

# **Analytical Modelling of RC Frame with Strength and Stiffness Degradation**

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**ABSTRACT:** In reinforced concrete (RC) frame structures, design of earthquake resistant design, forces and displacements are expected to greatly exceed those induced by the equivalent static lateral loads stipulated in the codes. When these structures are subjected to severe earthquake excitations they are expected to deform well into the inelastic range and dissipate the largest seismic energy input into the structure through large but controllable inelastic deformations at critical regions. In order to predict the distribution of forces and deformations in these structures under the maximum credible earthquake that can occur at the site, accurate models of the hysteretic behavior of the different critical regions of the structure are necessary. Reinforced concrete structures designed according to present building codes as moment resisting space frames, shear-walls or any combination thereof to withstand strong earthquake motions are expected to deform well into the inelastic range. Hysteretic is a highly nonlinear phenomenon occurring when a structure is subjected to strong earthquake. If the system is under repeated cyclic deformation, there is invariably strength and stiffness deterioration in the hysteretic curve. This effect is also must be taken into account in the modeling and design of seismic resistant structural system. RC FRAME is modeled in SAP2000 VERSION10. Non-Linear Analysis of the frame is done. The Variation of Stress Strain Curve for Each degradation is plotted.

**KEYWORDS:** Frame structures, Earthquake resistant design, Inelastic range, Cyclic deformation, Seismic resistant.

## **I. INTRODUCTION**

When the structures are subjected to severe earthquake excitations they are expected to deform well into the inelastic range and dissipate the largest seismic energy input into the structure through large but controllable inelastic deformations at critical regions. In order to predict the distribution of forces and deformations in these structures under the maximum credible earthquake that can occur at the site, accurate models of the hysteretic behavior of the different critical regions of the structure are necessary.

Hysteretic is a highly nonlinear phenomenon occurring when a structure is subjected to strong earthquake. If the system is under repeated cyclic deformation, there is invariably strength and stiffness deterioration in the hysteretic curve. This effect is also must be taken into account in the modeling and design of seismic resistant structural system.

When the structure is subjected to cyclic loading, there is a reduction in strength and stiffness occurs. Hence proper experimental and analytical study to find out the response of the building is required. Previous experimental studies give the important and amount of strength and stiffness reduction in each cycle. This analytical study aims to consider the effect of strength and stiffness degradation, the percentage decrease in young's modulus and percentage increase in displacement is found out.

The Present study aims to

- Non – Linear analysis of the RC Structure is to be carried out.

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- To develop analytical model for considering strength and stiffness degradation of Reinforced Concrete Frame

## II. MODELING OF RC FRAME

### RC building under earthquake

In structures designed according to the present state of earthquake resistant design the forces induced in the structure during a major earthquake will exceed the yield capacity of some members and cause large inelastic deformations. These deformations resulting from the combined effect of gravity and lateral loads are concentrated in areas of maximum internal forces which are called critical regions. The different types of critical regions in reinforced concrete frames are shown in Fig.1.

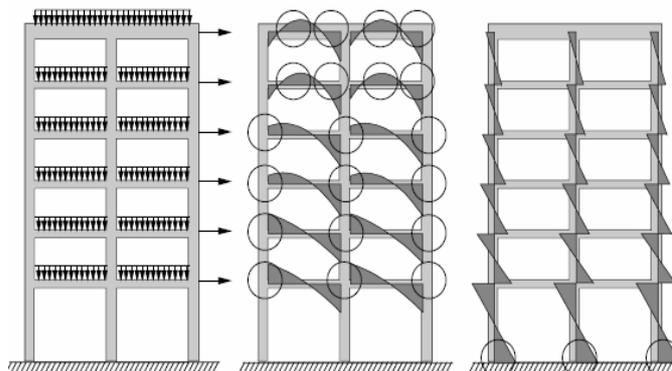


Fig.1: Bending Moments in Moment Resisting Frames under Combination of Gravity and Earthquake Loads

### Modeling of RC frame

In modelling the hysteretic behaviour of RC members under cyclic load reversals Phenomenological models of hysteretic behaviour are typically used. While only a few Parameters are needed to describe the hysteretic behaviour when flexure governs the response, many more parameters become necessary in members with complex interactions between bending moment, shear and axial force. Thus the derivation of empirical hysteretic rules, however complex, does not guarantee the general applicability of these rules. It, therefore, appears doubtful that a single hysteretic model can approximate the actual behaviour of RC regions over the wide range of possible interactions of bending moment, shear and axial force in structures subjected to earthquake excitations. The scope of this study the moment resisting frame consists of only three types of super elements:

