

# Comparison of Non-Linear Static & Dynamic Capacity of an existing Seven Storied RC Building

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# Outlines



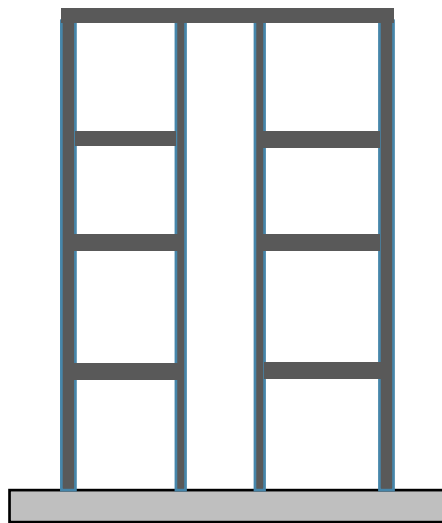
- ➔ **Background**
- ➔ **Objective**
- ➔ **Literature Review**
- ➔ **Numerical Modelling**
- ➔ **Results & Analysis**
- ➔ **Conclusions**



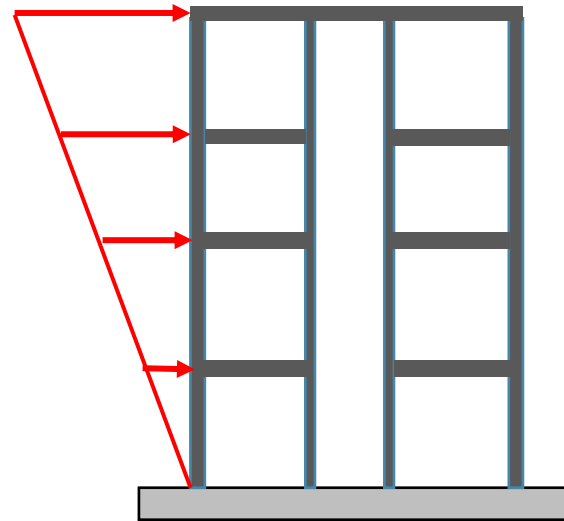
# Background



Nepal earthquake: a disaster that shows quakes don't kill people, buildings do

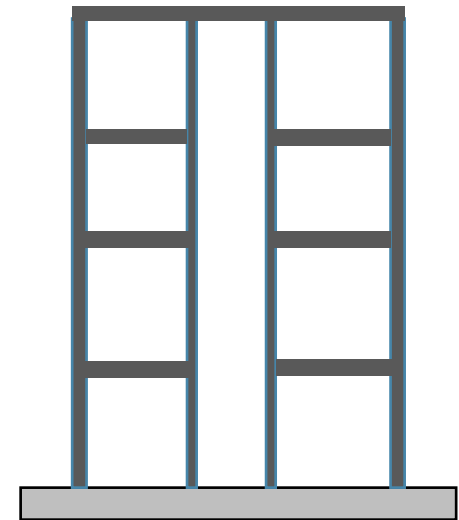
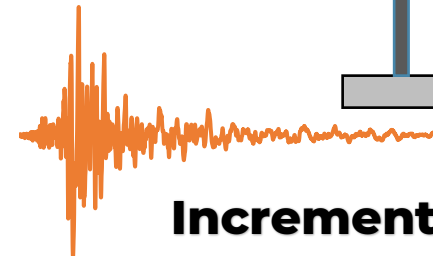


**Existing Building**



**Pushover Analysis**

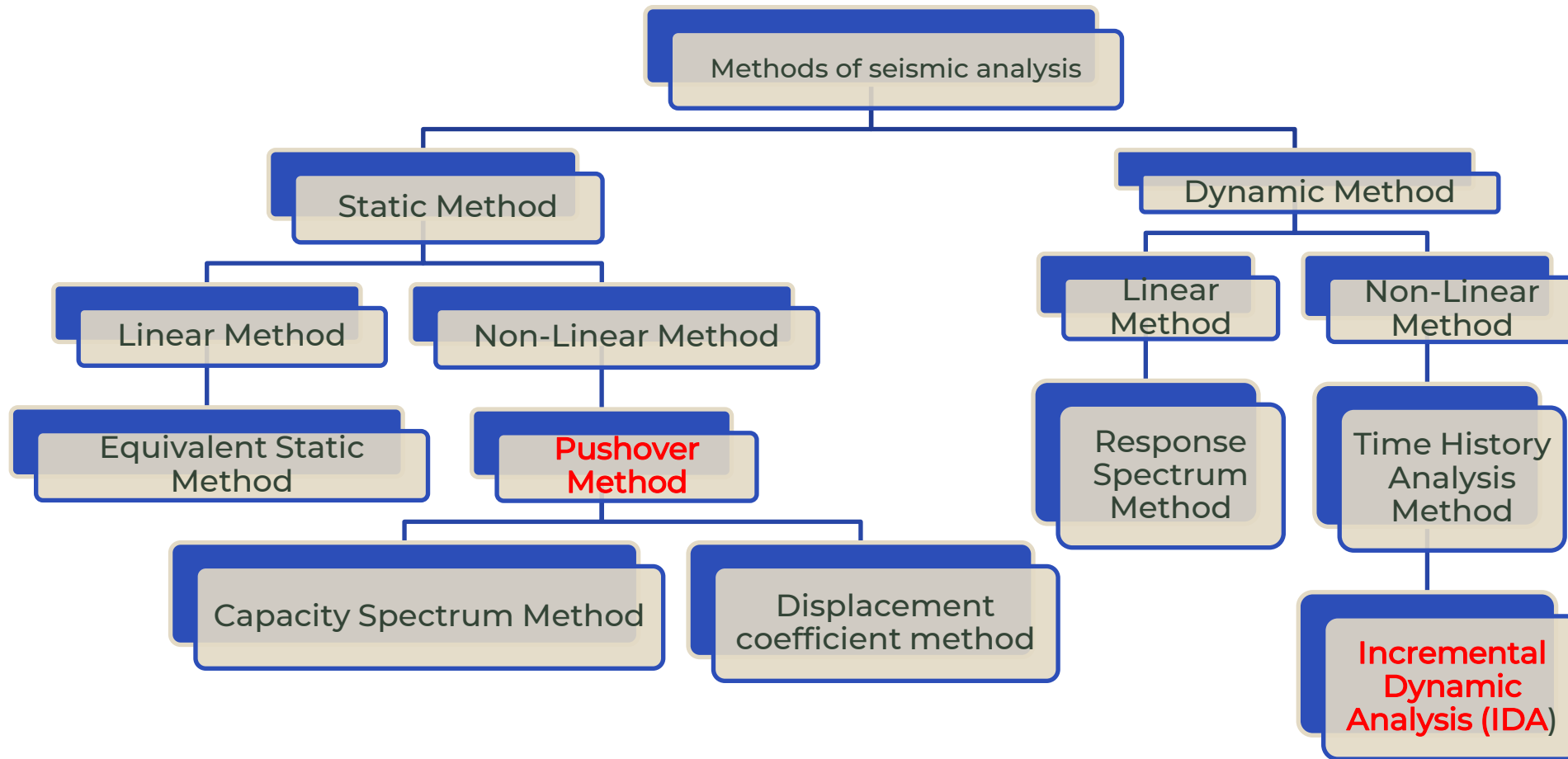
**Under multiple  
Ground motions**



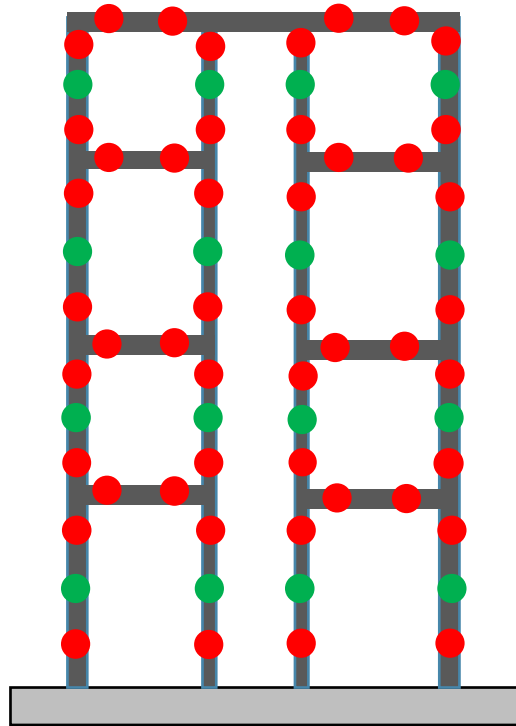
**Incremental Dynamic Analysis**

- ❖ To collect an existing building plan & make a model on the SAP2000 program.
- ❖ To perform non-linear static analysis (pushover analysis) of the building.
- ❖ To perform incremental dynamic analysis (IDA) of the building.
- ❖ To perform a comparative study of the capacity curve and damage state of pushover and incremental dynamic analysis.

