LEARNING OF ETABS SOFTWARE

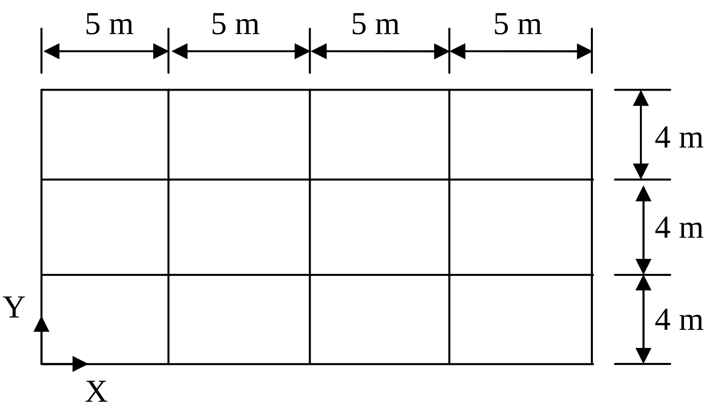
Prakash Siyani, Saumil Tank, Paresh V. Patel

A step-by-step procedure for modeling and analysis of frame structure using ETABS is explained through a simple example. Subsequently an example of seismic analysis of regular frame structure and irregular frame structure are solved manually and through ETABS.

Example

A plan of five storey reinforced concrete (RC) frame structure is considered for modeling and analysis using ETABS.

Beam sizes	300×450 mm	Storey Height	3.2 m.
Columns sizes	300×450 mm	Live Load	3 kN/m^2
Slab thickness	120 mm	Floor Finish Load	1 kN/m^2
Concrete grade	M25	Steel Fe415	



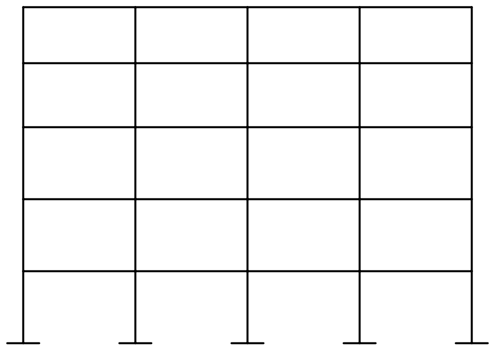


Fig. 1 Plan view of building

Elevation of Building

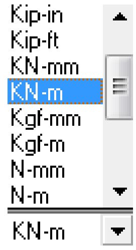
Earthquake parameters considered are:
Zone: V
Importance Factor 1
Medium soil,
Response Reduction Factor: 5
Site Specific Time history and response spectrum: Passport Office Site

Step by step procedure to learn ETABS

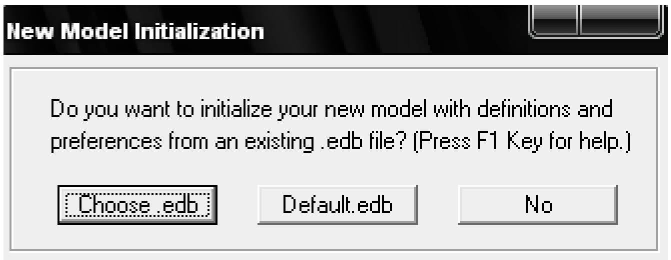
1) Modeling using ETABS.
2) Comparison of total DL and LL.
3) Time period and Mode participation factor of building in X and Y direction.
4) Seismic force calculation as per IS: 1893(Part 1) - 2002.
   a) Static method
   b) Dynamic method
5) Site specific response spectra
6) Site specific time history
7) Design under gravity and seismic load
8) Performance based design using pushover analysis

Step 1: Modeling using ETABS

1) Open the ETABS Program
2) Check the units of the model in the drop-down box in the lower right-hand corner of the ETABS window, click the drop-down box to set units to **kN-m**

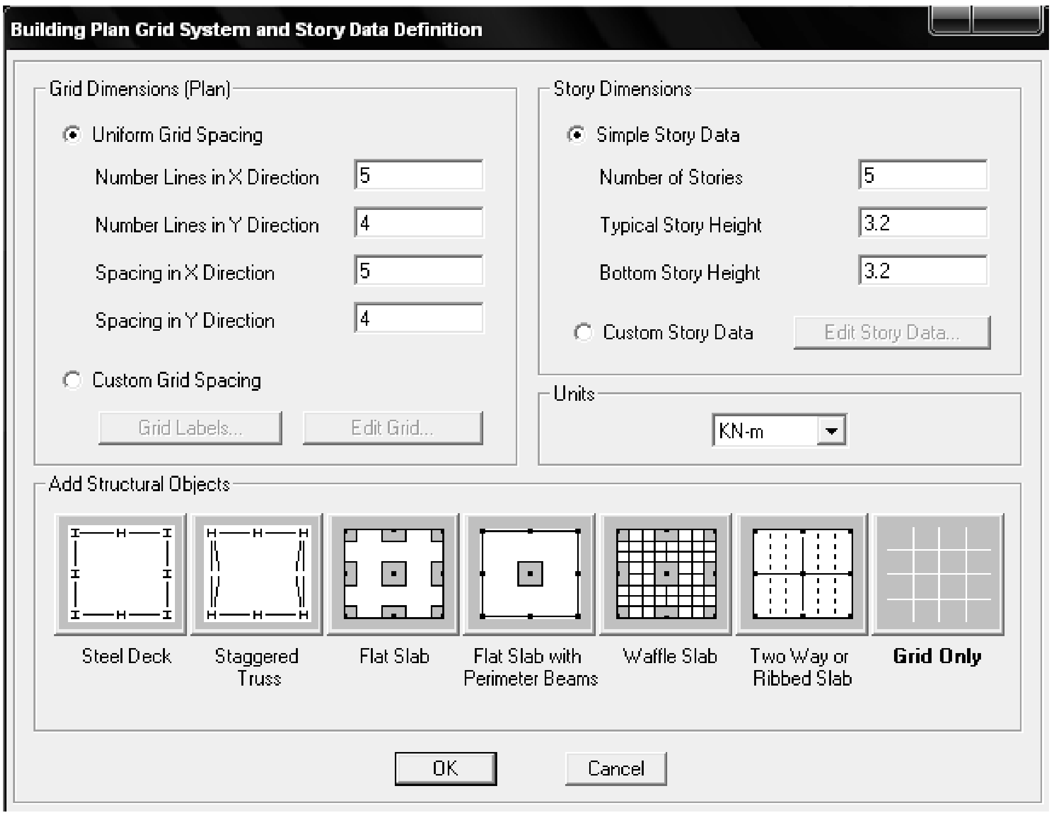


3) Click the **File** menu > **New model command**

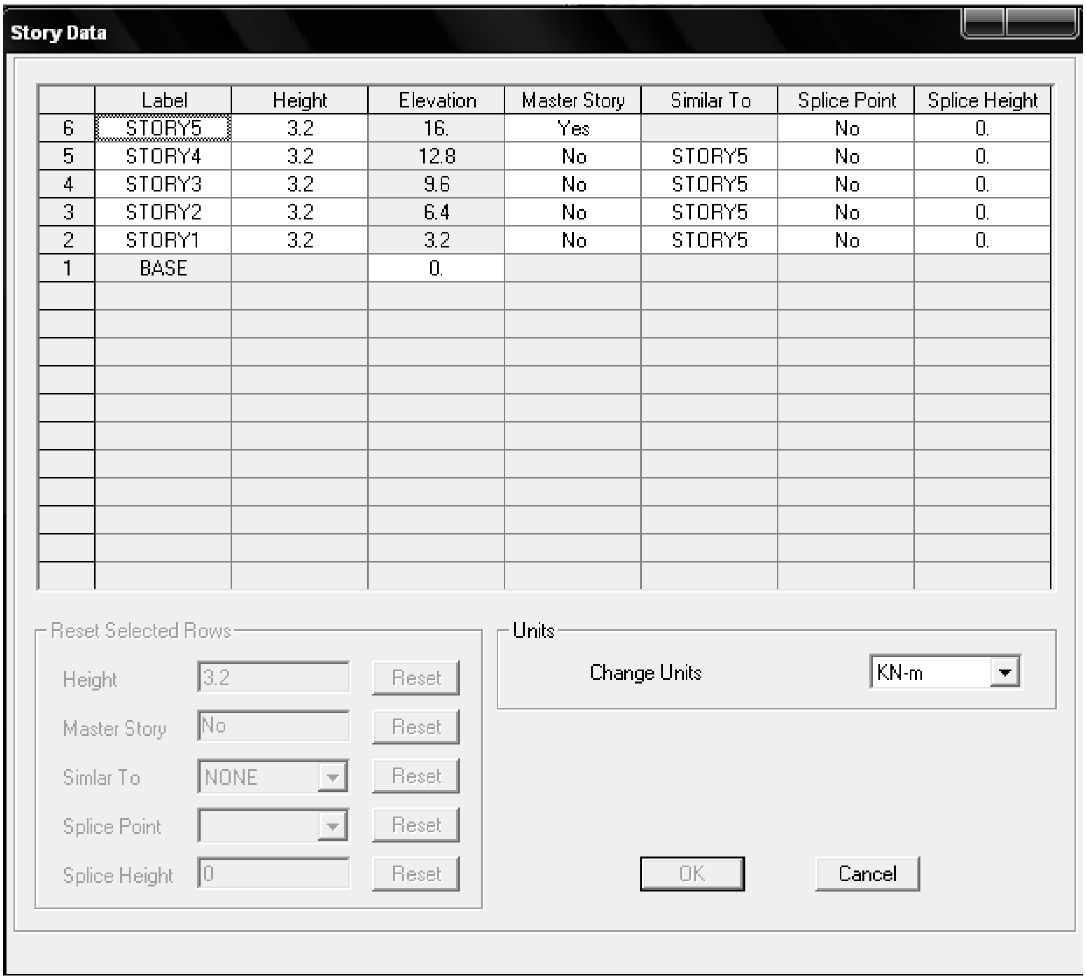


Note: we select ***No*** *because this first model you will built*

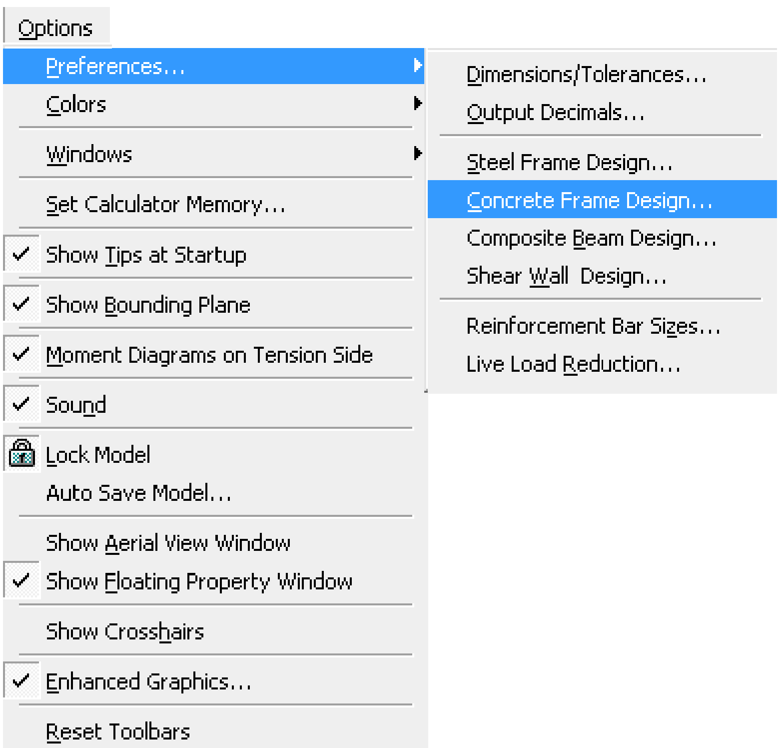
4) The next form of **Building Plan Grid System and Story Data Definition** will be displayed after you select **NO** button.