1. A Girder Element
2. A column Element
3. A Foundation Element

### Reinforced concrete girder element

In moment resisting frames designed according to current building codes to resist severe earthquake excitations, inelastic deformations are expected to take place at the ends or at midspan of girders and at beam-column joints. The behaviour of critical regions in girders is governed by flexure, shear and the transfer of stresses between reinforcing steel and concrete. The proposed model for analysing girder element is Spread Plasticity Element as shown in Fig.2.

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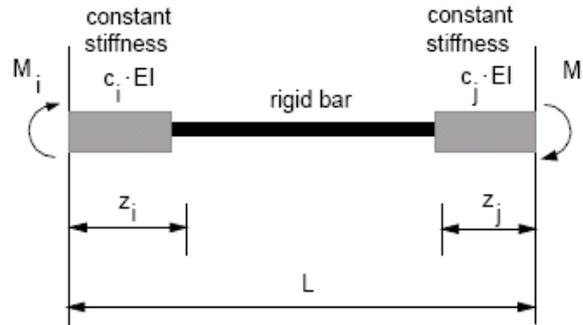


Fig. 2: Reinforced Concrete Girder Element

## Reinforced concrete column element

In designing reinforced concrete columns to resist severe earthquake excitations, designers favour the strong column-weak girder design concept which aims at dissipating energy in a flexural mode in a large number of hinges in the girders of the structure. Modern design codes attempt to ensure such behaviour by requiring that the sum of the moment strengths of columns framing into a beam-column connection exceed the sum of the moment strengths of the girders framing into the same connection along each principal plane of the frame. The proposed model for column element is shown in Fig.3.

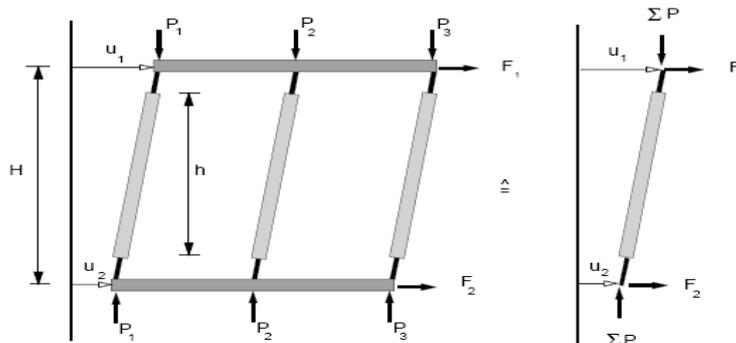


Fig. 3: Reinforced Concrete Column Element

## Foundation element

Most structures are built on flexible foundations. The foundation element, which is modelled as a spring element, represents vertical, rotational, and lateral displacements of the base of the building associated with settlement, rocking and sliding of the foundation the proposed model for foundation element is shown in Fig.4.

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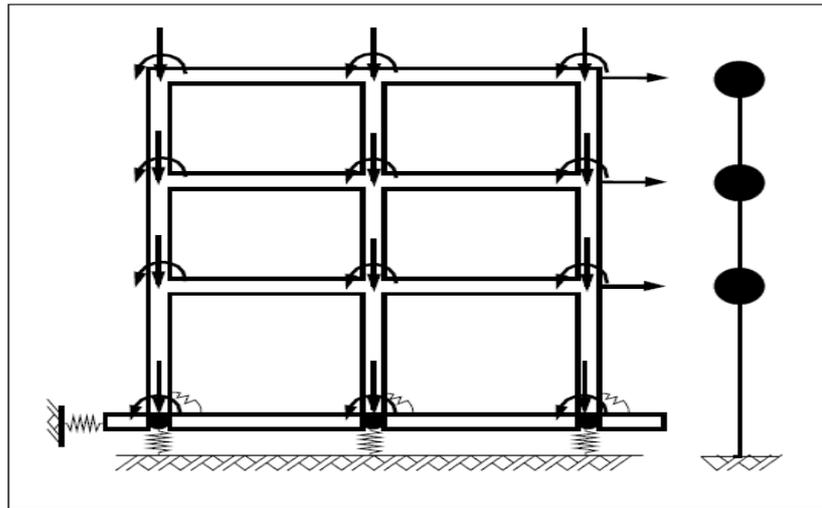


