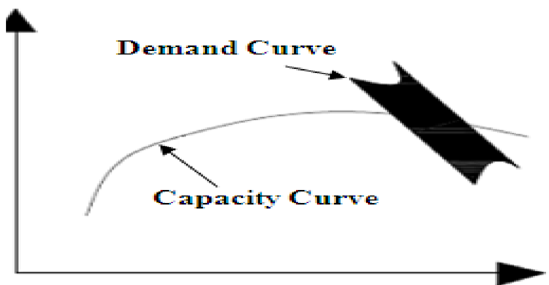
1. Definition of plastic hinges: In SAP2000, nonlinear behavior is assumed to occur within a structure at concentrated plastic hinges. The default types include an uncoupled moment hinges, an uncoupled axial hinges, an uncoupled shear hinges and a coupled axial force and biaxial bending moment hinges.
2. Definition of the control node: control node is the node used to monitor displacements of the structure. Its displacement versus the base-shear forms the capacity (pushover) curve of the structure.
3. Developing the pushover curve which includes the evaluation of the force distributions. To have a displacement similar or close to the actual displacement due to earthquake, it is important to consider a force displacement equivalent to the expected distribution of the inertial forces. Different forces distributions can be used to represent the earthquake load intensity
4. Estimation of the displacement demand: This is a crucial step when using pushover analysis. The control is pushed to reach the demand displacement which represents the maximum expected displacement resulting from the earthquake intensity under consideration.
5. Evaluation of the performance level: Performance evaluation is the main objective of a performance based design. A component or action is considered satisfactory if it meets a prescribed performance.

The main output of a pushover analysis is in terms of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range, Fig.1a, then the structure has a good resistance.
If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, Fig.1b, then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse.




(a)

(a)safe design




(b)

(b)unsafe design

**Fig.1 Typical seismic demand versus capacity**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Depending on the weak zones that are obtained in the pushover analysis, we have to decide whether to do perform seismic retrofitting or rehabilitation.

**Seismic retrofitting**

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes.

Various repair/retrofit options available today include crack injection, shortcreting, steel jacketing, steel plate bonding, CFRP/GFRP jacketing, RC jacketing, addition of new structural elements (braces, walls, etc.), incorporation of passive energy dissipation devices, and provision of base isolation.

**Types of Retrofitting**

1. Local technique
a) Column jacketing
b) Addition of beams at floor

The retrofitting of ground storey by column jacketing is a good cost effective technique but is adequate only when seismic deficiency is small.

The beam retrofitting reduces the sagging hinging significantly. Increasing the number of storey of retrofitting by either column retrofitting alone or beam retrofitting alone does not improve the behavior significantly.

2. Global technique

This can be typically done by the addition of cross braces or new structural walls.

**Rehabilitation**

Rehabilitation or reconstruction or replacement includes work to restore the original capacity to meet typical service loads by reconstructing the effected parts in a structure.

**Rehabilitation Options**

1. Addition of new concrete shear walls
2. Use of Fiber Reinforced Polymer laminates to strengthen masonry, unreinforced clay tile, or concrete members.
3. Add steel bracing
4. Improve connection capacities
5. Reduce structure mass
6. Global stiffening

A plot is drawn between base shear and roof displacement. Performance point and location of hinges in various stages can be obtained from pushover curve as shown in figure. The range AB is elastic range, B to IO is the range of immediate occupancy IO to LS is the range of life safety and LS to CP is the range of collapse prevention. If all the hinges are within the CP limit then the structure is said to be safe.

However, depending upon the importance of structure the hinges after IO range may also need to be retrofitted.

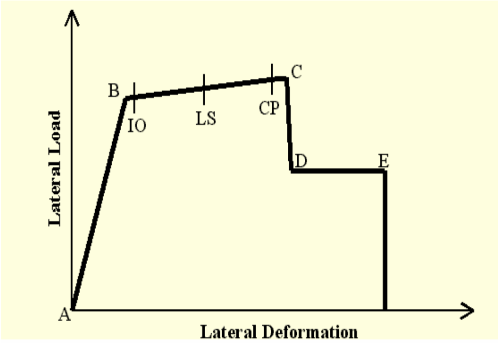


Fig 2. Lateral load Vs Deformation

**Design of flat slab**

A typical flat slab with two stories is considered in the present study.It has not been detailed for earthquake loads but have been designed for wind loads.The height of the each storey is 3m.

For the purpose of design, linear structural analysis of the building is carried out by the computer program SAP2000 (Structural Analysis Program, Version 12.00).The slab of the building is assumed to be acting like a rigid floor diaphragm. The building is designed as per IS: 456-1978 using limit state method of design. The load combinations used are as follows:

1.5 DL+1.5 LL
1.5 DL+1.5 LL+1.2 WL

For the purpose of wind load calculations, the structure is assumed to be situated in Vijayawada.