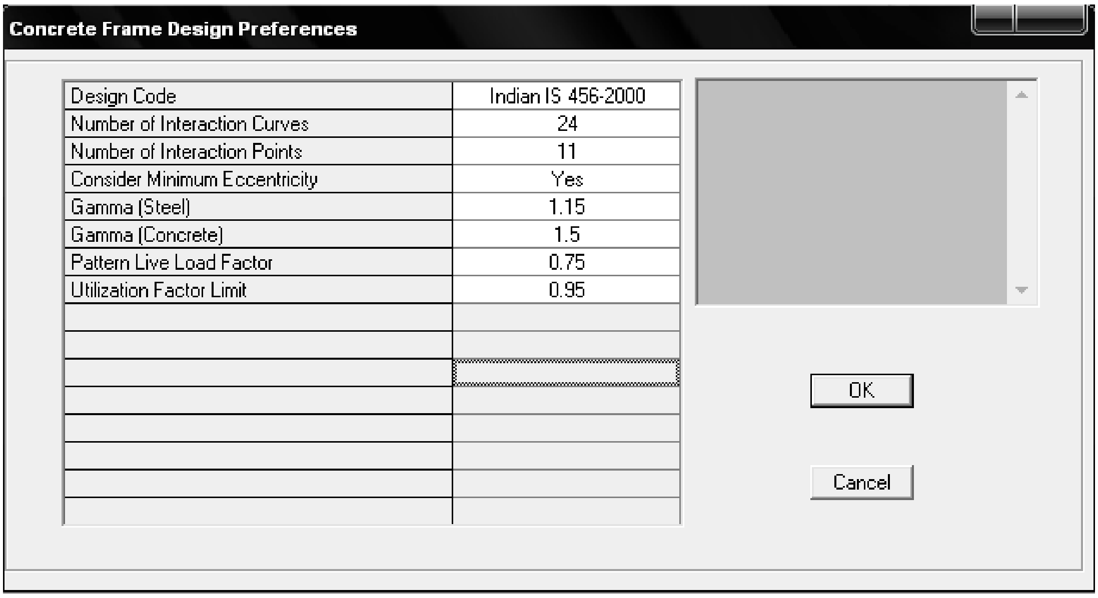
Set the grid line and spacing between two grid lines. Set the story height data using **Edit Story Data command**



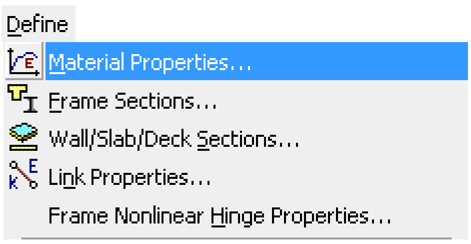
5) Define the design code using **Options > Preferences > Concrete Frame Design command**

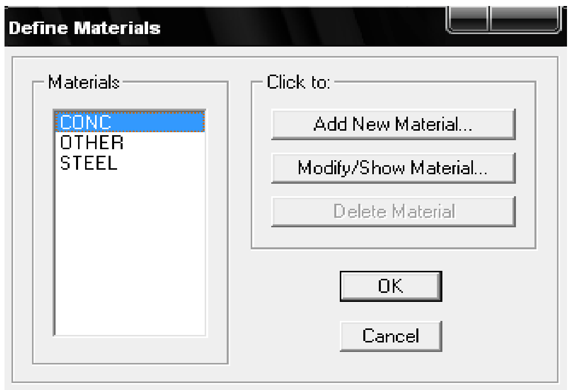


This will Display the **Concrete Frame Design Preference** form as shown in the figure.

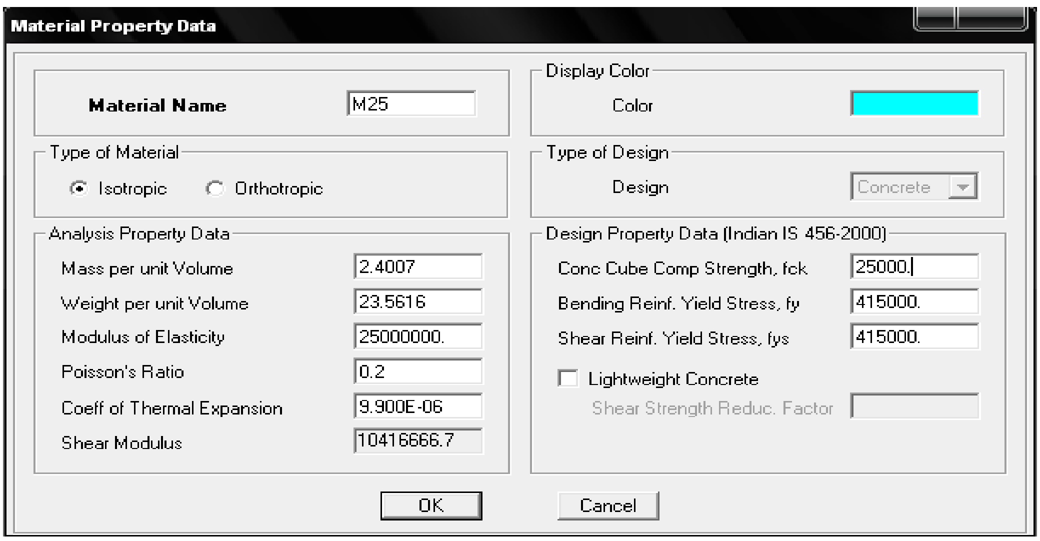


6) Click the **Define menu > Material Properties**

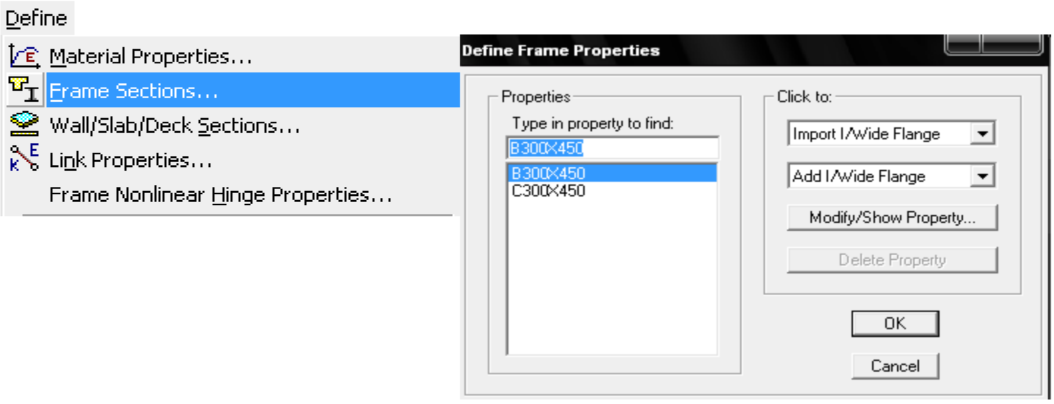




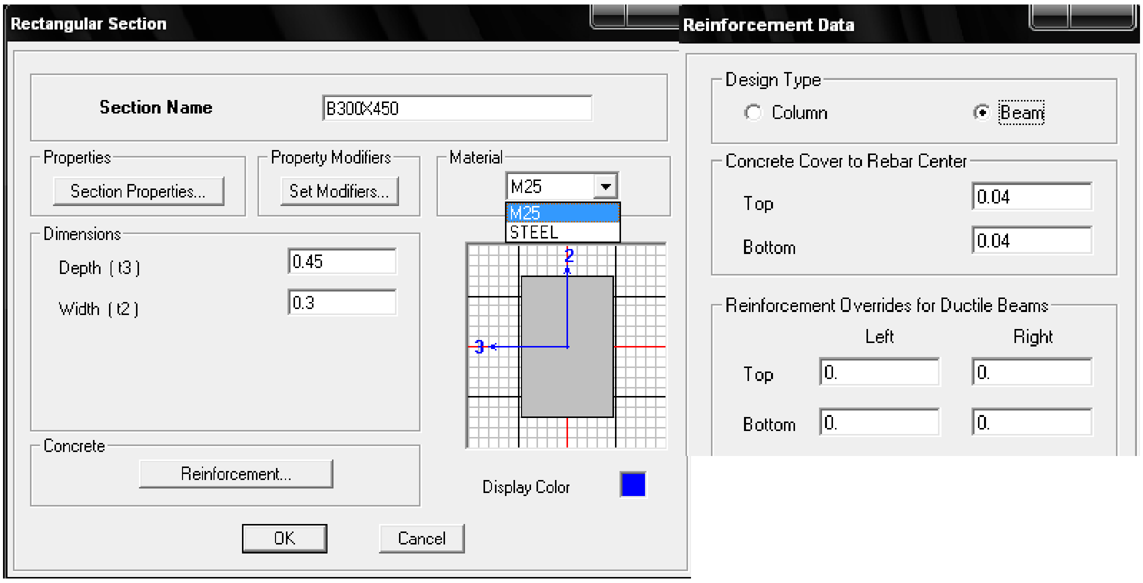
Add New Material or Modify/Show Material used to define material properties



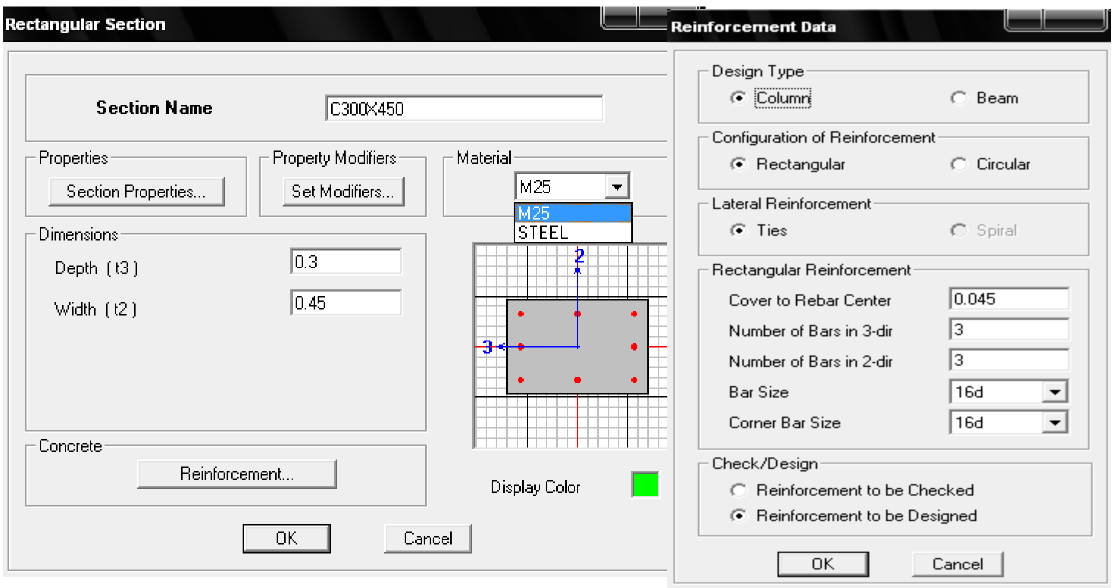
7) Define section columns and beams using **Define > Frame section**