Fig.4:Foundation Element

### III.ANALYTICAL STUDY

#### SAP 2000 version 10

The Finite Element analysis of the Reinforced Concrete frame has been performed using SAP2000. This is a three-dimensional finite element program with static and dynamic analysis capabilities. Static analysis capabilities include the ability to consider the stresses caused by various loads. Dynamic analysis capabilities include natural frequency and mode shape analysis, direct and modal superposition time history analysis and response spectrum analysis. Finite elements include beams, truss elements, thin shell/plate elements, axisymmetric solid/plane strain elements, plane stress membrane elements, brick elements, thick shells, boundary elements and straight or curved pipe work elements.

#### Preliminary analysis

The preliminary analysis carried out with single bay RC frame. The height of the column is 3m and the dimension of the column is 300X200mm. The beam length is considered as 3m with 300X200mm size. The Young's modulus of the material is taken as 25000N/mm<sup>2</sup>.

#### Approaches for analysis

There are generally two approaches used for the analysis of the structure. These are,

- Linear Approach
- Non – Linear Approach

#### Linear Approach

Linear approach is computationally convenient and provides reasonable result for many practical problems, but in case of earthquake excitation the main variables are displacement, velocity, and acceleration. Accurately predict this effect in linear Approach is somewhat difficult.

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## Non – Linear Approach

Non – Linear Approach is further classified into two types.

- Nonlinear Static Analysis
- Nonlinear Dynamic Analysis

## Nonlinear Static Analysis

Non-linear static analysis is used to consider the effect of material and geometric nonlinear behaviour of the structure. In SAP2000, to consider the effect of strength and stiffness degradation for the analysis “start from previous load case” is taken. Also, the stress- strain curve of the material is changed in each load step.

## Analysis of the model

In the analysis, self-weight of the beams and columns are taken as dead load and live load is taken as  $3\text{kN}/\text{m}^2$ . Earthquake load is applied as lateral load at the top of the building. The non-linear static analysis is carried out. The stress Vs strain curve for the first load cycle is shown in Fig.5. (without considering degradation). From this stress, strain curve it is observed that, young’s modulus of the material is changed to  $22.13 \times 10^3 \text{N}/\text{mm}^2$ . The percentage reduction in young’s modulus is 12.13%

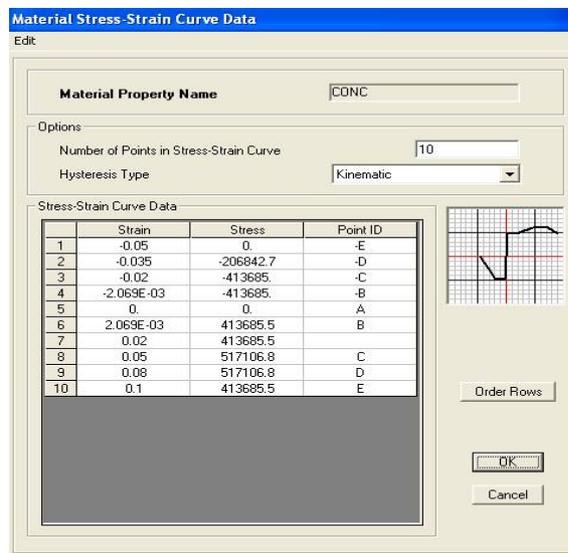


Fig.5: Stress Vs Strain Curve (Without considering Degradation)

The modified Young’s modulus is applied during the second cycle of loading. The stress strain value during the second cycle of loading with the consideration of modified Young’s modulus is shown in Fig. 6. In this stress strain curve it is observed that young’s modulus of the material is further reduced to  $19.42 \times 10^3 \text{N}/\text{mm}^2$ . The percentage of reduction in young’s modulus is 13%

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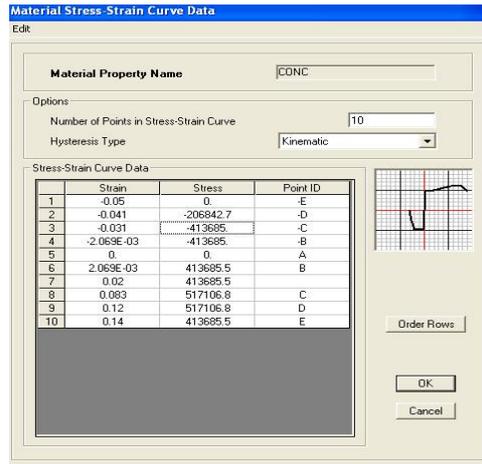


Fig.6: Stress Vs Strain Curve (Considering Degradation due to first cycle)

Due to nonlinear static analysis the corresponding displacement value is found out by considering the effect of degradation in each cycle. Top storey displacement of the building is noticed. Displacement values are given in Table 1.