# Literature Review

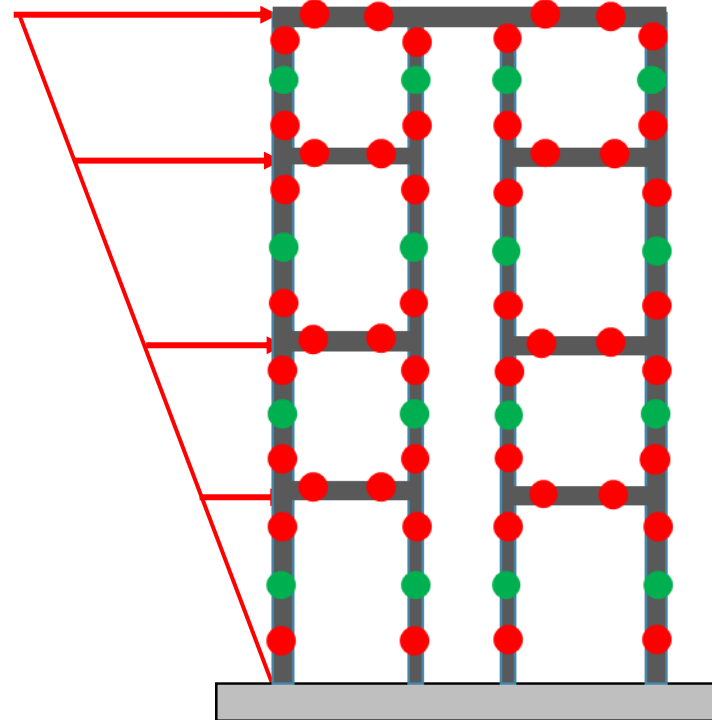


## Pushover Analysis

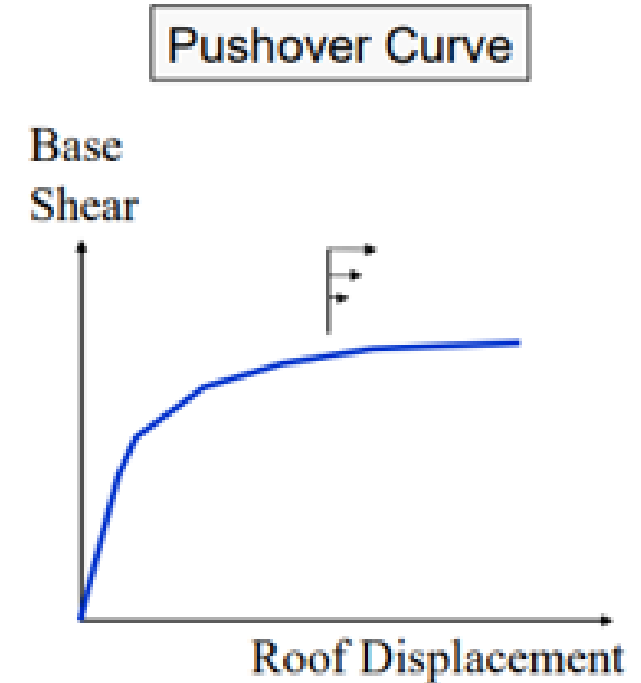


● = Flexural Hinge  
● = Shear Hinge

**Step 1 : Assign hinges to the model**

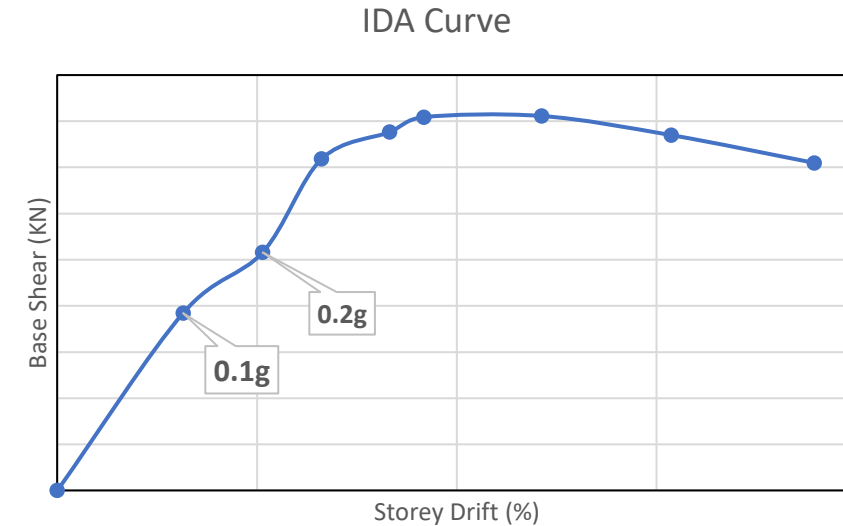
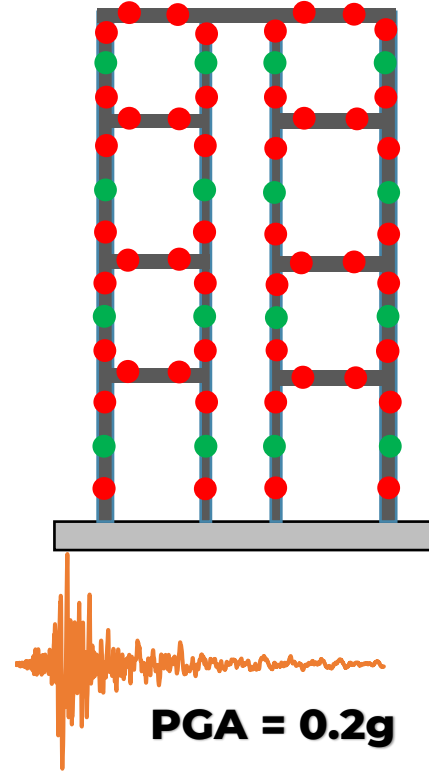
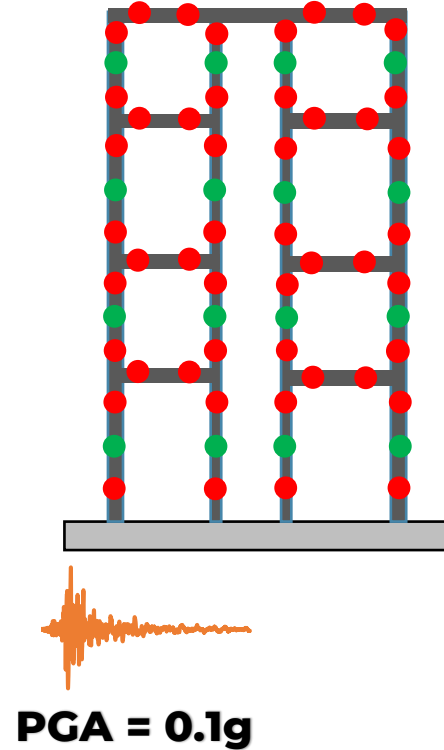
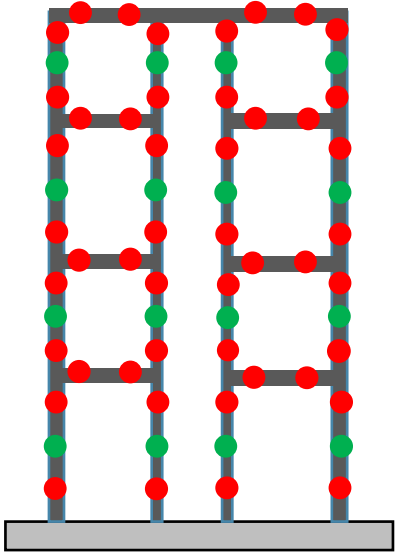


**Step 2 : Monotonic triangular load pattern application**



**Step 3 : Nonlinear analysis to obtain pushover curve**

## Incremental Dynamic Analysis (IDA)

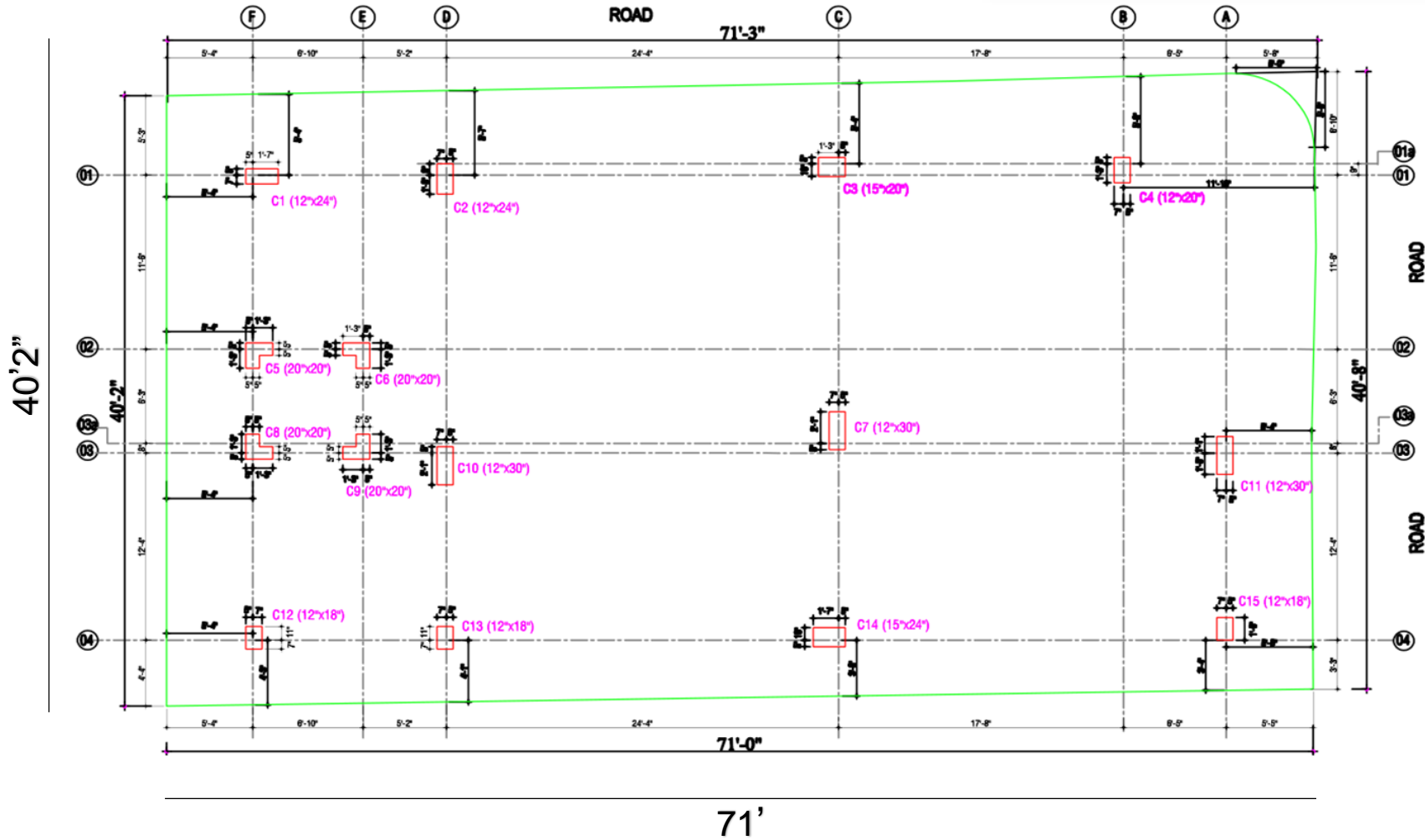


**Step 1 : Assign hinges to the model**

**Step 2 : Scale up & down to the ground motions**

**Step 3 : Nonlinear analysis to obtain IDA curve**

# Numerical Modelling of an existing RC building



Column Layout

| Information         | Corresponding data                    |
|---------------------|---------------------------------------|
| Project Name        | (G+6) 07 Storied Residential Building |
| Project Location    | Dhaka                                 |
| f'c (Column)        | 3500 psi                              |
| f'c (Other Members) | 3000 psi                              |
| fy                  | 72.5 ksi                              |
| Seismic Zone        | II                                    |