The wind loads are calculated as per the IS: 875(Part 3)-1987:

$V_z=V_b k_1 k_2 k_3$

where $V_z$=design wind speed at any height z in m/s,$V_b$=basic wind speed in m/s(=50 m/s for building in Vijayawada).The design wind pressure($p_z$) is calculated as follows:

$P_z=0.6V_z^2$

From the above equations, the total design wind speed on the building was obtained as 1.5 kN/m$^2$ acting along X-direction.The materials used are M 20 grade concrete and Fe 415 grade steel. The thickness of the slab is 200 mm and no shear reinforcement is provided in the slabs. The columns are 250 mm square in section.

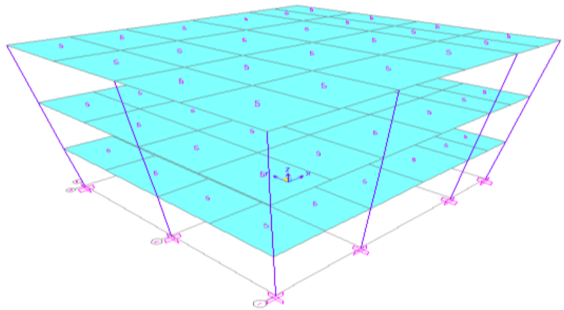

**Fig 3. 3-D View**


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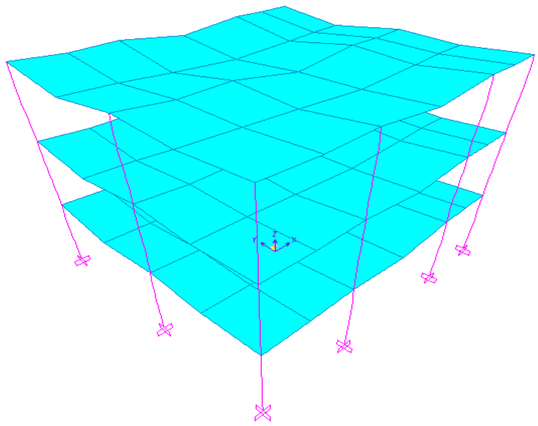

**Fig 2. Deformed shape (DEAD)**

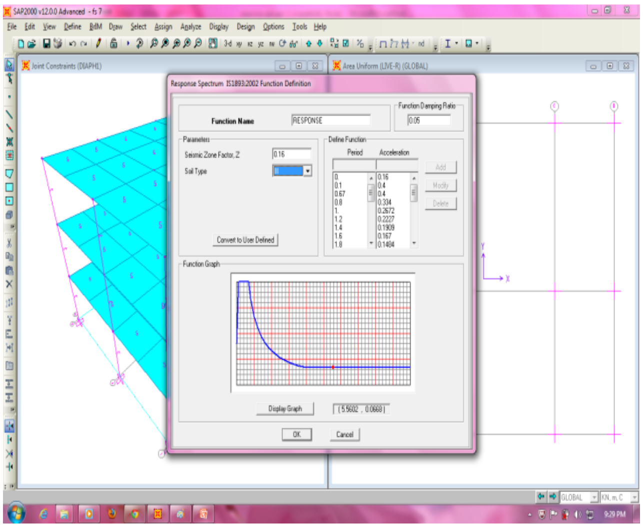

**Fig3. Response spectrum**

**Table1:Centre Of Masses At Different Levels**

| Height in m | Mass in kN-s²/m |
|---|---|
| 3 | 30.32 |
| 6 | 30.32 |
| 9 | 28.03 |

**Table2:Pushover Loads(IS1893)**

| Height in m | $Q_i$ (kN) |
|---|---|
| 9 | 125.25 |
| 6 | 125.25 |
| 3 | 27.36 |