Table I: Load vs. Displacement (Considering Degradation in each cycle)

LOAD (KN)	DISPLACEMENT in each cycle (m)		
	FIRST	SECOND	THIRD
0	0	0	0
100	0.0224	0.0287	0.031
200	0.0445	0.0574	0.0593
400	0.089	0.115	0.132
500	0.175	0.215	0.231

It was observed that percentage increase in displacement in each cycle is approximately 25%. Load vs. Displacement curve was drawn with considering the degradation shown in Fig.7.

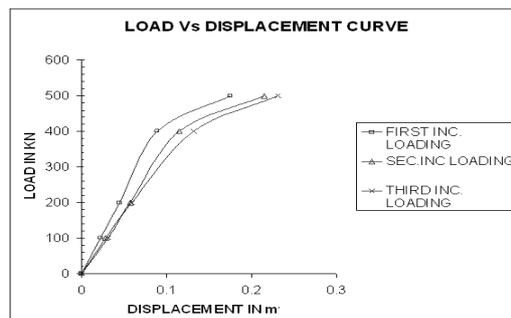


Fig .7: Variation of Load Vs Displacement Curve for Incremental Loading

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Percentage reduction in strength = 14.29%  
Percentage reduction in stiffness = 18.60%

Difference in equation between the second and first curve, third and second curve is found out from MATLAB  
**Matlab**

MATLAB is a special purpose computer program optimized to perform engineering and scientific calculations. It is the flexible computing system capable of solving essentially any technical problem. MATLAB provides a very extensive library of predefined functions to make technical programming easier and more effective. Difference in curve and equation between second and first curve as shown in Fig.8.

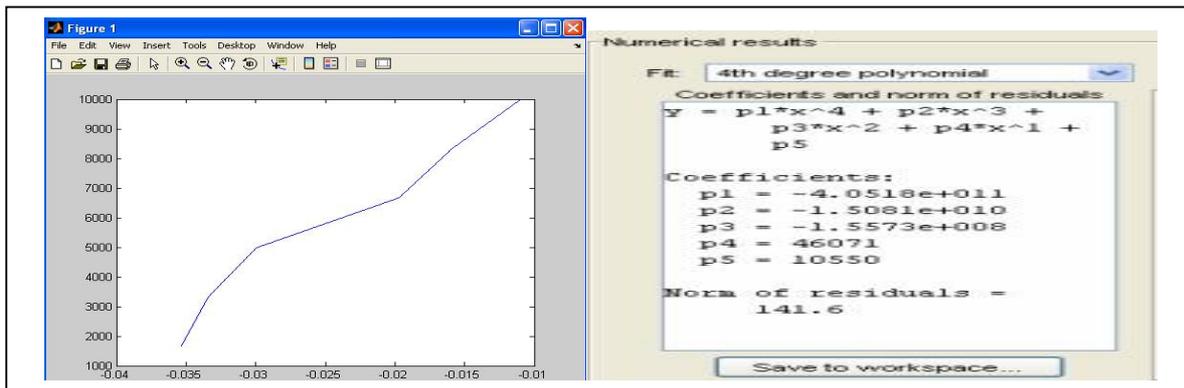


Fig.8: Difference in curve and equation between second and first curve

Difference in curve and equation between third and second curve as shown in Fig.9.