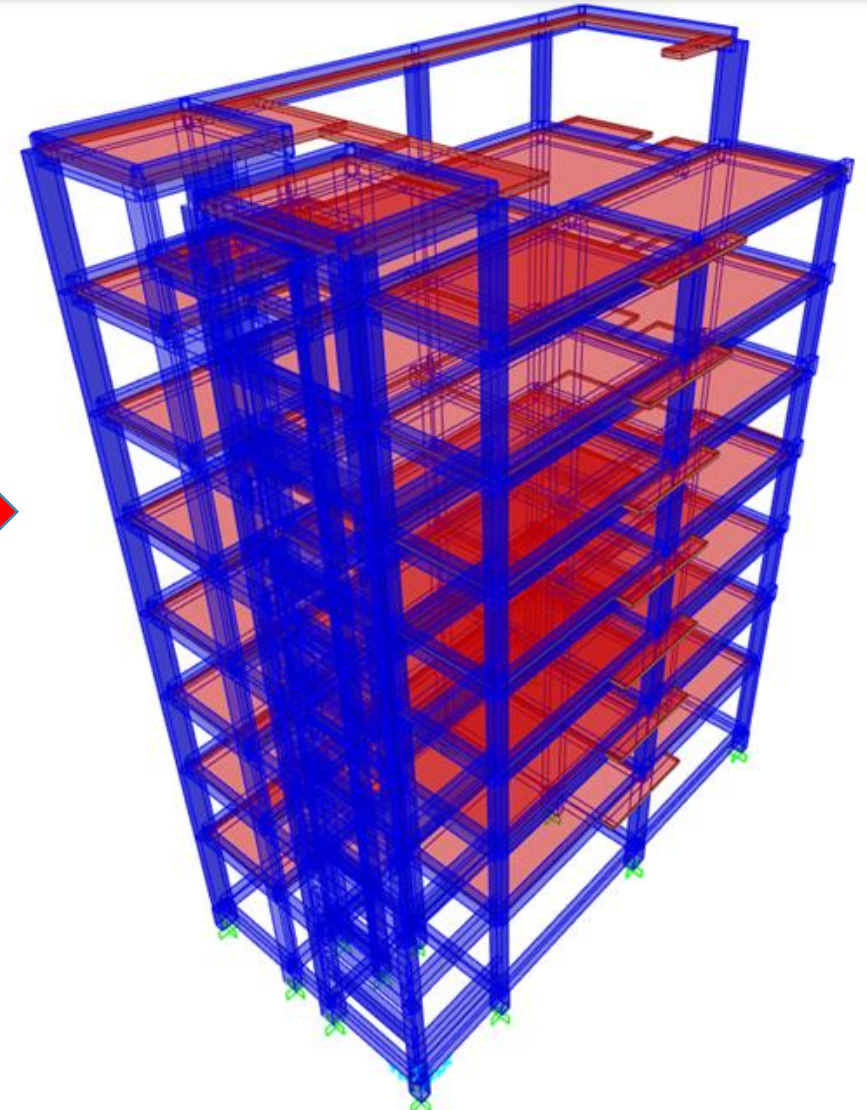


# Numerical Modelling of an existing RC building

| Loads | Value  |
|-------|--------|
| FF    | 20 psf |
| PW    | 25 psf |
| LL    | 40 psf |



**Elevation view of existing building**

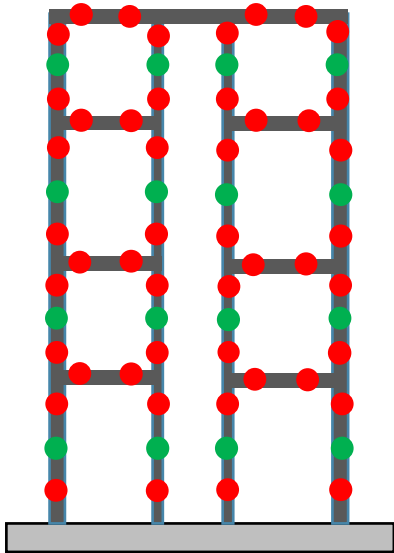


**SAP2000 model of existing building**

# Numerical Modelling of an existing RC building

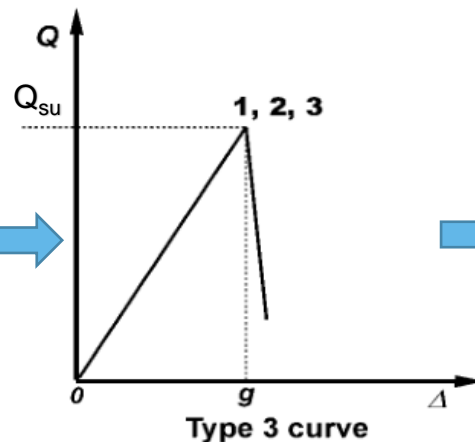
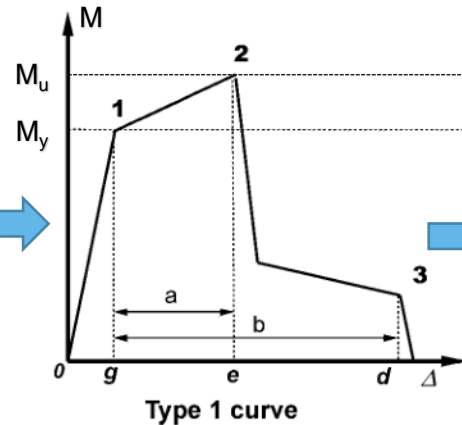
## Details of Pushover Analysis in SAP2000

### Plastic Hinge Definition and Assignment



● = Flexural Hinge

● = Shear Hinge



JBDPA (2001) formula used for calculating ultimate moment of columns:

$$M_u = \{0.8a_t \cdot \sigma_y \cdot D + 0.12b \cdot D^2 \cdot F_c\} \cdot \left( \frac{N_{max} - N}{N_{max} - 0.4b \cdot D \cdot F_c} \right)$$

JBDPA (2001) formula used for calculating ultimate moment of Beams:

$$M_u = 0.9a_t \cdot \sigma_y \cdot d$$

JBDPA (2001) formula used for calculating shear capacity of Columns:

$$Q_{su} = \left\{ \frac{0.053p_t^{0.23}(18 + F_c)}{\frac{M}{Q \cdot d} + 0.12} + 0.85\sqrt{p_w \cdot \sigma_{wy}} + 0.1\sigma_0 \right\} \cdot b \cdot j$$

# Numerical Modelling of an existing RC building

## Hinge Assignment



Table: Yield Moment calculation of columns at Second Floor

| Column Notation | No. of bars | Bar dia (mm) | Total reinforce ment area, ag (mm <sup>2</sup> ) | Total area of tensile reinforcing bars, at (mm <sup>2</sup> ) | Axial Force (N) | Ultimate flexural strength, Mu (N-mm) | Yield Moment, My (KN-mm) |
|-----------------|-------------|--------------|--|---|-----------------|---------------------------------------|--------------------------|
| C-201           | 16          | 16           | 3216   | 1407  | 488474.3        | 4.757E+08                             | 432.419                  |
| C-202           | 4           | 20           | 1256   | 1633  | 933469.3        | 3.117E+08                             | 283.353                  |
|                 | 12          | 16           | 2412   |   | 9               |                                       |                          |

Frame Hinge Property Data for C-201\_M - Moment M3

Edit

Displacement Control Parameters

| Point | Moment/SF | Rotation/SF |
|-------|-----------|-------------|
| E-    | -0.2      | -0.025      |
| D-    | -0.2      | -0.015      |
| C-    | -1.1      | -0.015      |
| B-    | -1        | 0           |
| A     | 0         | 0           |
| B     | 1.        | 0.          |
| C     | 1.1       | 0.015       |
| D     | 0.2       | 0.015       |
| E     | 0.2       | 0.025       |

☒ Symmetric

Load Carrying Capacity Beyond Point E

☒ Drops To Zero

☐ Is Extrapolated

Scaling for Moment and Rotation

|   | Positive          | Negative |
|---|-------------------|----------|
| <input type="checkbox"/> Use Yield Moment   | Moment SF 432.419 |          |
| <input type="checkbox"/> Use Yield Rotation | Rotation SF 1.    |          |

(Steel Objects Only)

Acceptance Criteria (Plastic Rotation/SF)

|   | Positive  | Negative |
|---|-----------|----------|
| <input checked="" type="checkbox"/> Immediate Occupancy | 3.000E-03 |          |
| <input type="checkbox"/> Life Safety                    | 0.012     |          |
| <input type="checkbox"/> Collapse Prevention            | 0.015     |          |

☐ Show Acceptance Criteria on Plot

Type

☒ Moment - Rotation

☐ Moment - Curvature

Hinge Length

Relative Length

Hysteresis Type And Parameters

Hysteresis Type

No Parameters Are Required For This Hysteresis Type

OK Cancel

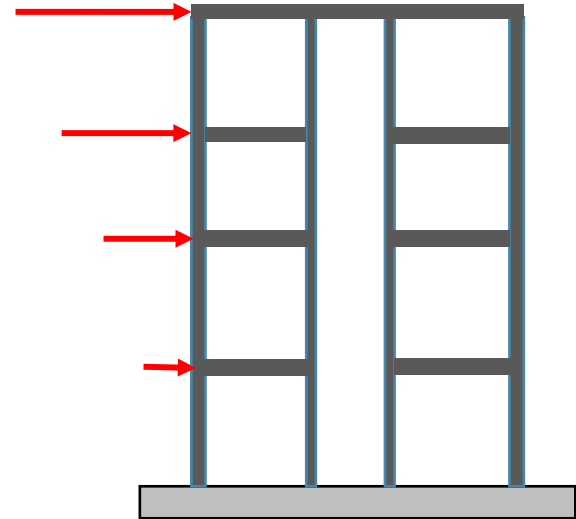
Yield Moment is obtained dividing the ultimate moment by 1.1

# Numerical Modelling of an existing RC building

## Load Cases for Pushover Analysis

### Earthquake load case (Eqx)

EQx load



S 1994 UBC Seismic Load Pattern

**Load Direction and Diaphragm Eccentricity**

☒ Global X Direction  
☐ Global Y Direction

Ecc. Ratio (All Diaph.)

Override Diaph. Eccen.