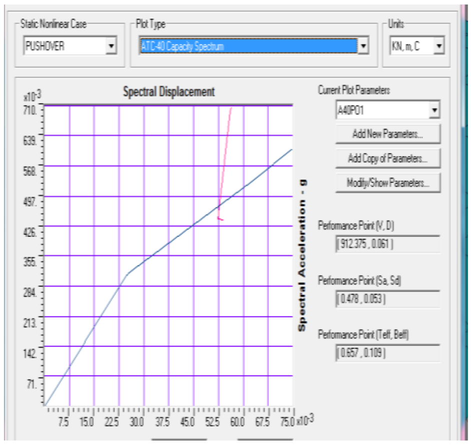


**Fig 4 Pushover curve**

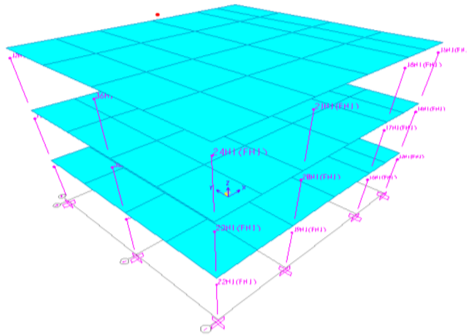

**Fig 5 Framed hinges**

## II. RESULT AND DISCUSSION

The resulting pushover curve for the G+2 building is shown in fig 4. The curve is initially linear but start to deviate from linearity as the columns undergo inelastic actions. When the building is pushed well into the inelastic range, the curve become linear again but with a smaller slope. The curve could be approximated by a bilinear relationship.

Plastic hinges formation for the building mechanisms have been obtained at different displacement levels. The hinging patterns are plotted at different levels in figures 8 to16. Plastic hinges formation starts at base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories.

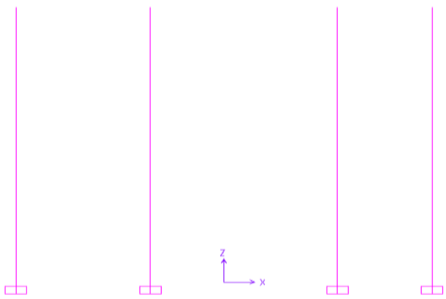

**Fig 6 Deformed shape at step 0**



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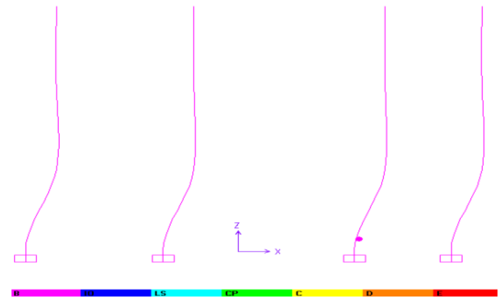

Fig 7 Deformed shape at step 1

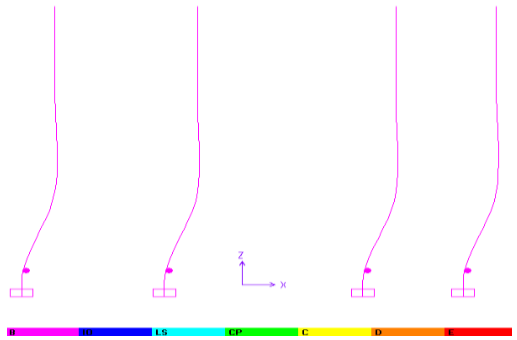

Fig 8 Deformed shape at step 2

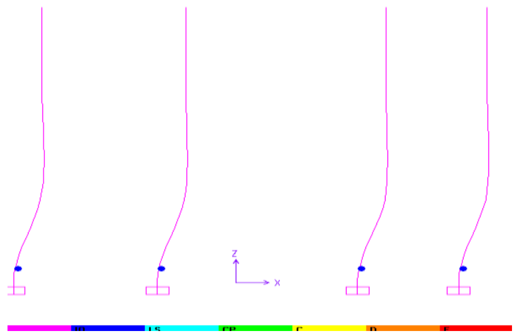

Fig 9 Deformed shape at step 3

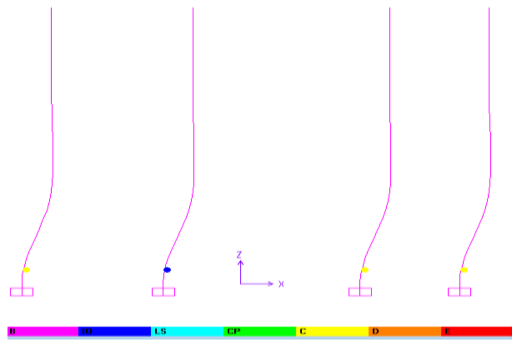

Fig10 Deformed shape at step 4

## III. CONCLUSION

Under the pressure of recent developments, seismic codes have begun to explicitly require the identification of sources of inelasticity in structural response, together with the quantification of their energy absorption capacity. Many existing buildings do not have been designed for seismic forces. It is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. Hence push over analysis has been gaining importance for the strengthening and evaluation of the existing structures. By conducting the pushover analysis on flat slabs, pushover curve and demand curve can be obtained.Then, based on the results we need to decide whether to perform rehabilitation or retrofitting depending upon the seismic zone of the existing structures.

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