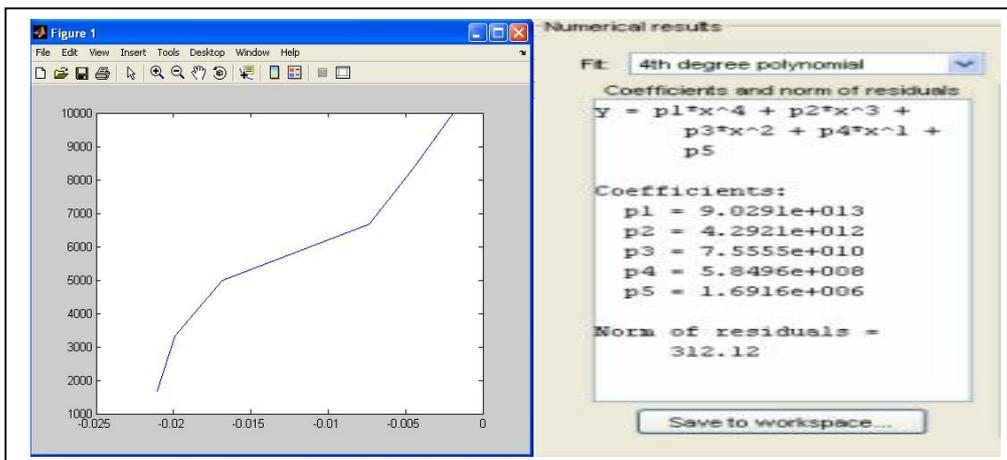


Fig.9: Difference in curve and equation between third and second curve

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Considering degradation the variation of displacement under each cycle as shown in Table 2.

Table II: Variation of Displacement under each cycle (without considering degradation)

Cyclic loading (KN)			Displacement (mm)		
First Cycle	Second Cycle	Third Cycle	First Cycle	Second Cycle	Third Cycle
0	0	0	0	0	0
100	100	100	0.3	0.351	0.393
0	200	200	0.0425	0.402	0.547
-100	100	300	-0.386	0.397	0.683
0	0	200	-0.0432	0.0527	0.591
-	-100	100	-	-0.475	0.223
-	-200	0	-	-0.78	0.0671
-	-100	-100	-	-0.513	-0.436
-	0	-200	-	-0.0615	-0.668
-	-	-300	-	-	-0.885
-	-	-200	-	-	-0.784
-	-	-100	-	-	-0.152
-	-	0	-	-	-0.0792

Load vs. Displacement curve for cyclic loading (without considering degradation) as shown in Fig.10.

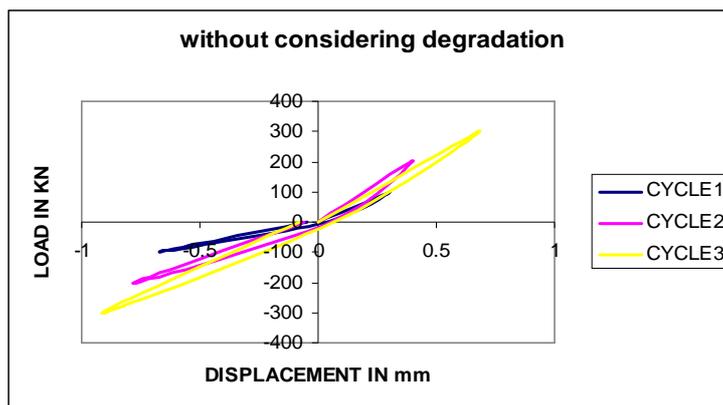


Fig.10: Load vs. Displacement Curve for cyclic loading (without considering degradation)

The variation of displacement under each cycle (with considering degradation) as shown in Table .3.

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Table III: Variation of Displacement under each cycle (with considering degradation)

Cyclic loading (KN)			Displacement (mm)		
First Cycle	Second Cycle	Third Cycle	First Cycle	Second Cycle	Third Cycle
0	0	0	-0.0432	-0.0615	-0.0735
100	100	100	0.421	0.351	0.393
0	200	200	0.0513	0.77	0.547
-100	100	300	-0.547	0.614	0.683
0	0	200	-0.0615	0.0651	0.591
-	-100	100	-	-1.02	0.223
-	-200	0	-	-0.78	0.0797
-	-100	-100	-	-0.513	-0.436
-	0	-200	-	-0.0735	-0.668
-	-	-300	-	-	-0.885
-	-	-200	-	-	-0.784
-	-	-100	-	-	-0.521
-	-	0	-	-	-0.122

Load vs. Displacement curve for cyclic loading (with considering degradation) as shown in Fig.11.