**Time Period**

☐ Method A Ct (ft) =   
☒ Program Calc Ct (ft) =   
☐ User Defined T =

**Lateral Load Elevation Range**

☒ Program Calculated  
☐ User Specified

Max Z   
Min Z

**Seismic Coefficients**

Seismic Zone Factor, Z   
☒ Per Code  
☐ User Defined

Site Coefficient, S   
Importance Factor, I

**Factors**

Numerical Coeff, Rw

### Pushover load case

S Load Case Data - Nonlinear Static

**Load Case Name**

**Load Case Type**

**Initial Conditions**

☐ Zero Initial Conditions - Start from Unstressed State  
☒ Continue from State at End of Nonlinear Case

Important Note: Loads from this previous case are included in the current case

**Modal Load Case**

All Modal Loads Applied Use Modes from Case

**Loads Applied**

| Load Type    | Load Name | Scale Factor |
|--------------|-----------|--------------|
| Load Pattern | EQx       | 1.           |
| Load Pattern | EQy       | 1.           |

**Other Parameters**

Load Application    
Results Saved    
Nonlinear Parameters

**Analysis Type**

☐ Linear  
☒ Nonlinear

**Geometric Nonlinearity Parameters**

☐ None  
☒ P-Delta  
☐ P-Delta plus Large Displacements

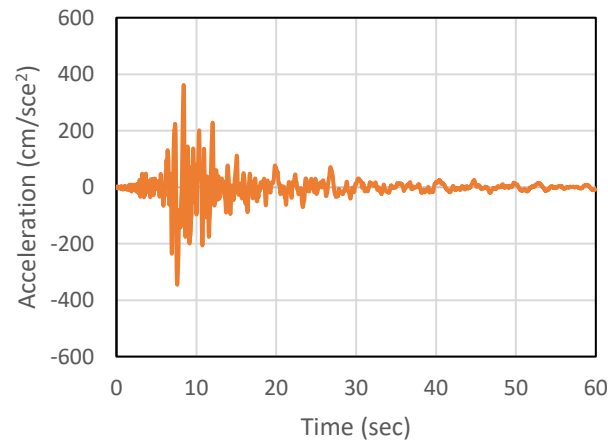
**Mass Source**

Load Cases for Pushover analysis Y direction is defined in a similar manner

# Numerical Modelling of an existing RC building

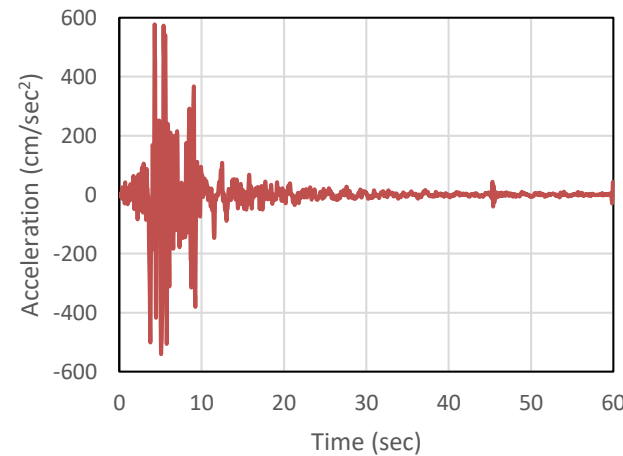
## Details of Incremental Dynamic Analysis in SAP2000

### Ground motions used for the IDA



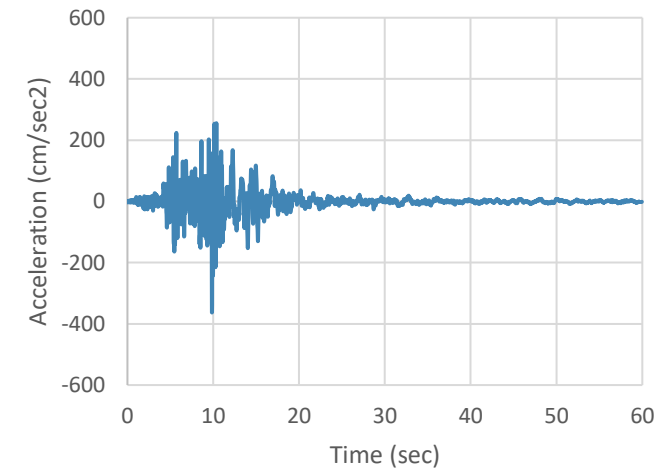
**Hollister Earthquake**

PGA = 361.787 cm/sec<sup>2</sup>  
= 0.3688 g



**Newhall Earthquake**

PGA = 575.1675 cm/sec<sup>2</sup>  
= 0.5863 g



**Santa Monica Earthquake**

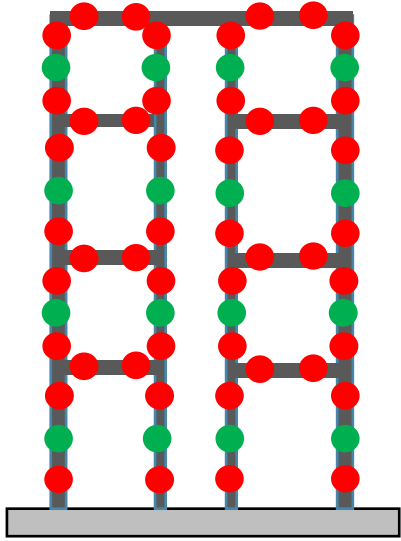
PGA = 362.127 cm/sec<sup>2</sup>  
= 0.3691 g

**Newhall has the highest PGA among three earthquake**

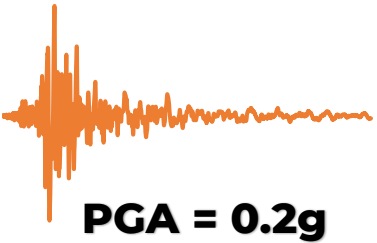
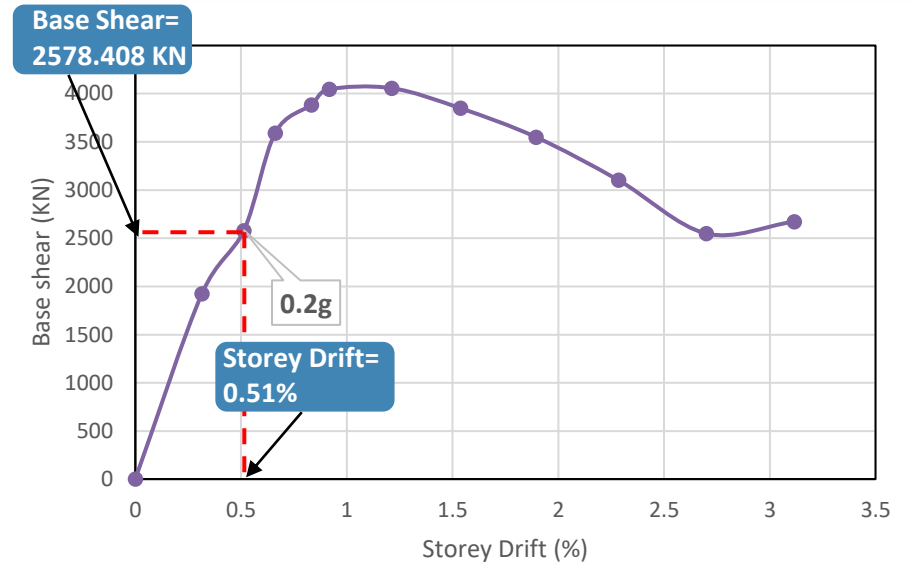


# Numerical Modelling of an existing RC building

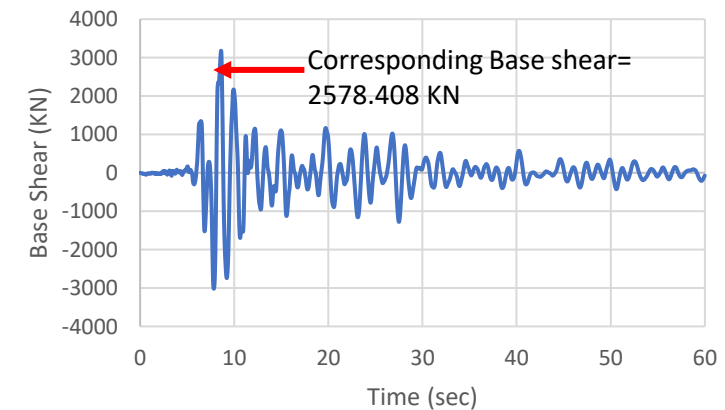
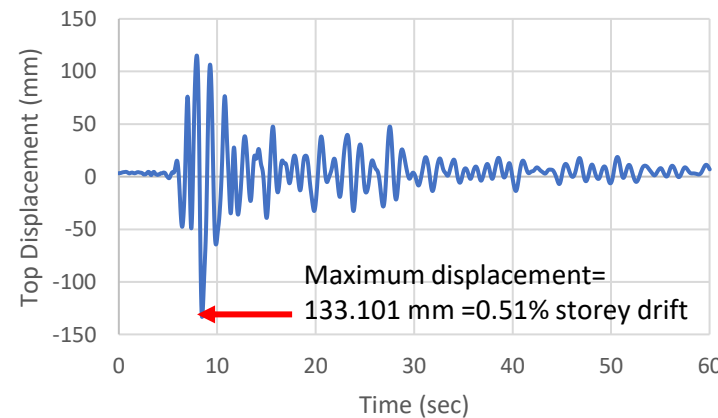
## Scale Factor



|                       | Peak Acceleration | Scale Factor<br>( $\frac{\text{Required Peak}}{\text{Peak Ground Acceleration}}$ ) |
|-----------------------|-------------------|--|
| Original Time History | 0.3688g           | 1  |
| Scaled Time History   | 0.1g              | 0.271  |
|                       | 0.2g              | 0.542  |
|                       | 0.3g              | 0.813  |
|                       | 0.4g              | 1.085  |
|                       | 0.5g              | 1.356  |
|                       | 0.6g              | 1.627  |
|                       | 0.7g              | 1.898  |
|                       | 0.8g              | 2.169  |
|                       | 0.9g              | 2.44   |
|                       | 1.0g              | 2.711  |



Scale Factor for Hollister Earthquake



# Numerical Modelling of an existing RC building

## Load Cases for IDA

### Non-linear gravity load cases

**S Load Case Data - Nonlinear Static**

Load Case Name: NL-GR [Set Def Name] [Modify/Show...]

Load Case Type: Static [Design...]