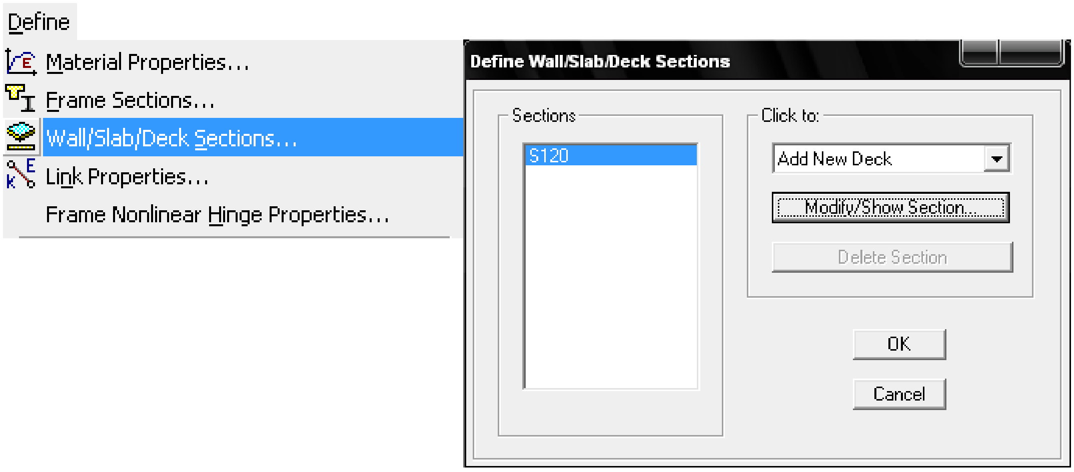
Define beam sizes and click **Reinforcement command** to provided concrete cover



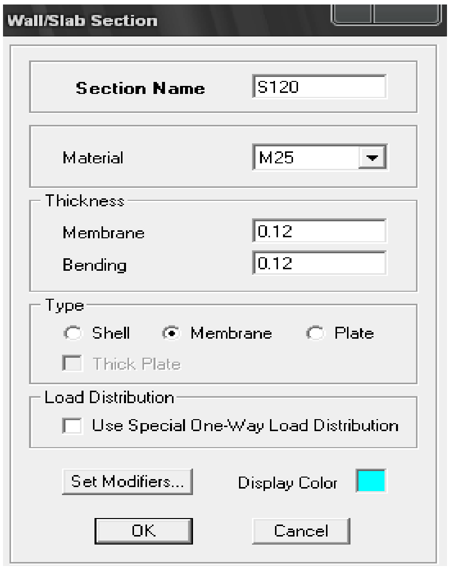
Define column sizes and click **Reinforcement command** to provided concrete cover and used two options **Reinforcement checked or designed**



8) Define wall/slab/deck

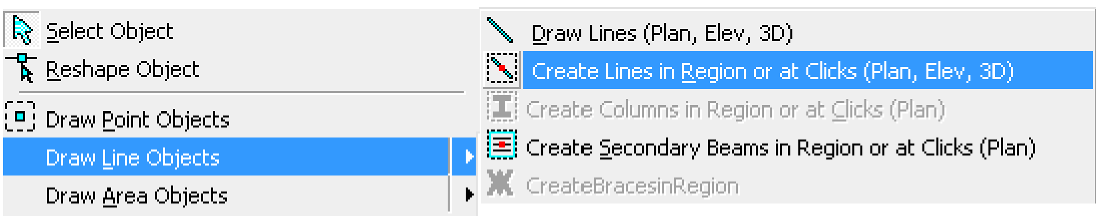


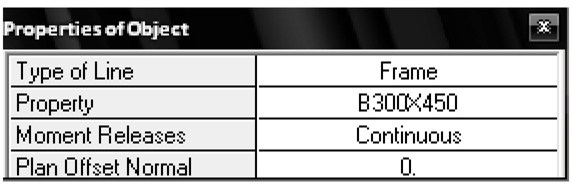
To define a slab as membrane element and one way slab define using **special one way load distribution**



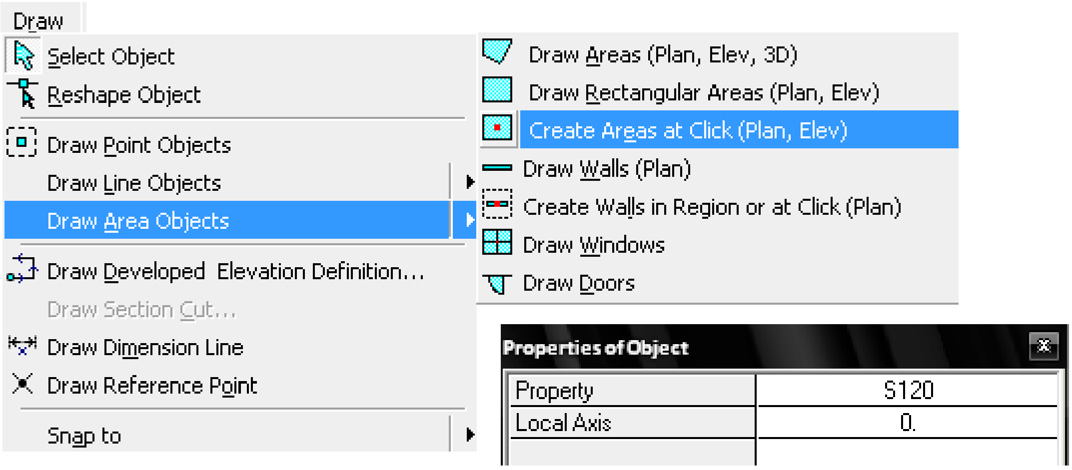
9) Generate the model

Draw beam using **Create Line Command** and draw column using **Create Column command**

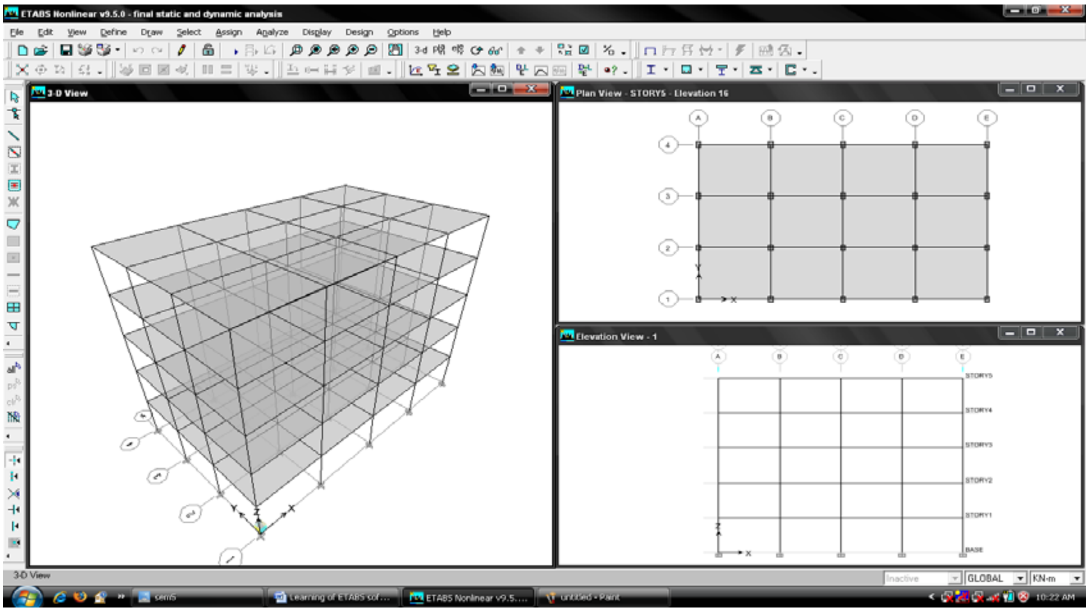




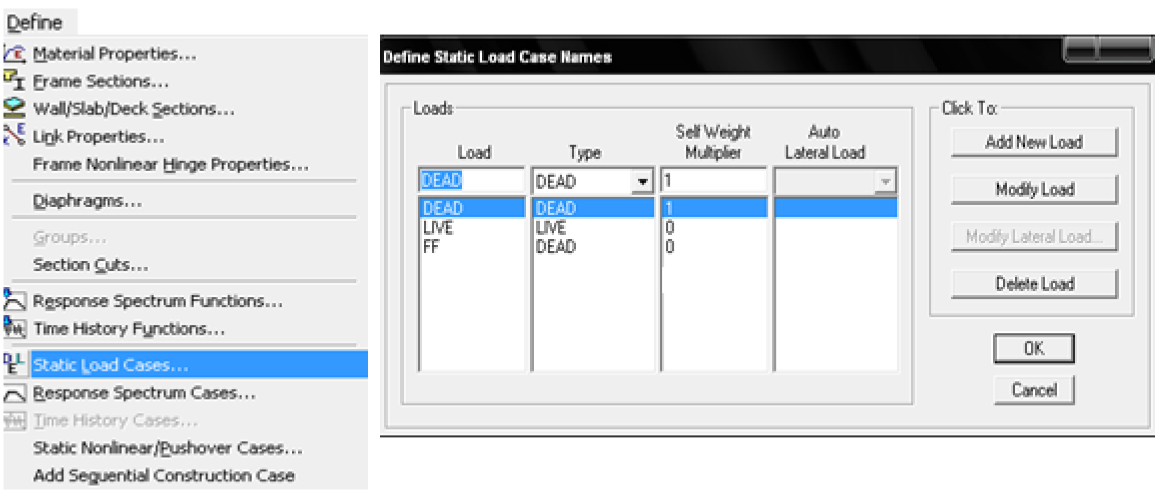
Slab is created using 3 options in which 1st draw any shape area, 2nd draw rectangular area and 3rd create area in between grid line



Above creating option used to generate the model as shown in below figure

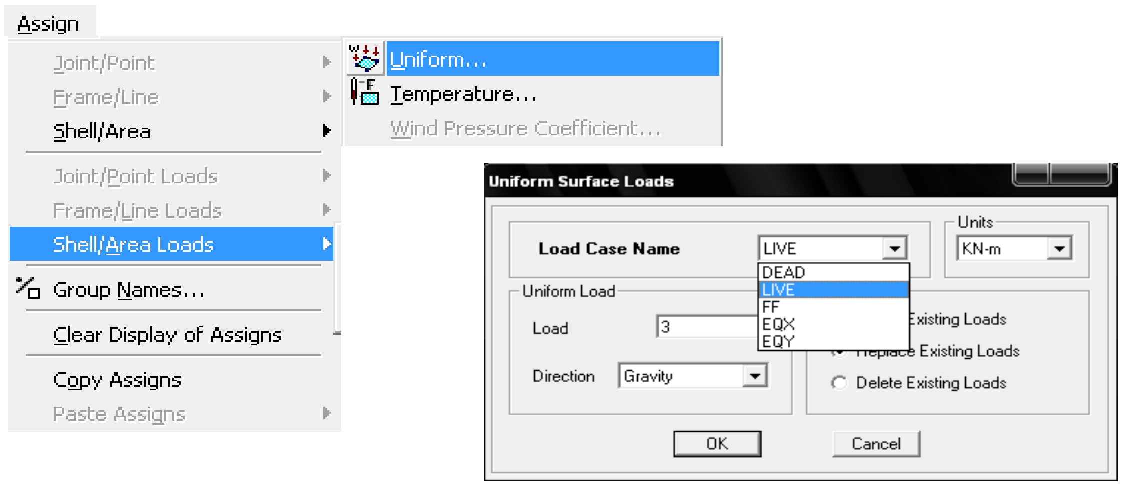


10) Define various loads (Dead load, live load, Earthquake load)