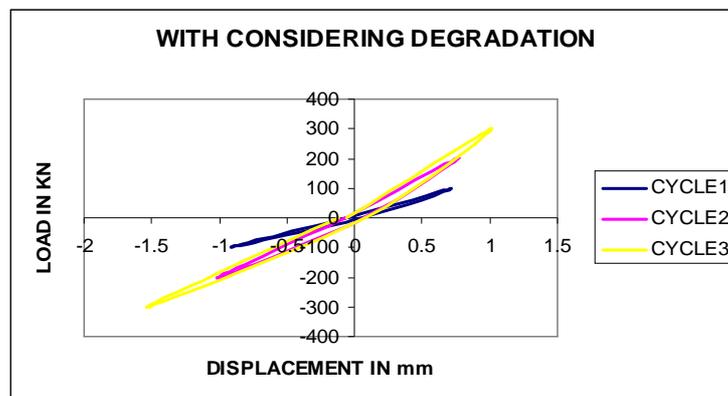


Fig.11: Load vs. Displacement curve for cyclic loading (with considering degradation)

Percentage reduction in stiffness = 13.43%

Percentage reduction in strength = 12.67%

Using this reduction in strength and stiffness degradation, a real building which is situated in Kodambakkam, Chennai is considered in the the analysis. The dimension of the building is 28m x 7mx15m. The column sizes are given in Table.4. In modelling beams and columns are modelled as frame elements. Beam-column joint modelled as rigid connection and end of the column is considered as fixed.

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Table IV: Column Dimensions

Column Number	Dimensions (mm)
C <sub>1</sub>	230X300
C <sub>2A</sub> , C <sub>2B</sub>	230X400
C <sub>3A</sub> , C <sub>3B</sub>	230X450

Table V: Beam Dimensions

Beam Number	Dimensions (mm)
R <sub>B1A</sub>	230X400
R <sub>B3</sub> , R <sub>B5</sub> , R <sub>B8</sub> , R <sub>B9</sub> , R <sub>B10</sub> , R <sub>B11</sub>	230X450

Table VI: Reinforcement details for beams and columns

Beams and Columns	Top reinforcement	Bottom reinforcement
R <sub>B1A</sub>	3 No's of 12 mm dia	3 No's of 12 mm dia
R <sub>B3</sub> , R <sub>B5</sub> , R <sub>B8</sub> , C <sub>3A</sub> , C <sub>3B</sub>	3 No's of 16 mm dia	3 No's of 16 mm dia
R <sub>B9</sub> , R <sub>B11</sub>	2 No's of 20mm dia	2 No's of 20mm dia
R <sub>B10</sub>	2 No's of 20mm dia	3 No's of 16 mm dia
C <sub>1</sub>	2 No's of 12 mm dia	3 No's of 12 mm dia

Three dimensional modelling of the building in SAP 2000 as shown in Fig.12.

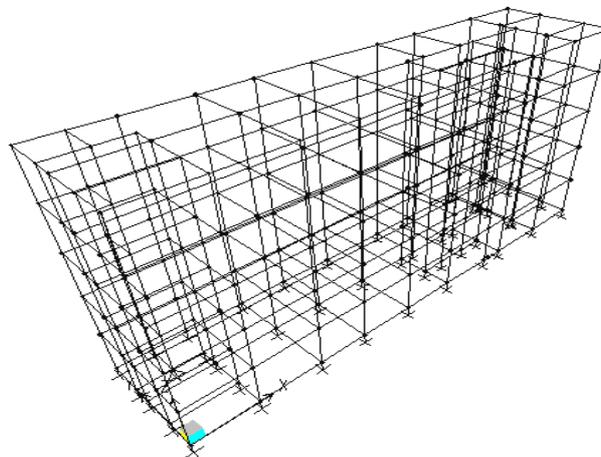


Fig 12: 3D Modeling of RC Frame in SAP 2000

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## Pushover analysis

This is a static non-linear analysis procedure. This is a performance based design approach, which has three characteristics such as, Demand, Capacity and Performance. The demand represents earthquake ground motion, the capacity represents the strength of the structure and the performance represents whether the capacity is able to withstand the demand or not. The base shear for the structure is to be calculated from the spectral acceleration ( $A_h$ ), and this force is distributed as a force at centers of mass of different stories. The pushover analysis gives the step-by-step hinge formation in the structure. The formation of hinges depends on the hinge properties of the element and its strength. In SAP2000, the hinge properties are to be defined as moment-rotation curves as input. For the analysis of beams, shear (V) and in-plane moment (M) are assigned and for columns, axial load (P) and axial load with biaxial moment (PMM) hinges are assigned. For simulating the effect of strength and stiffness degradation in each loading, extra hinges are added in both beams and columns, considering the load vs. displacement values already given in Table4.1.