Initial Conditions:  
☒ Zero Initial Conditions - Start from Unstressed State  
☐ Continue from State at End of Nonlinear Case [v]  
Important Note: Loads from this previous case are included in the current case

Modal Load Case:  
All Modal Loads Applied Use Modes from Case: MODAL [v]

Loads Applied

| Load Type    | Load Name | Scale Factor |
|--------------|-----------|--------------|
| Load Pattern | DEAD      | 1.           |
| Load Pattern | DEAD      | 1.           |
| Load Pattern | Live      | 1.           |

[Add] [Modify] [Delete]

Analysis Type:  
☐ Linear  
☒ Nonlinear

Geometric Nonlinearity Parameters:  
☒ None  
☐ P-Delta  
☐ P-Delta plus Large Displacements

Mass Source: MSSSRC1 [v]

Other Parameters:  
Load Application: Full Load [Modify/Show...]  
Results Saved: Final State Only [Modify/Show...]  
Nonlinear Parameters: Default [Modify/Show...]

[OK] [Cancel]

### Non-linear Time history load case for a specific scaled ground motion

**S Load Case Data - Nonlinear Direct Integration History**

Load Case Name: 0.2g [Set Def Name] [Modify/Show...]

Load Case Type: Time History [Design...]

Initial Conditions:  
☐ Zero Initial Conditions - Start from Unstressed State  
☒ Continue from State at End of Nonlinear Case [NL-GR v]  
Important Note: Loads from this previous case are included in the current case

Modal Load Case:  
Use Modes from Case: MODAL [v]

Loads Applied

| Load Type | Load Name | Function  | Scale Factor |
|-----------|-----------|-----------|--------------|
| Accel     | U1        | HOLLISTER | 0.542        |
| Accel     | U1        | HOLLISTER | 0.542        |

[Add] [Modify] [Delete]

☐ Show Advanced Load Parameters

Time Step Data:  
Number of Output Time Steps: 3000  
Output Time Step Size: 0.02

Other Parameters:  
Damping: Proportional [Modify/Show...]  
Time Integration: Hilber-Hughes-Taylor [Modify/Show...]  
Nonlinear Parameters: Default [Modify/Show...]

Analysis Type:  
☐ Linear  
☒ Nonlinear

Solution Type:  
☐ Modal  
☒ Direct Integration

Geometric Nonlinearity Parameters:  
☒ None  
☐ P-Delta  
☐ P-Delta plus Large Displacements

History Type:  
☒ Transient  
☐ Periodic  
☐ Consider Collapse

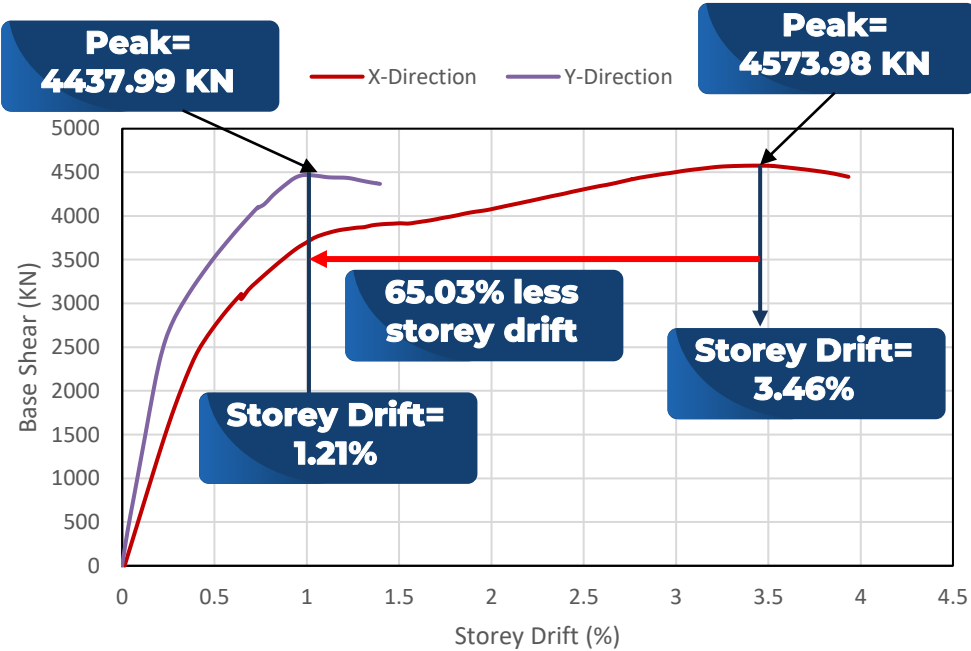
Mass Source: MSSSRC1 [v]

[OK] [Cancel]

The background features a dark blue gradient with abstract geometric elements. On the left side, there are several light blue lines and circles of varying sizes, some overlapping. A large, dark blue rectangular frame is positioned on the right side of the image.

# Results & Analysis

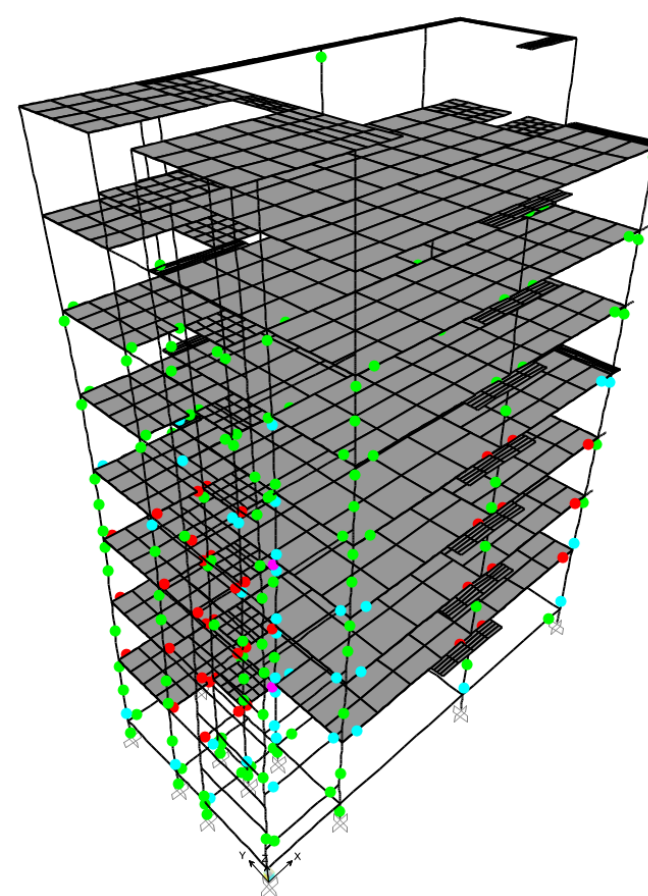
## Pushover Analysis



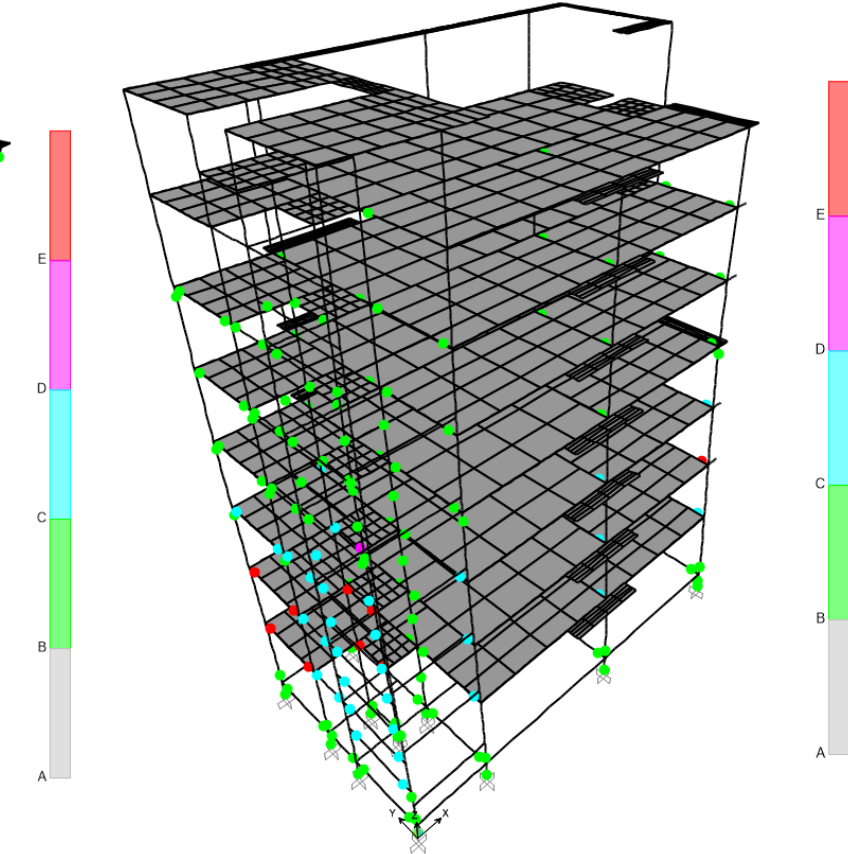
Nearly Same Lateral Capacity

More ductile behavior X-direction

More damage in X-direction as more deformation occurs

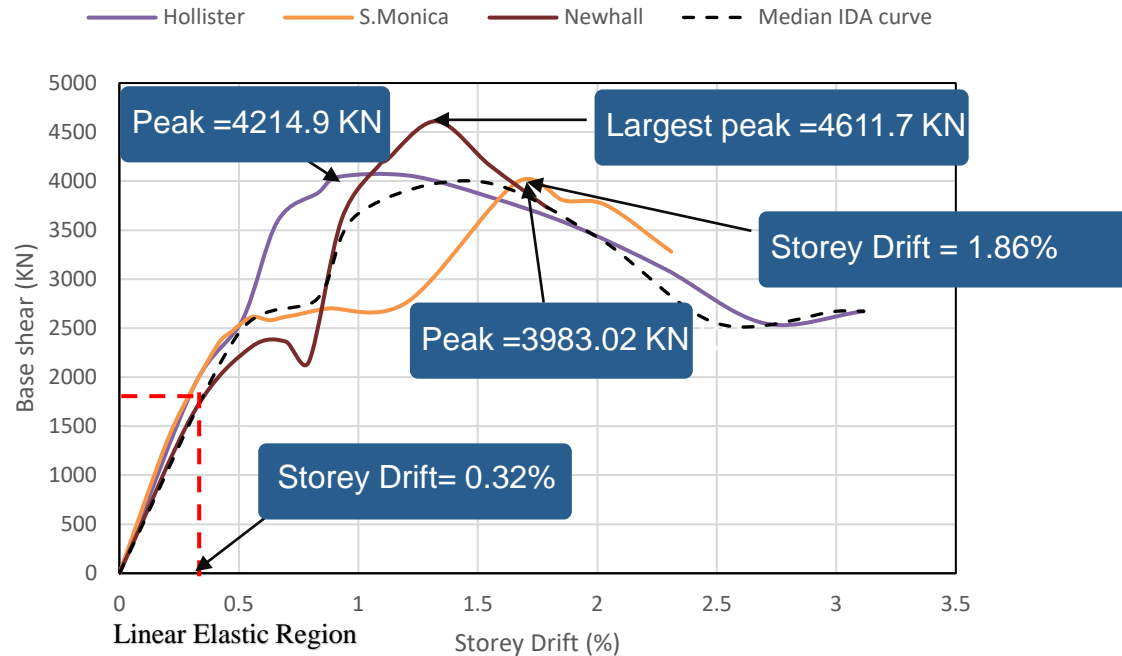


Pushover Analysis (X-direction)