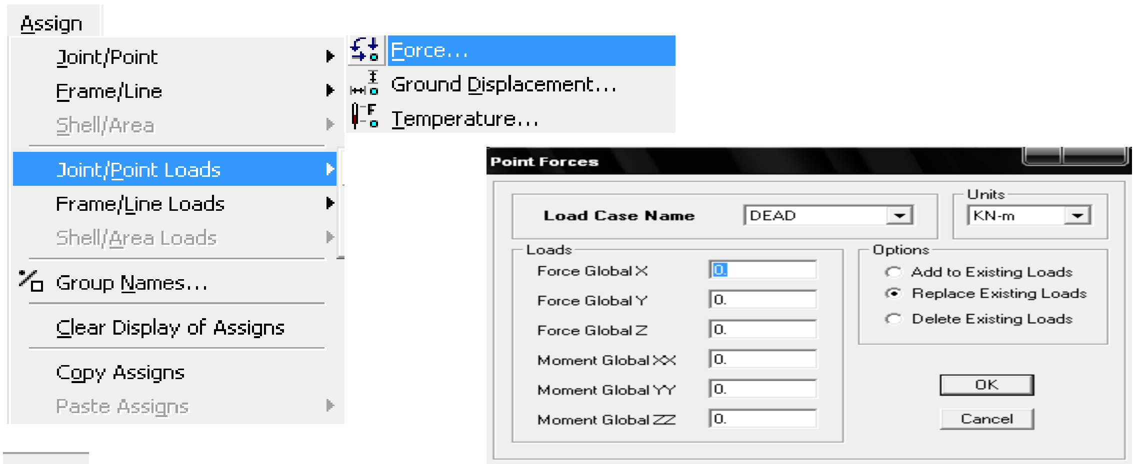
Dead Load: self weight multiplier is used 1 to calculate dead load as default.
Live load or any other define load

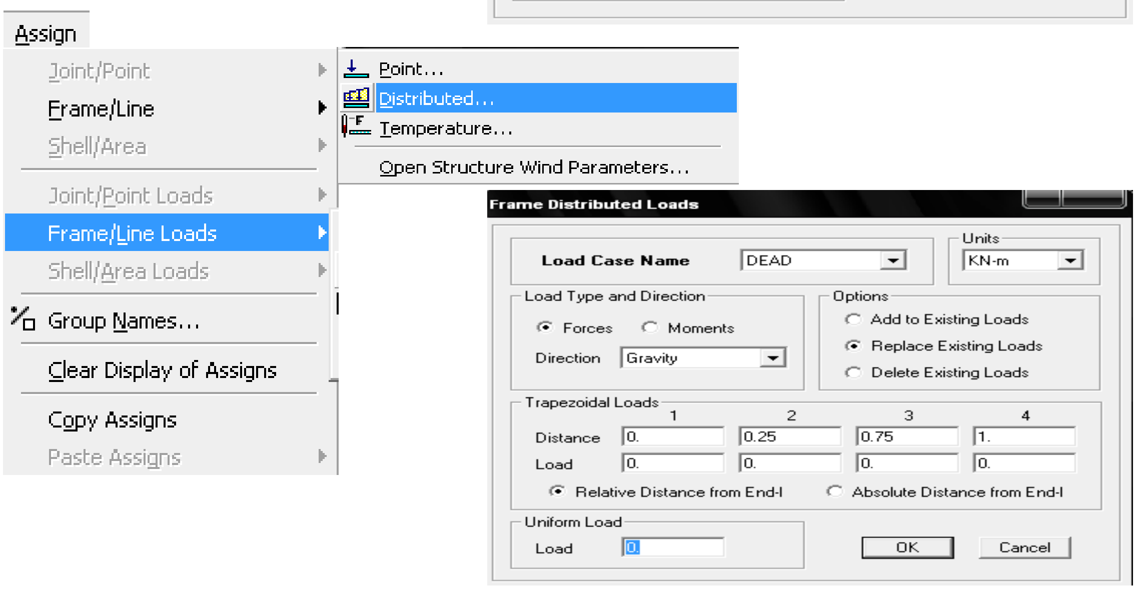
1st select the member where assign this load than click the assign button.



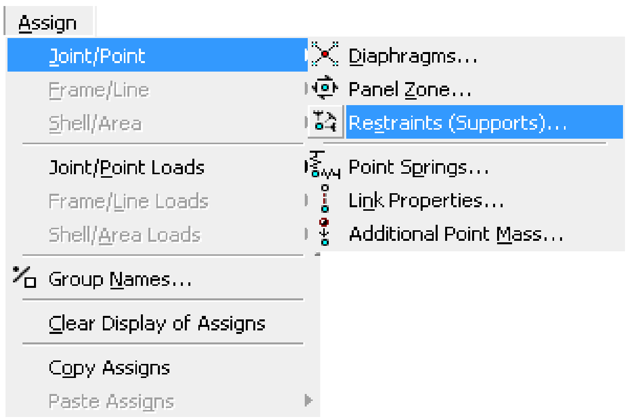
Assign point load and uniform distributed load

Select assigning point or member element than click the assign button

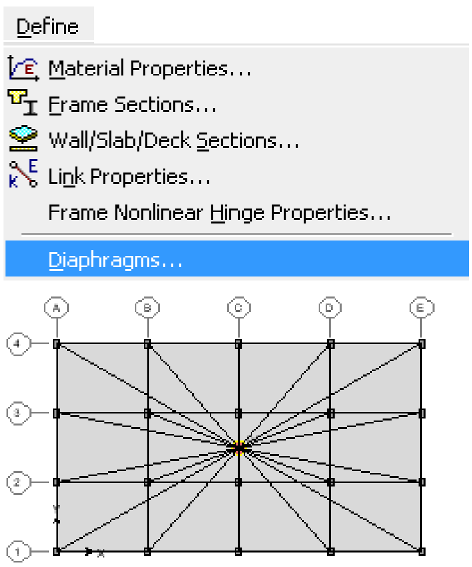


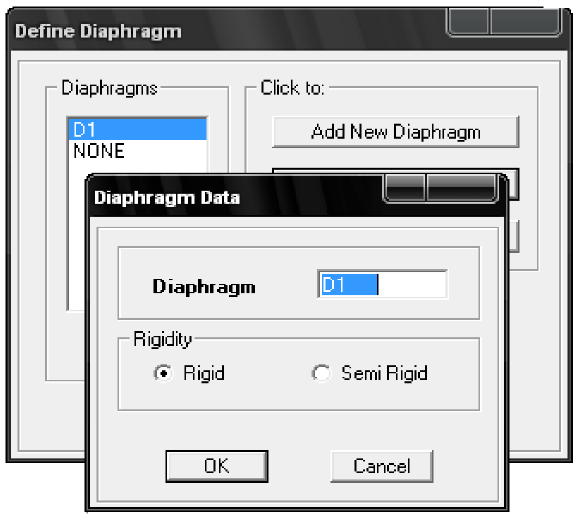


11) Assign support condition
Drop-down box in the lower right-hand corner of the ETABS window, Select only bottom single storey level to assign fixed support using **assign > Joint/Point>Restrain (Support) command**

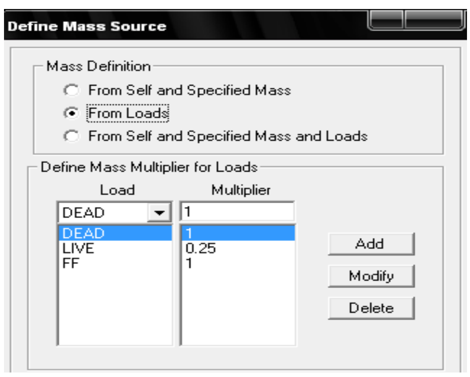


12) In building, slab is considered as a single rigid member during earthquake analysis. For that, all slabs are selected first and apply diaphragm action for rigid or semi rigid condition.

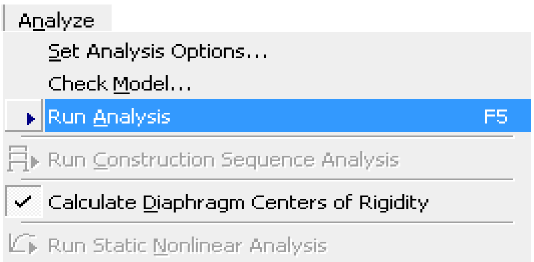




13) Mass source is defined from **Define > mass source command**. As per IS: 1893-2002, 25% live load (of 3 kN/m^2) is considered on all floor of building except at roof level.



14) Run analysis from **Analysis > Run Analysis command**



Step 2: Comparison of total DL and LL

Dead Load

Weight of slab = 5×12×20×0.12×24 = 345 kN
Weight of beam = 5×0.3×0.45×(12×5+20×4) ×24 = 2268 kN
Weight of column = 5×0.3×0.45×(3.2-.45) ×24 = 891 kN
Total weight = 6615 kN

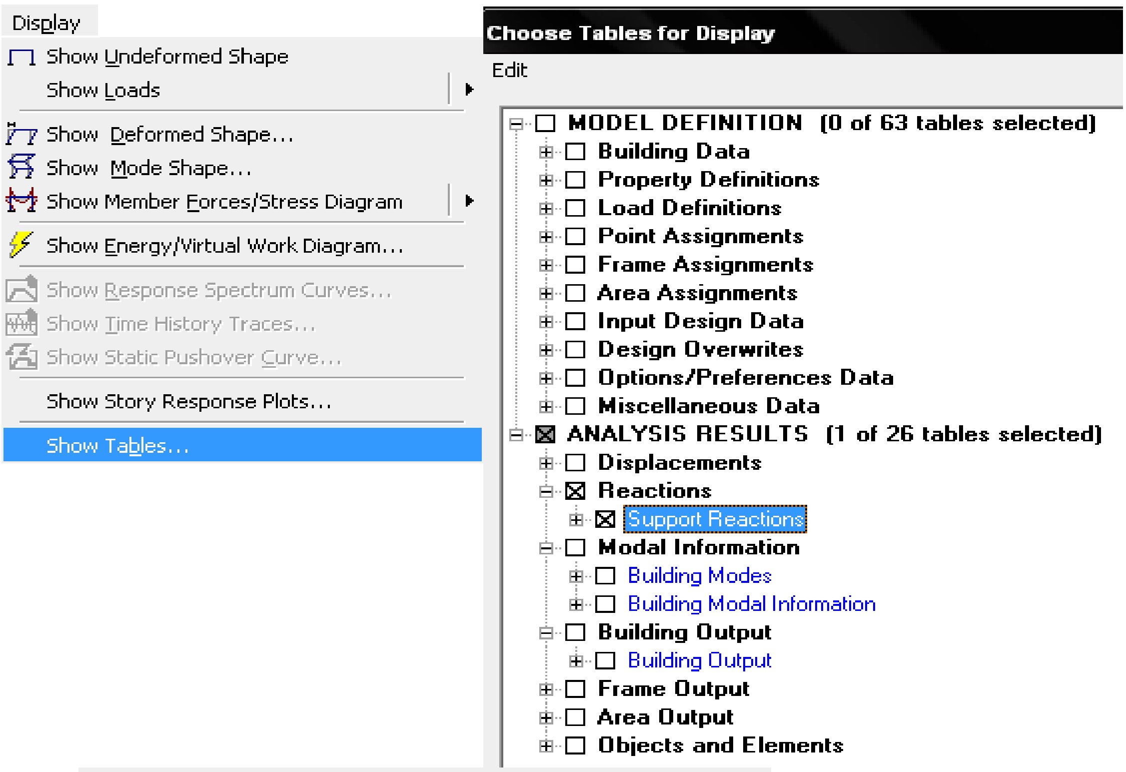
Live Load

Live load = 4×12×20×3+1×12×20×1.5 = 3240 kN

Floor Finish Load

FF = 5×12×20×1 = 1200 kN

In ETABS, dead load and other loads are shown from table as shown in figure.