Three different pushover cases are defined. 'GRAV' is the gravity pushover, which is performed for (DL + 0.25LL). Gravity pushover was force controlled, i.e., gravity load is given at small increments in steps until full gravity load was applied. 'PUSH X' is the lateral push in X- direction, which was performed for 100% of lateral storey forces in x- direction plus 30% of storey forces in y- direction. PUSH forces in x- direction plus 30% of storey forces in y- direction. PUSH Y is the 30% of storey forces in x-direction and 100% of storey forces in y-direction. Both the lateral pushovers were displacement controlled which are applied following the gravity pushover analysis. Various push over cases, are given in Table.7.

Table VII: Varies Pushover Cases

Pushover case	Name	Loads	Controlled by	Previous pushover
1	GRAV	DL + 0.25LL	Force	-----
2	PUSHX	EQ1 + 0.3EQ2	Displacement	GRAV
3	PUSHY	EQ2 + 0.3EQ1	Displacement	GRAV

The deformed shape of the structure due to the first loading as shown in Fig.13.

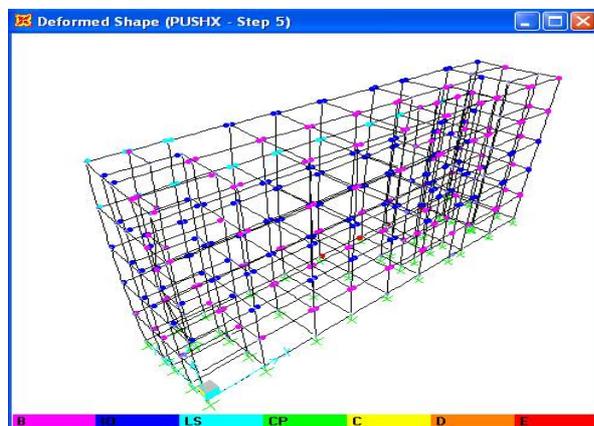


Fig 13: Deformed shapes for first Load case

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In first loading without considering any degradation in young's modulus, from the deformed shape there were maximum hinges formed in B-IO range, and IO-LS range, 9 hinges in Life safety range, only 4 hinges >D range. The deformed shape of the structure due to second loading as shown in Fig.14.

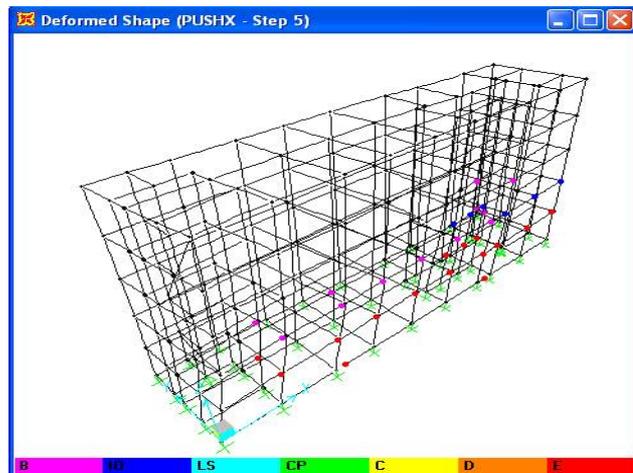


Fig 14: Deformed shapes for second Load case

In second loading with considering degrading young's modulus from previous loading, from the deformed shape there were 12 hinges formed in B-IO range and 6 hinges were in IO-LS range, but 15 hinges >E range. Due to consider the reduction in young's modulus the number of hinges formed for collapse stage increased. The deformed shape of the structure due to third loading as shown in Fig.15.