Pushover Analysis (Y-direction)

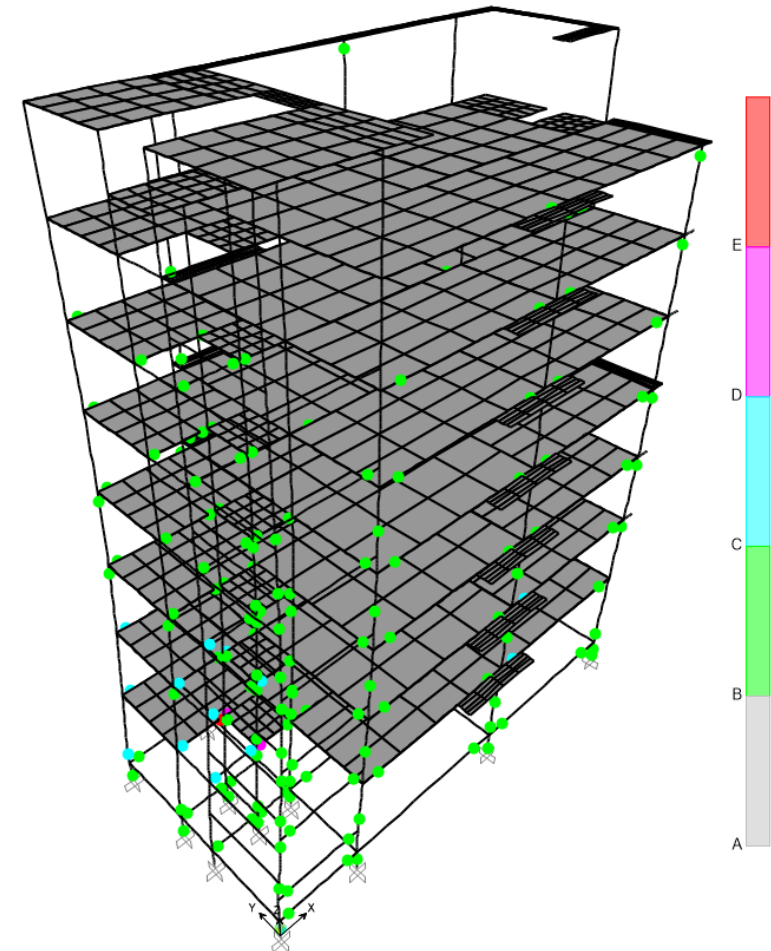
## Incremental Dynamic Analysis



**Same Linear Elastic Region till 0.32% storey drift**

**Newhall Earthquake have 9.41% and 15.78% more lateral capacity than Hollister and Santa Monica Earthquake**

**Santa Monica Earthquake resist 53.72% and 39.85% more storey drift than Hollister and Newhall Earthquake before dropping it's capacity**



**Damage states of Hollister Earthquake**



## Comparison of capacity curve between Pushover and Incremental Dynamic Analysis

### Initial Stiffness

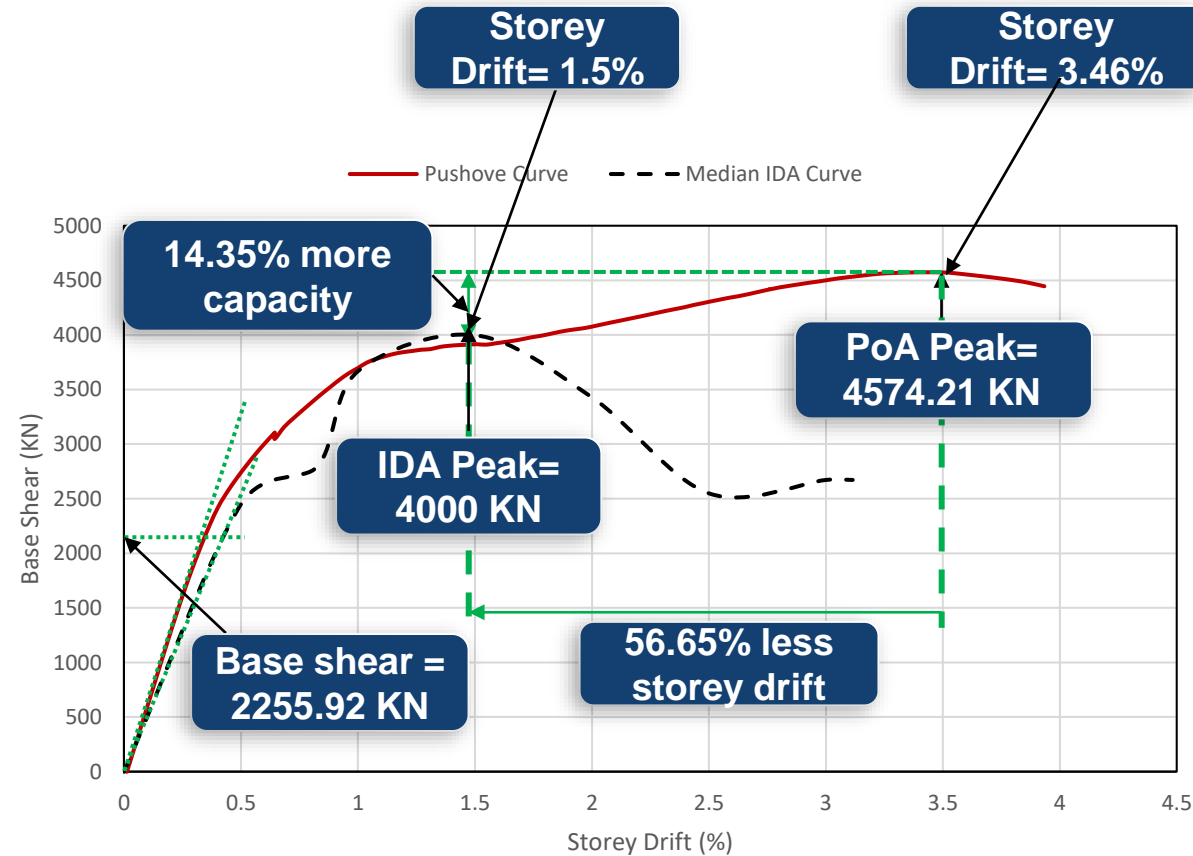
The building shows almost similar elastic properties under pushover and IDA

### Maximum Resistance

The building shows more resistance under static loading

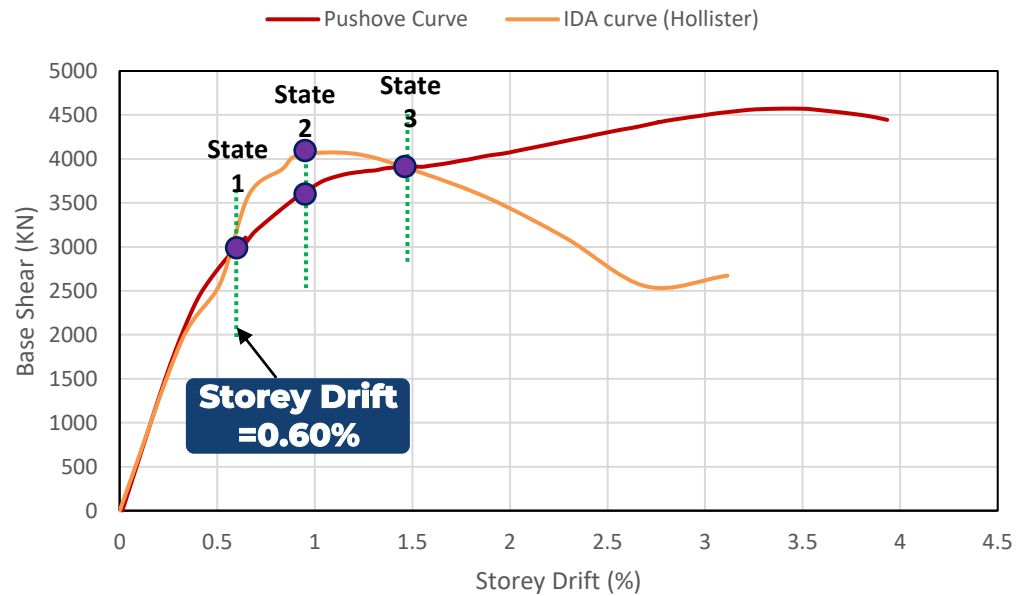
### Ductility

Pushover curve shows more ductile behavior



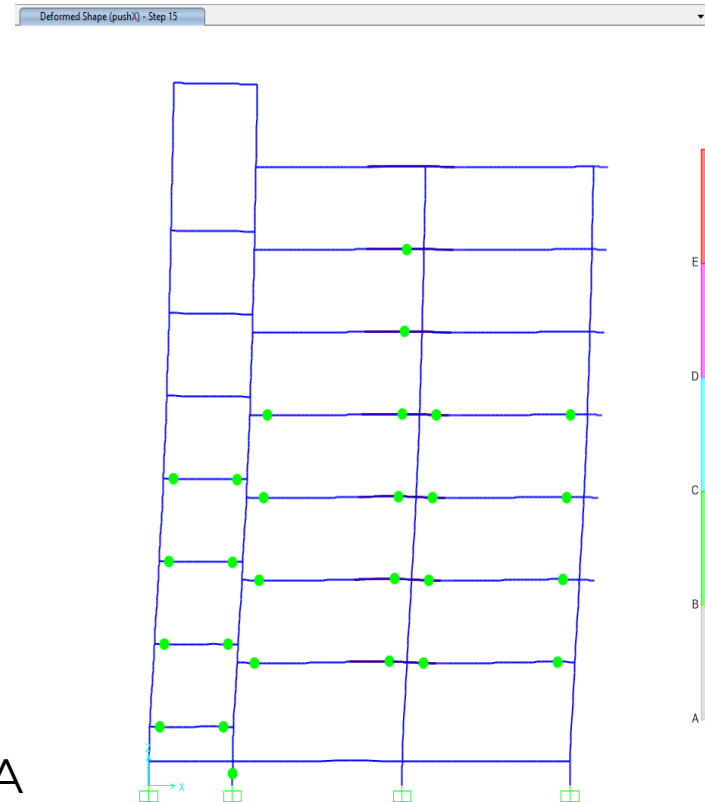
## Comparison of damage states between Pushover and Incremental Dynamic Analysis