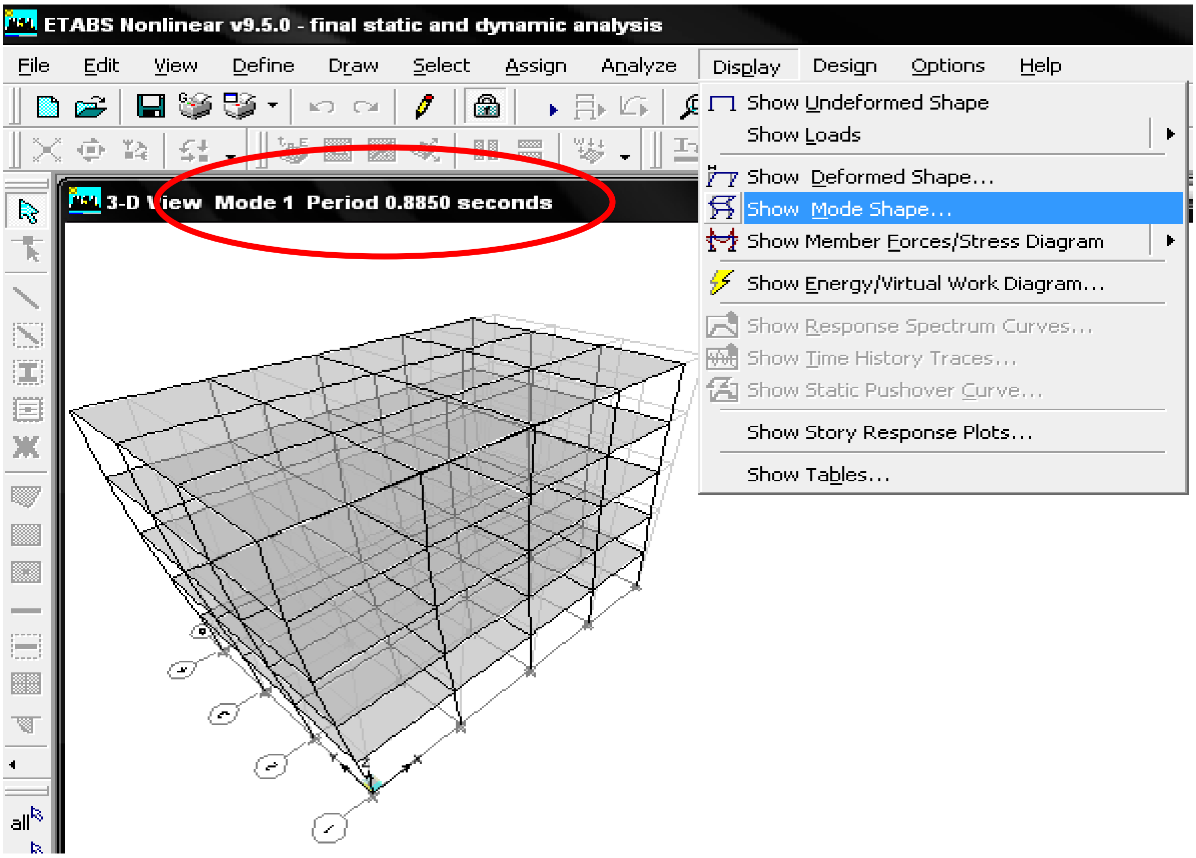
Support Reactions

Story	Point	Load	FX	FY	FZ
Summation	0, 0, Base	DEAD	0.00	0.00	6637.30
Summation	0, 0, Base	LIVE	0.00	0.00	3240.00
Summation	0, 0, Base	FF	0.00	0.00	1200.00

Step 3: Time period and Mode participation factor of building in X and Y direction.

- Static time period base on the IS 1893 is $0.075H^{0.75}$ = 0.6 sec
- Dynamic time period as per ETABS analysis is 0.885 sec in X direction and 0.698 sec in Y direction

Time period is shown in ETABS from **Display** > **Show Mode Shape**



Mass participation factor is shown from **Display** > **Show Table** > **Model Information** > **Building Model Information** > **Model Participating Ratio.**

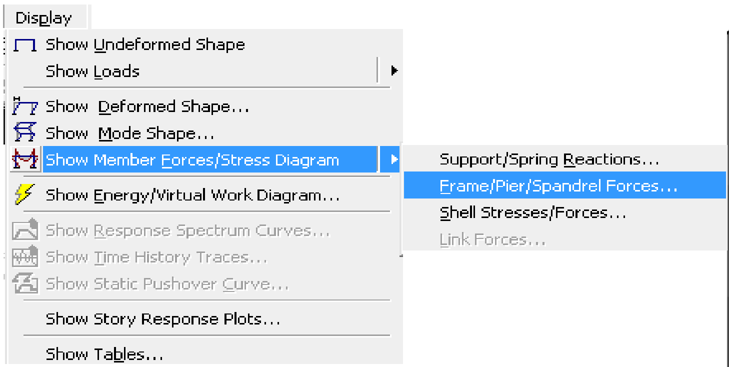
Modal Participating Mass Ratios

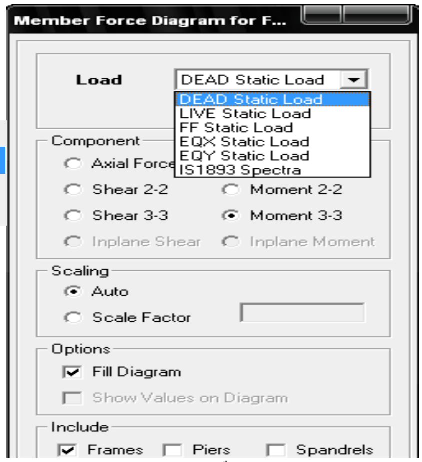
Edit View

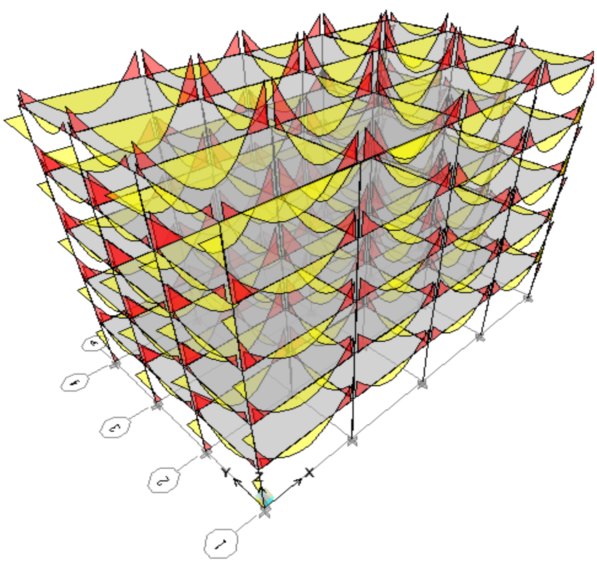
Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX
1	0.884954	85.0817	0.0000	0.0000	85.0817	0.0000	0.0000	0.0000
2	0.697994	0.0000	83.5026	0.0000	85.0817	83.5026	0.0000	99.4182
3	0.649635	0.0000	0.0000	0.0000	85.0817	83.5026	0.0000	0.0000
4	0.291666	9.7869	0.0000	0.0000	94.8686	83.5026	0.0000	0.0000
5	0.224333	0.0000	10.4317	0.0000	94.8686	93.9343	0.0000	0.3093
6	0.210519	0.0000	0.0000	0.0000	94.8686	93.9343	0.0000	0.0000
7	0.173069	3.3883	0.0000	0.0000	98.2568	93.9343	0.0000	0.0000
8	0.127575	0.0000	3.8521	0.0000	98.2568	97.7863	0.0000	0.2607
9	0.125375	1.3785	0.0000	0.0000	99.6353	97.7863	0.0000	0.0000
10	0.121394	0.0000	0.0000	0.0000	99.6353	97.7863	0.0000	0.0000
11	0.103887	0.3647	0.0000	0.0000	100.0000	97.7863	0.0000	0.0000
12	0.088617	0.0000	1.7181	0.0000	100.0000	99.5044	0.0000	0.0000

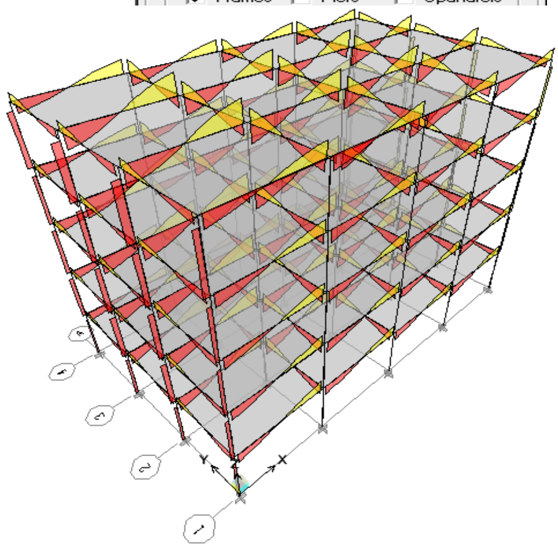
Bending moment and shear force diagram is shown from **Display > Show Member Forces > Frame/Pier/Spandrel Forces command**