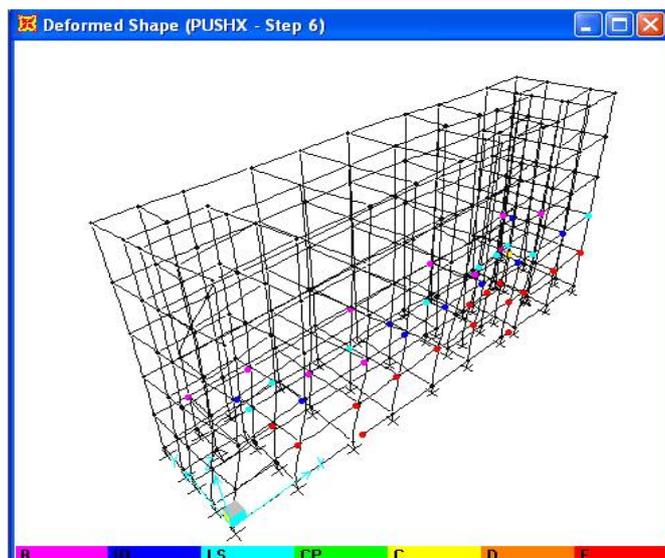


Fig .15: Deformed shapes for third Load case

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In third loading with considering degrading young's modulus from second loading, from the deformed shape there were 0 hinges formed in B-IO range and 9 hinges were in IO-LS range, 11 hinges were in life safety range, but 16 hinges >E range. Due to consider the reduction in young's modulus the number of hinges formed for collapse stage was increased. From the pushover analysis Base shear and Displacement is noticed. For first loading no extra hinges are added for the analysis. Second and third loading extra hinges are added considering the Load vs. Displacement values already given in Table4.1. The increased displacement under each loading is given in Table4.7

Table VII: Base shear vs. Displacement

Base shear (KN)	Displacement in each cycle (m)		
	First loading	Second loading	Third loading
0	0	0	0
8015.7056	0.0145	0.0163	0.0179
11673.86	0.0214	0.0241	0.0265
11722.72	0.0215	0.0245	0.0266
12303.97	0.0303	0.0338	0.0369
1897.05	0.0077	0.0112	0.0231

From the output table, the maximum base shear in push X is 12303.97KN and the corresponding displacement in first loading is 0.0303m. For the same base shear second and third loading (with reduced young's modulus), the displacements are 0.0338m, 0.0369m. It shows that considering degrading young's modulus in each cycle with the same base shear, the displacement of the element get increased. The variation of displacement with base shear is given in Fig.16.

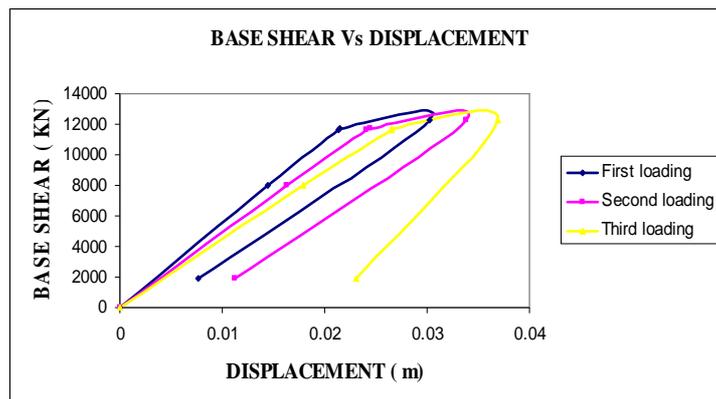


Fig.16: Variation of Displacement

From the pushover analysis base shear and displacement are noticed. By considering the effect of degradation in each loading, the displacement is increased for the same base shear. Percentage of increase in displacement is around 12%.

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## IV. CONCLUSIONS

A one bay 2 dimensional RC frame was modeled in SAP 2000. Non-linear static analysis was done. Reduction in young's modulus due to strength and stiffness degradation in each cycle was found out. The difference in curve between the second and first cycle, third and second cycle was found out from MATLAB. Using this reduction in young's modulus, a 3 dimensional RC building was analyzed for pushover. The number of hinges in each cycle with reduced young's modulus, displacement and base shear was found out.

From the analytical work carried out, following conclusions were drawn.

- From the nonlinear static analysis, percentage reduction in strength and stiffness in each cycle was 14% and 18% respectively.
- Due to the reduction in strength and stiffness, percentage reduction in young's modulus for first cycle was 12.13% and percentage reduction in young's modulus for second cycle was 13%.
- Considering this young's modulus in each cycle, displacement of the structure was increased.
- From the push over analysis, the maximum base shear in push X was 12303.97KN, and the corresponding displacement in first loading was 0.0303m. For the same base shear second and third loading (with reduced young's modulus) the displacements were 0.0338m, 0.0369m. Percentage increase in displacement was around 12% in each cycle. It shows that by considering the degraded young's modulus in each cycle with the same base shear, the displacement of the element gets increased. Also the number of hinges formed where increased in the failure range.

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