### Hinge formation of **State 1**

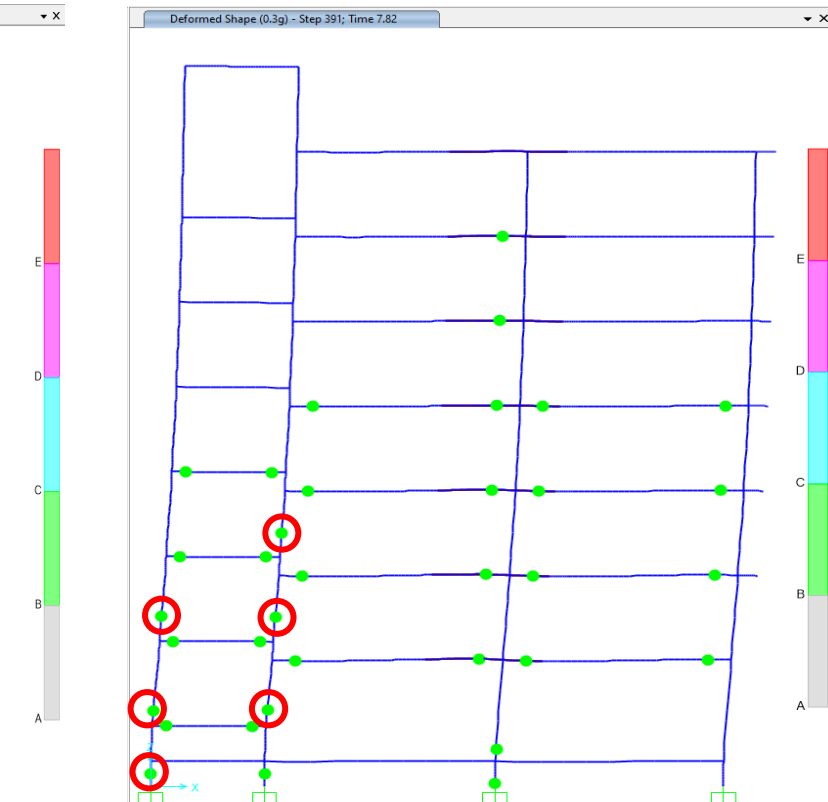


○ = Additional hinges formed during IDA

○ = More damaged hinge during IDA



Pushover  
Analysis



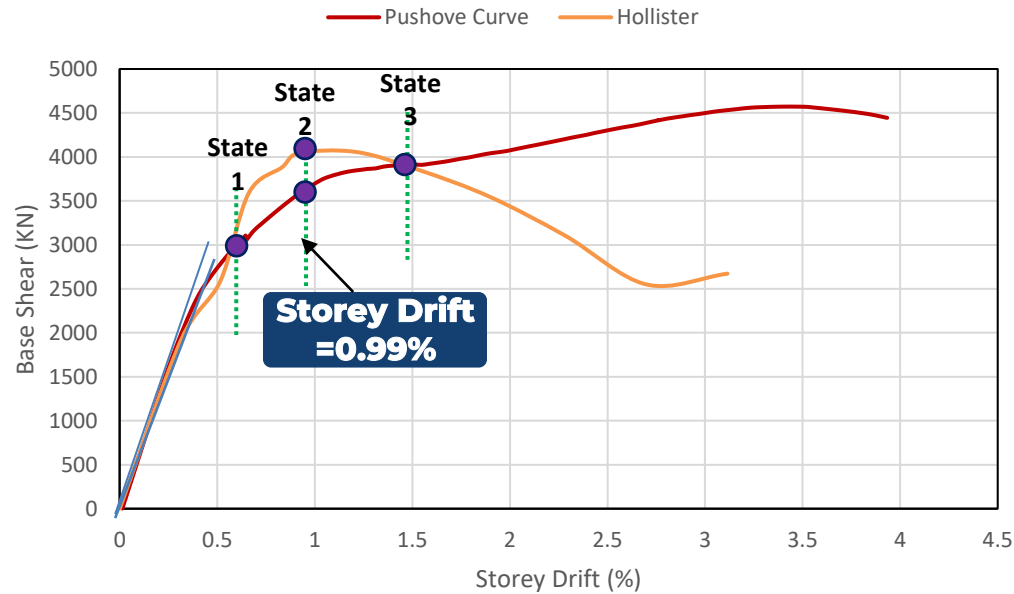
Incremental Dynamic  
Analysis (Hollister Earthquake)

**More hinge formation is observed at state 1 between pushover analysis & IDA**

# Results & Analysis

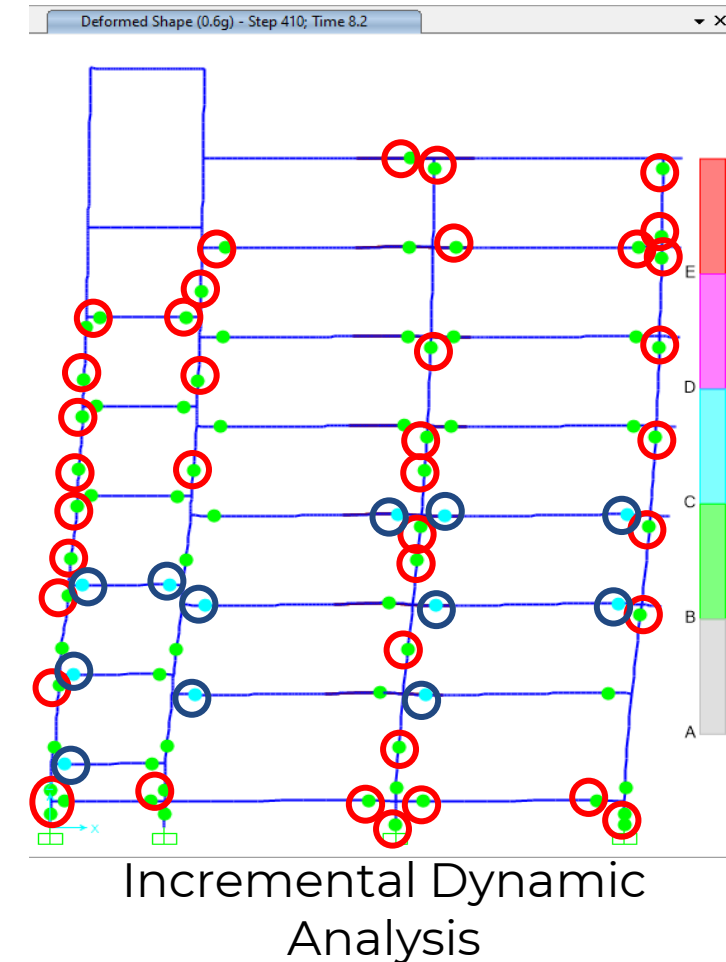
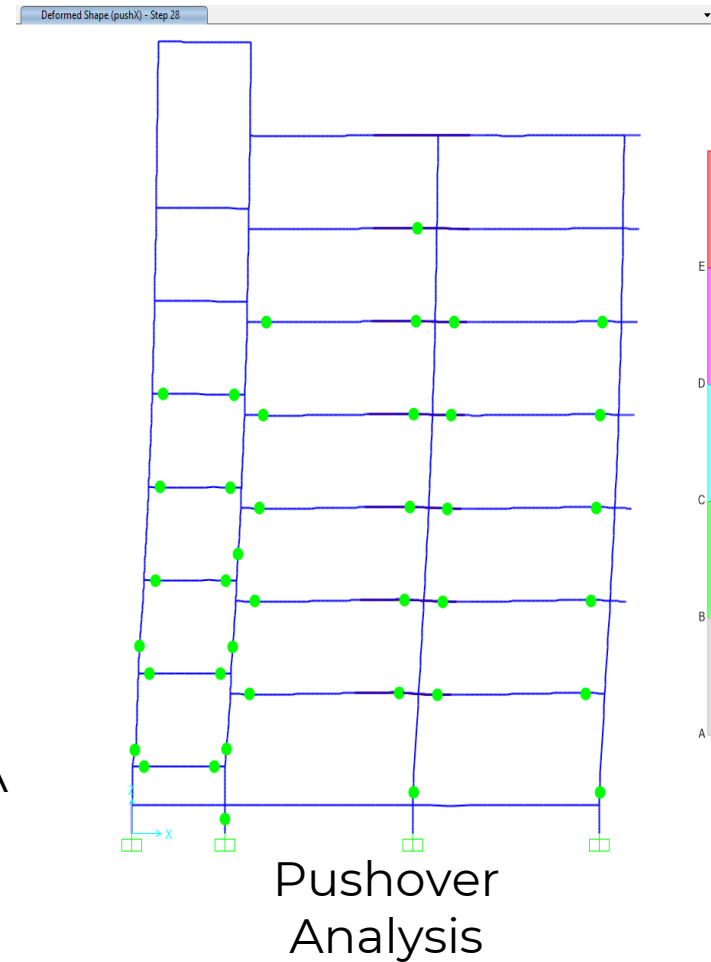
## Comparison of damage states between Pushover and Incremental Dynamic Analysis