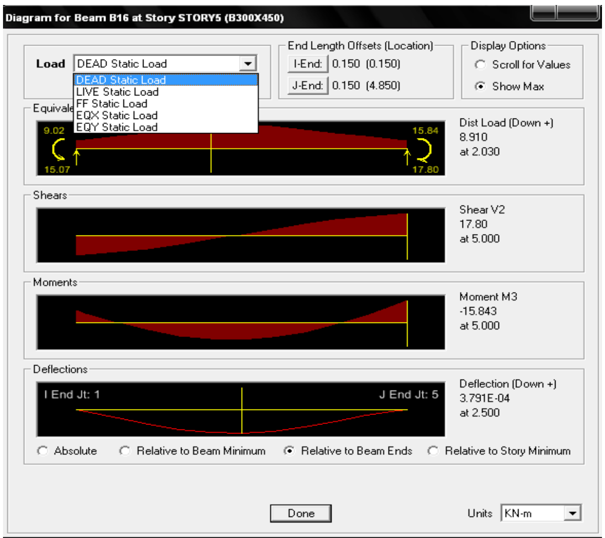


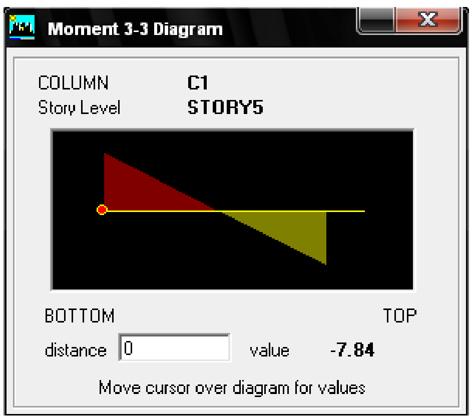
Bending Moment Diagram for Dead Load



Shear Force Diagram for Dead Load

Select any beam or column member and press right click to shown below figure

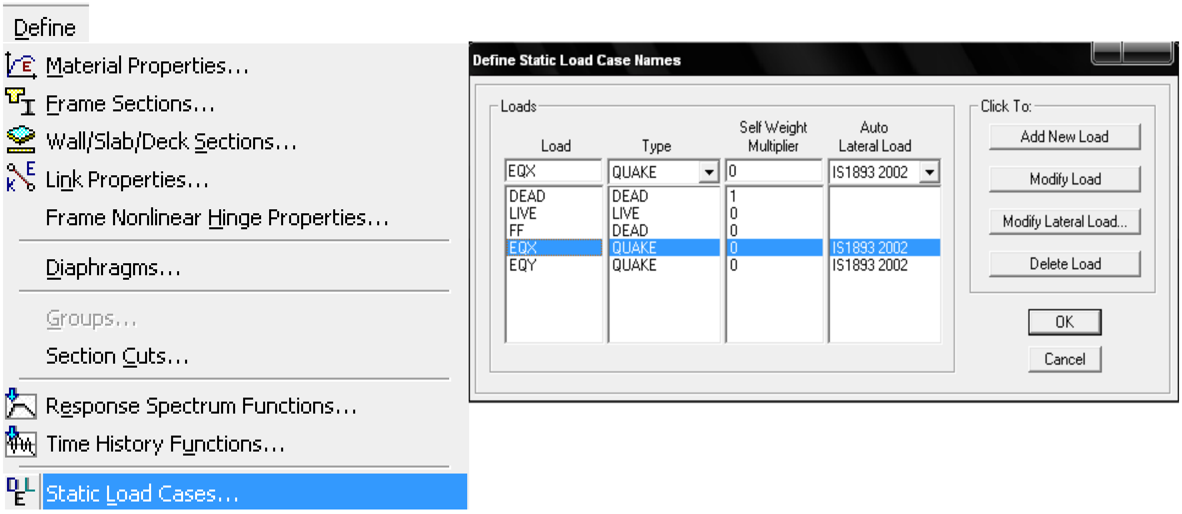




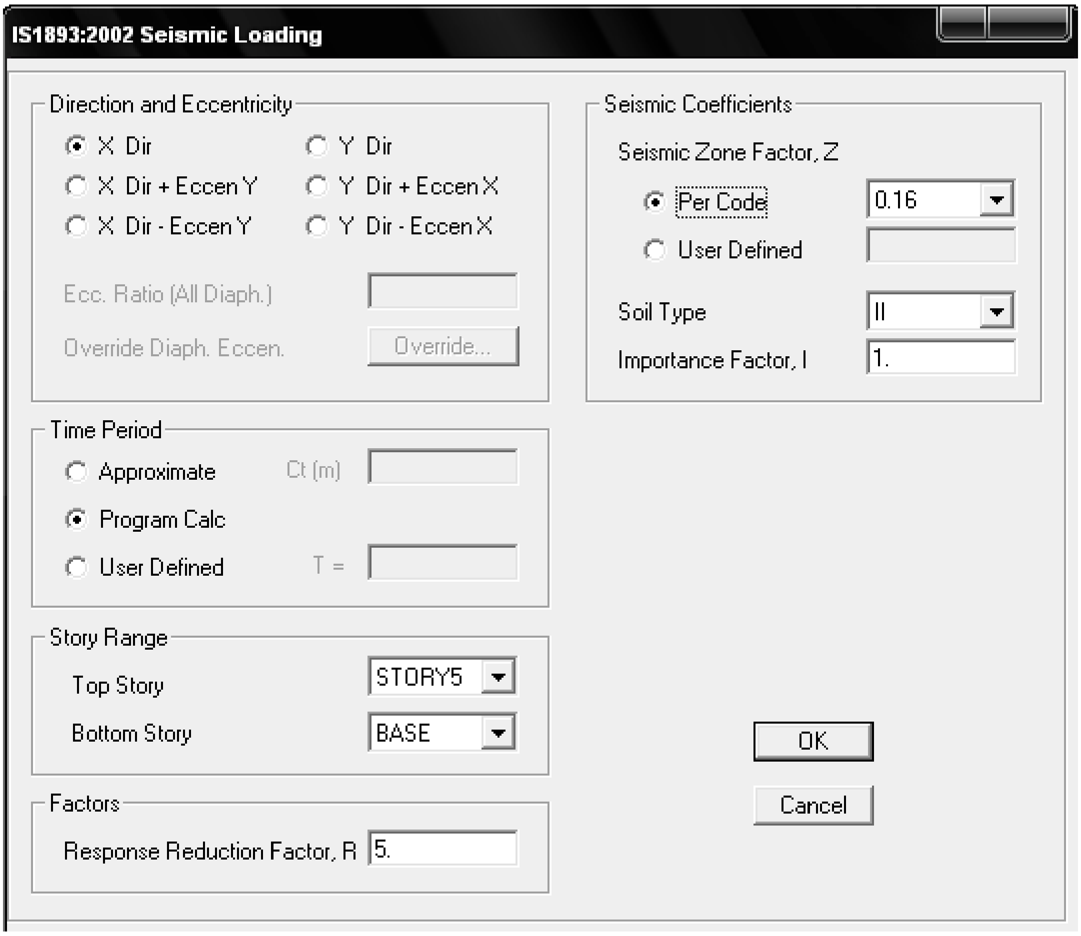
Step 4: Seismic force calculation as per IS: 1893(Part 1) - 2002.

(a) Static Method

Define static load from **Define > Static load command**

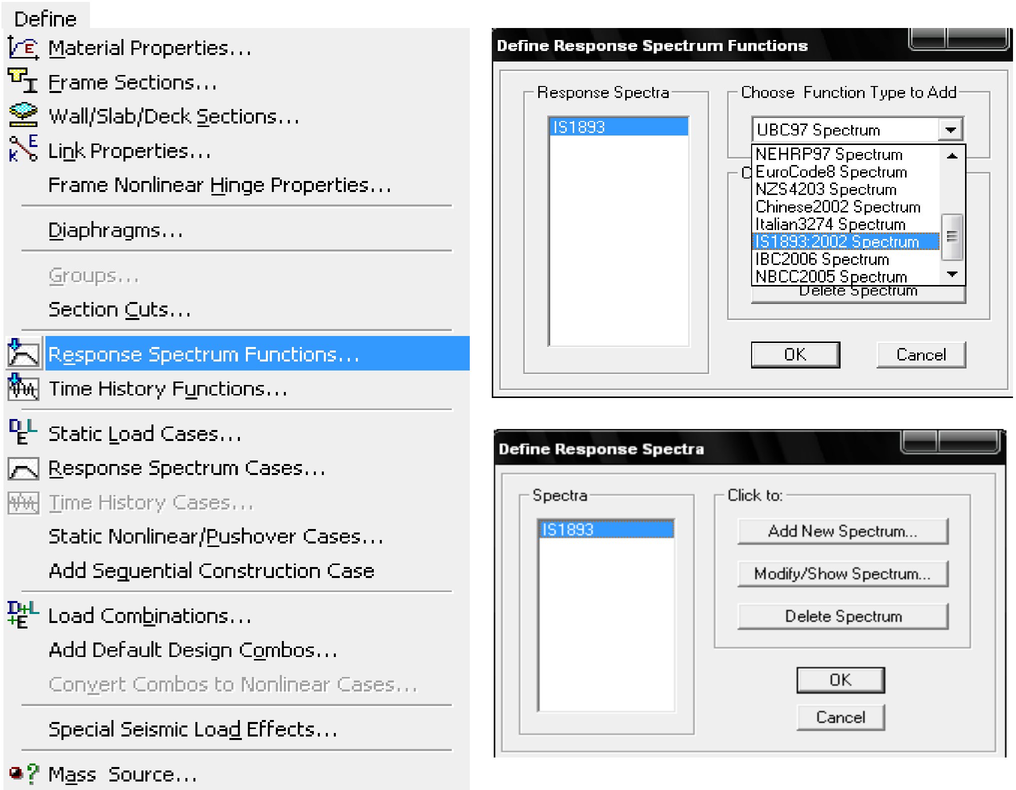


Press modify lateral load to shown below figure and assign various value as per IS 1893.

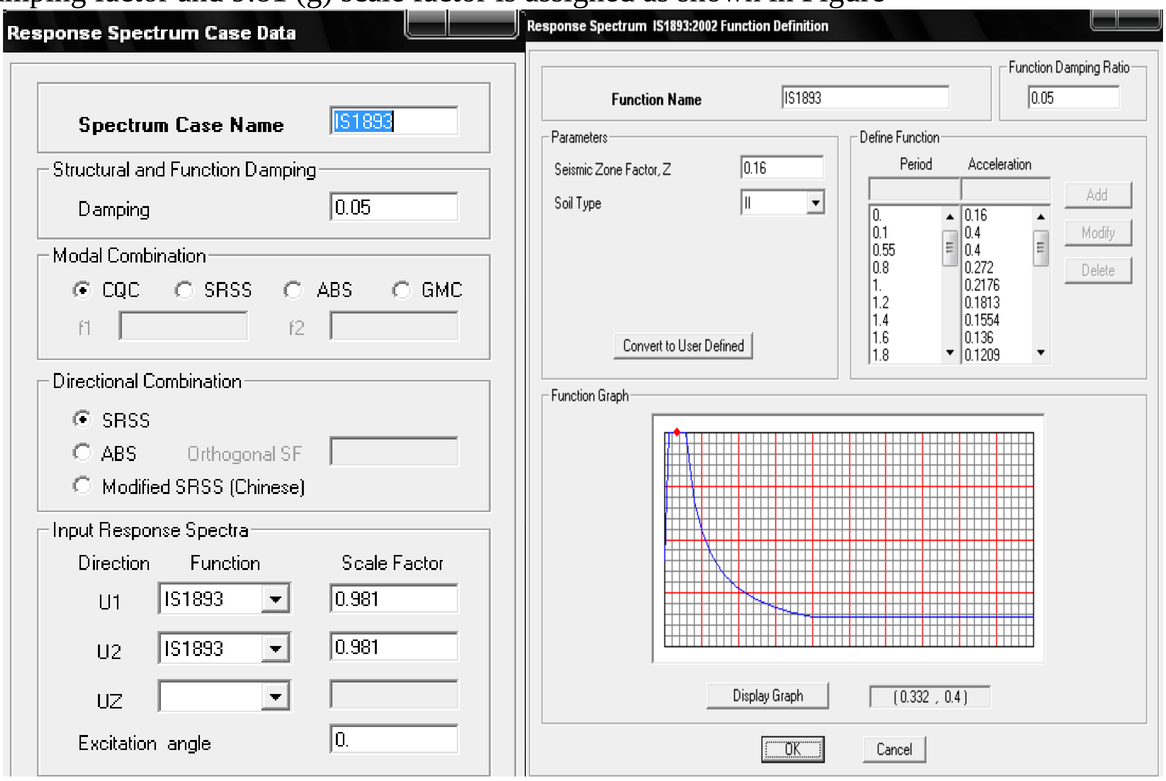


(b) Dynamic Analysis Method

The design response spectra of IS 1893-2002 given as input in the **Define menu** > **Response Spectrum Functions.** Response spectra load cases are define in **Response Spectrum cases**

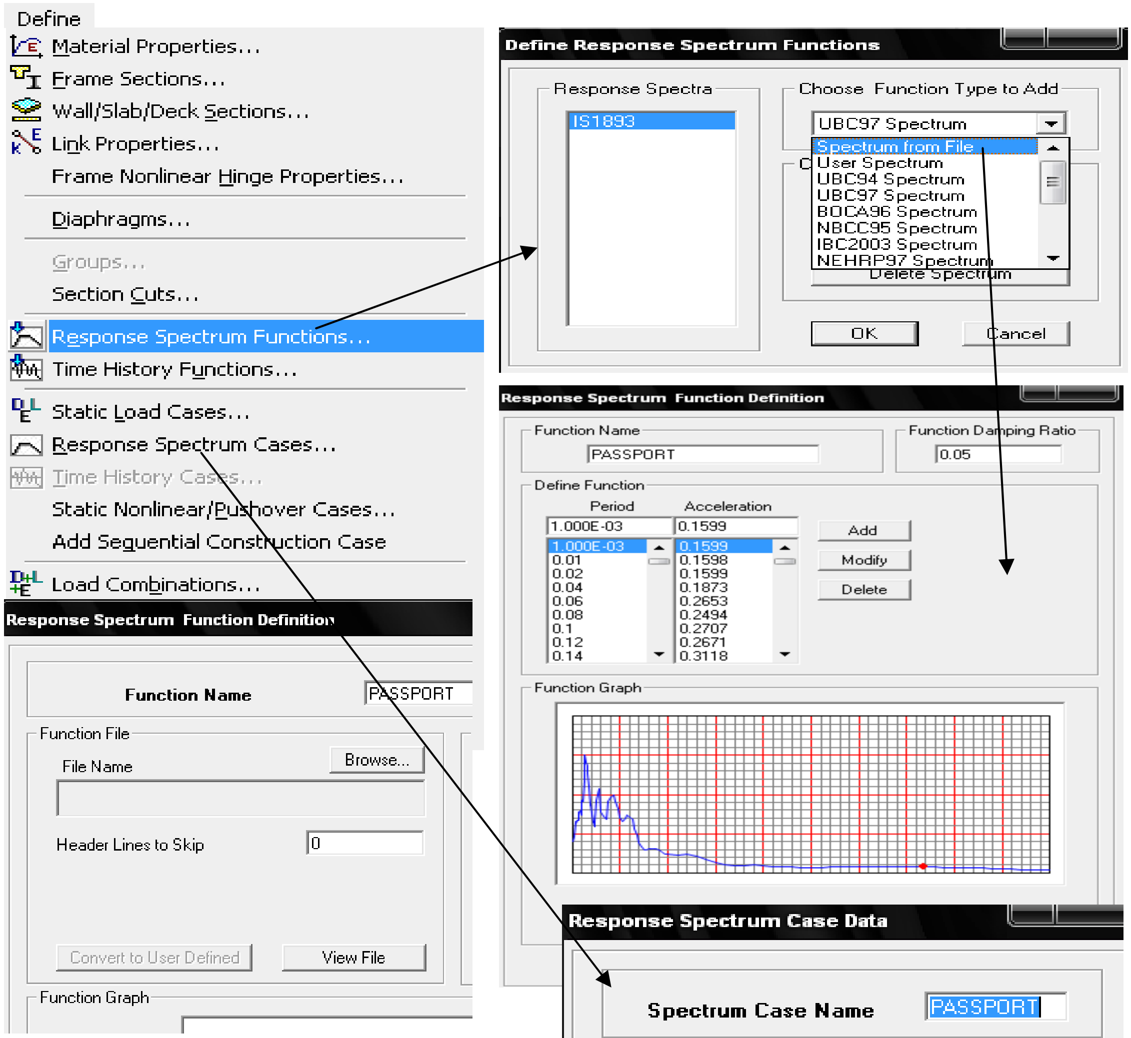


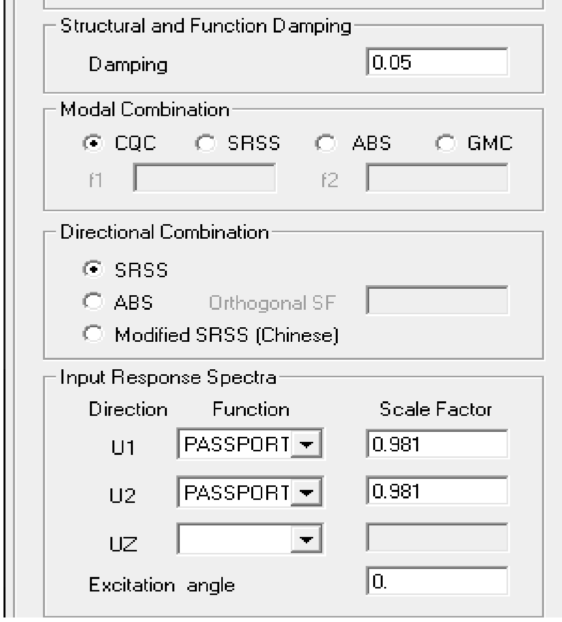
The damping value is specified which is used to generate the response spectrum curve. 5% damping factor and 9.81 (g) scale factor is assigned as shown in Figure



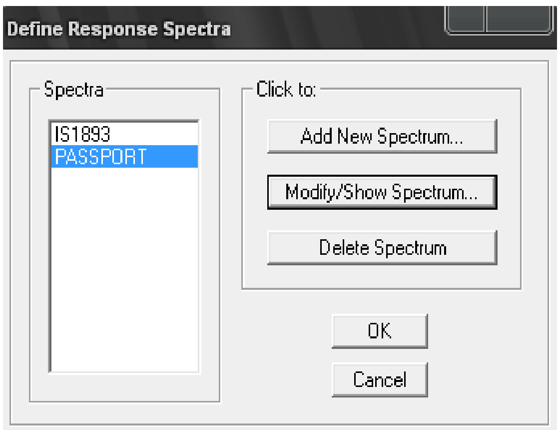
Step 5: Site Specific Response Spectra

Site specific response spectrum is define from **Define > Response Spectrum Function > Spectrum from File.**



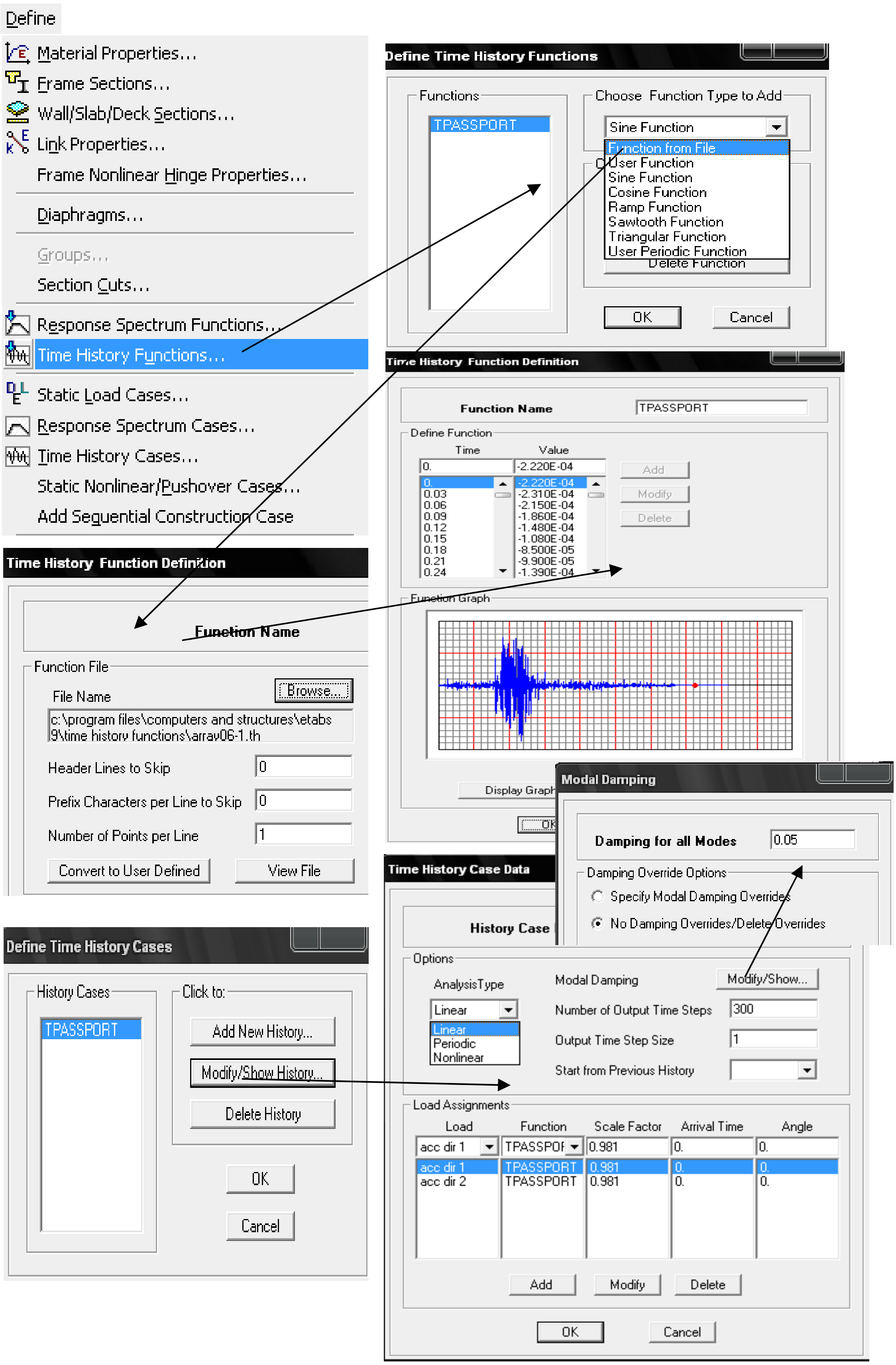


The damping value is specified which is used to generate the response spectrum curve. 5% damping factor and 9.81 (g) scale factor is assigned as shown in Figure