Hinge formation of **State 2**



○ = Additional hinges formed during IDA

○ = More damaged hinge during IDA

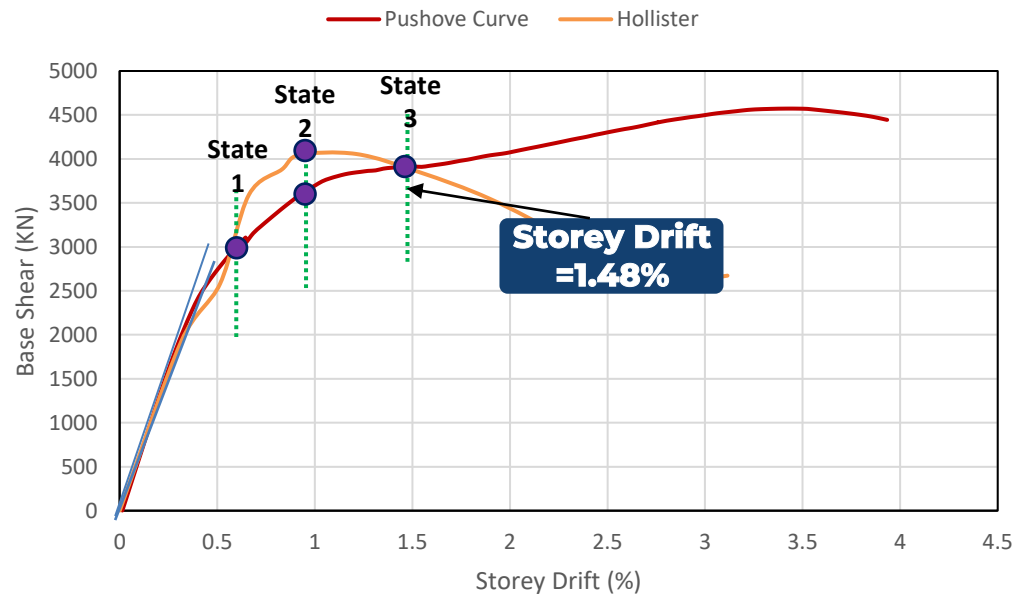


More hinge formation is observed with increase of storey drift in IDA than pushover analysis

# Results & Analysis

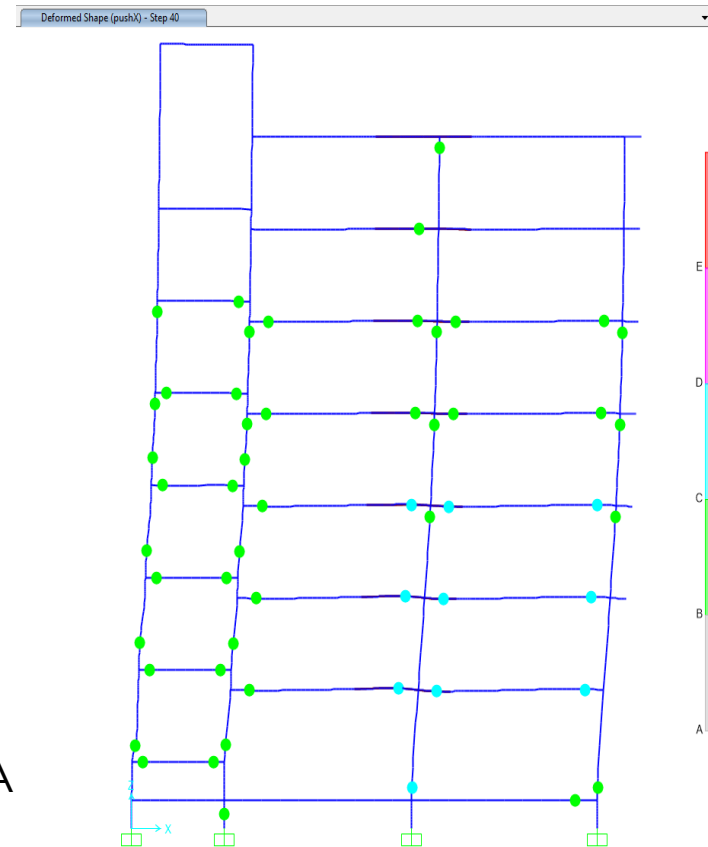
## Comparison of damage states between Pushover and Incremental Dynamic Analysis

### Hinge formation of State 3

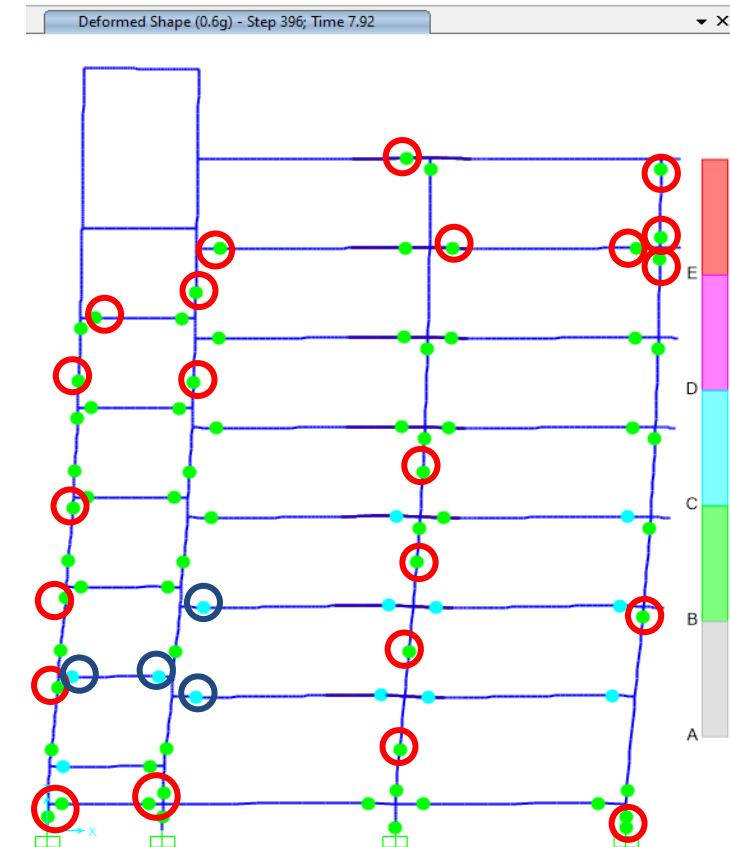


○ = Additional hinges formed during IDA

○ = More damaged hinge during IDA



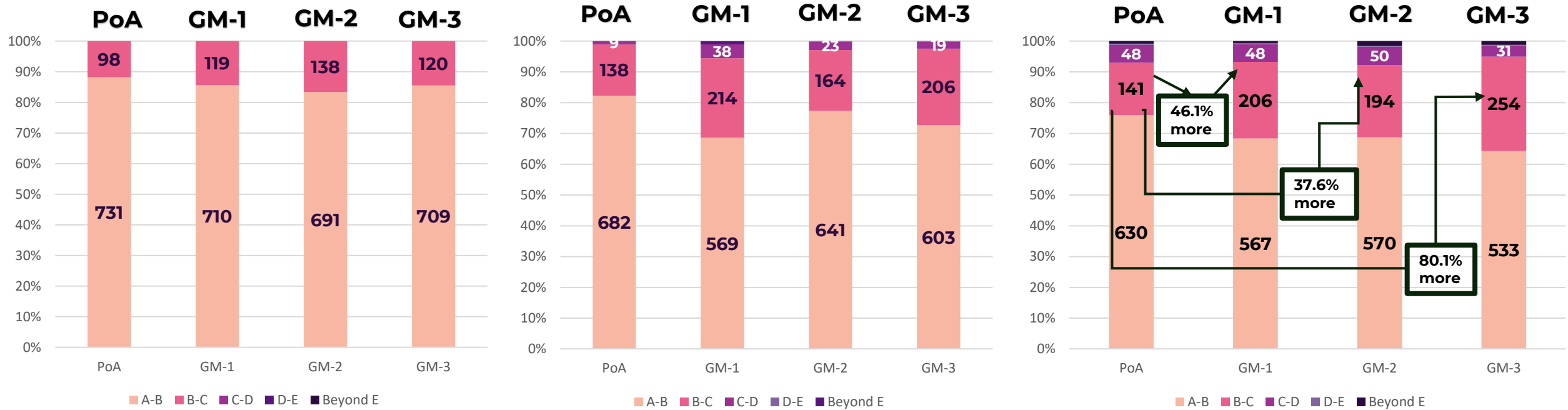
Pushover Analysis



Incremental Dynamic Analysis

More hinge formation is observed with increase of storey drift in IDA than pushover analysis

## Comparison of damage states between Pushover and Incremental Dynamic Analysis

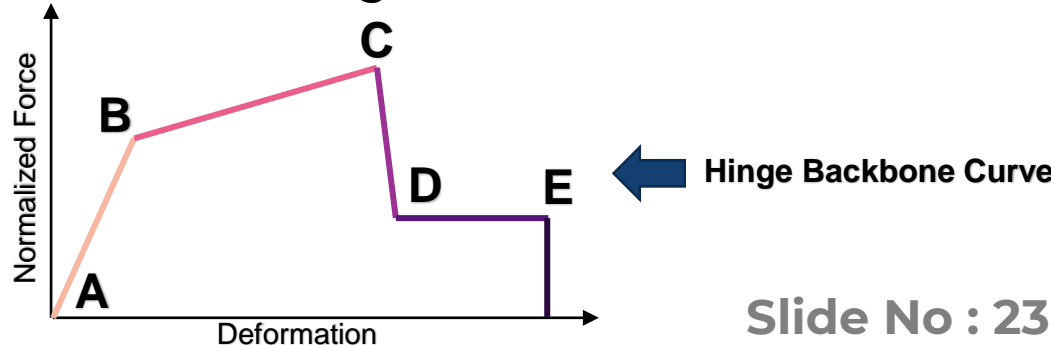


Hinge formation of **State 1**

Hinge formation of **State 2**

Hinge formation of **State 3**

At near peak state, IDA shows 54.6% more damages at B-C from Pushover analysis





# Conclusions

1

## Numerical Model Generation in SAP2000

A numerical model of an existing building has been developed in SAP2000 to perform Pushover and Incremental Dynamic Analysis

2

Both Capacity curves are similar considering initial stiffness however varies in ductility and strength

- Strength: PoA shows 14.35% larger than IDA
- Ductility: IDA shows 56.65% less than PoA

3

## Damages are concentrated more in case incremental dynamic analysis

At near peak state, IDA shows 54.6% more damages at B-C from Pushover analysis

The background is a solid dark blue color. It is decorated with various light blue geometric elements: several thin, straight lines of varying lengths and orientations; a few small, hollow circles; and larger, semi-transparent, rounded rectangular and circular shapes that overlap each other, creating a layered effect.

**THANK YOU**

The background of the slide is an abstract geometric pattern composed of numerous triangles of varying sizes and shades of blue. The top half of the image features darker blue triangles, while the bottom half transitions into lighter blue and white triangles. A horizontal white band runs across the middle of the image, serving as a backdrop for the text.

# **Question and Answer Session**