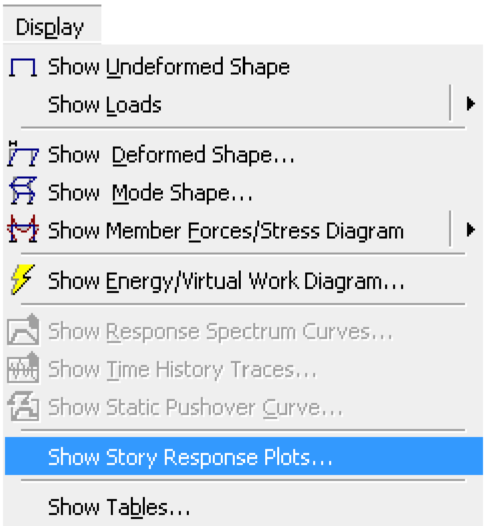


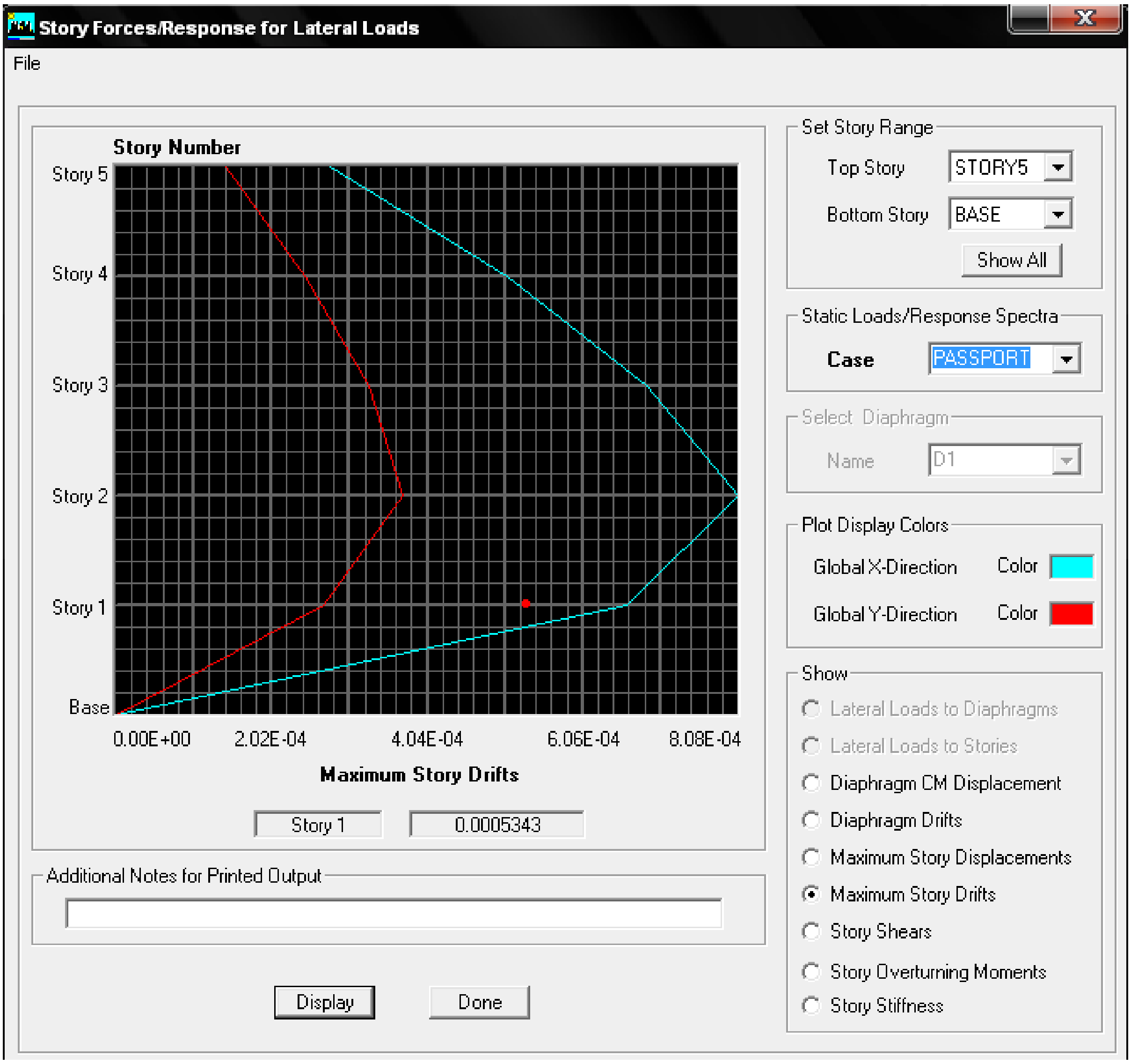
Step 6: Site Specific Time History

Site specific time history is define from **Define > Time History Function**



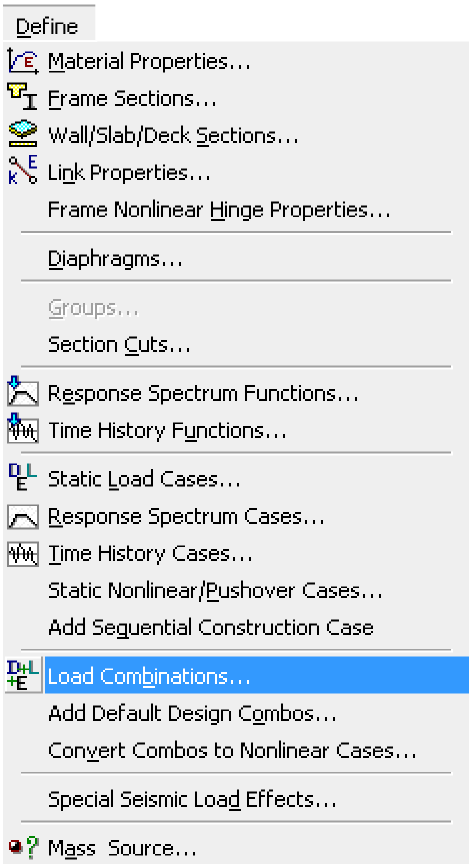
Run the analysis and various curves is shown from **Display > Show Story Response Plot**

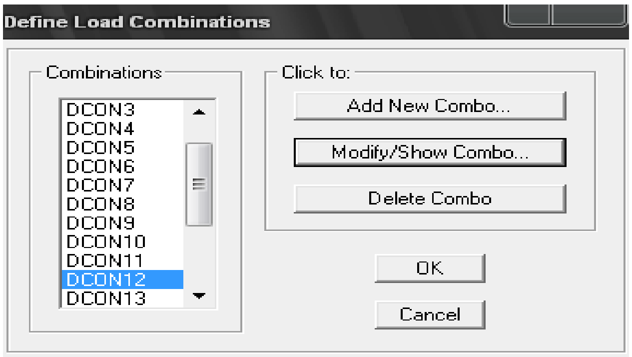


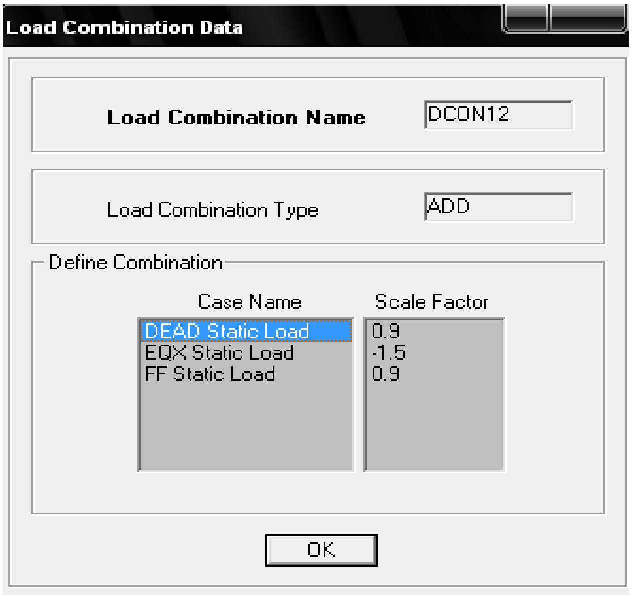


Step 7: Design under Gravity and Seismic Load

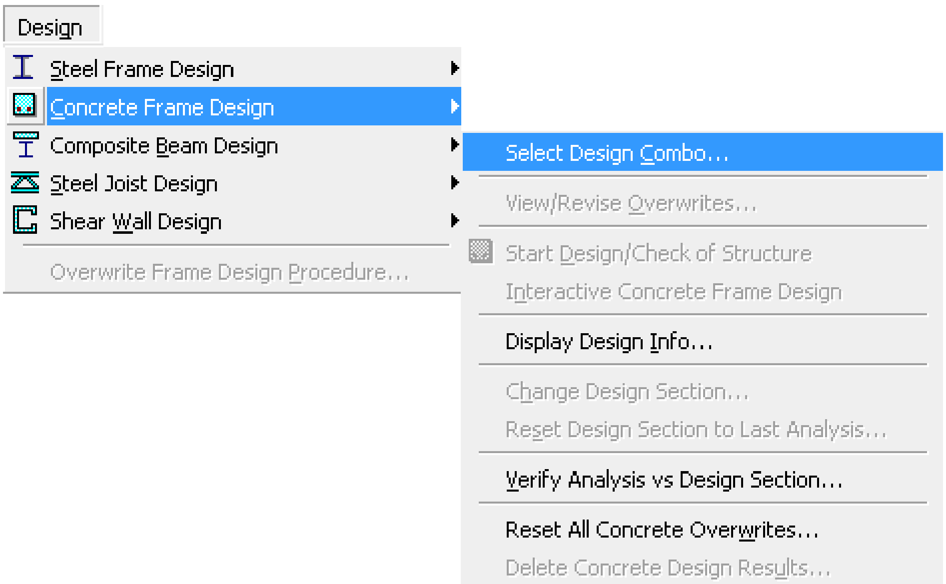
Design is carried out using different combination. ETABS have facility to generate combination as per IS 456-2000.

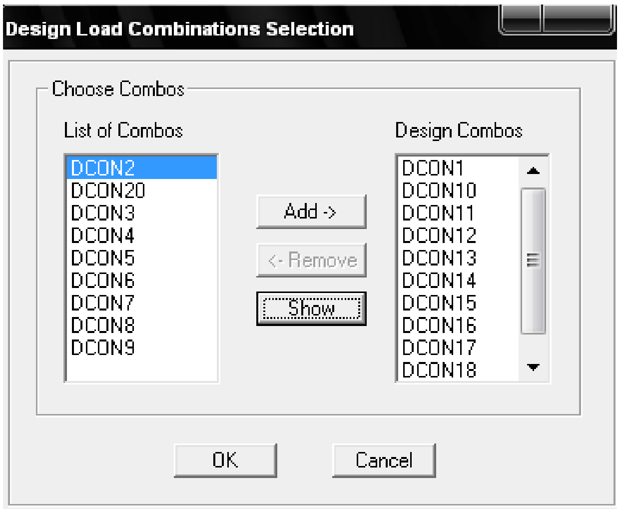




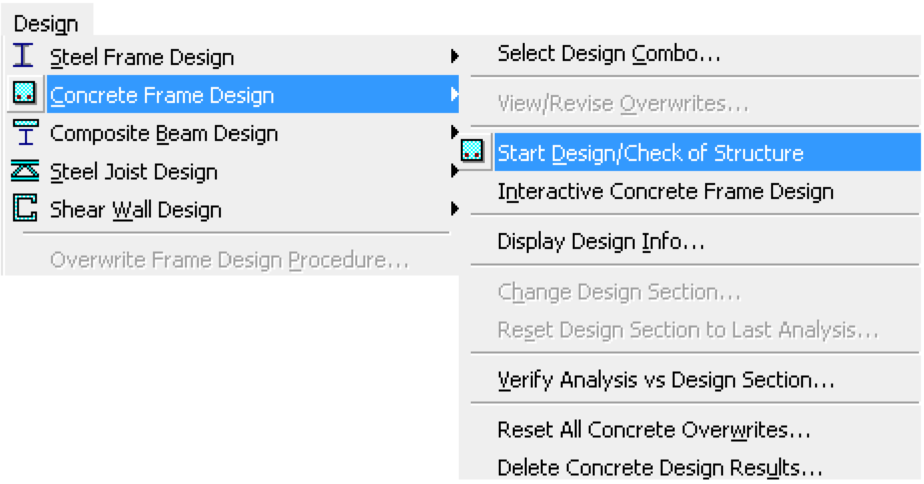


Select assigning combination for Design from **Design > Concrete Frame Design > Select Design Combination**

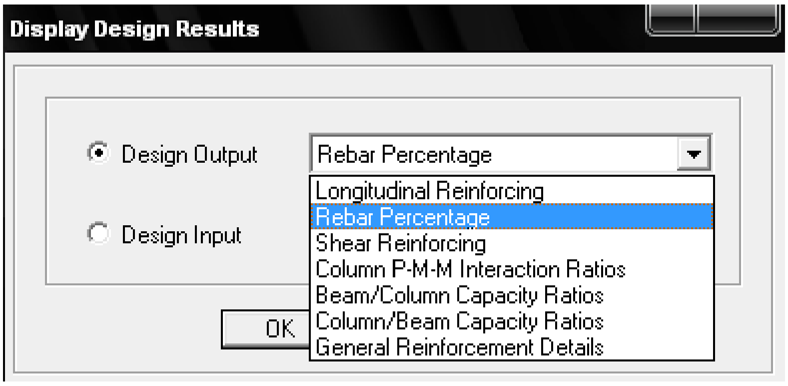


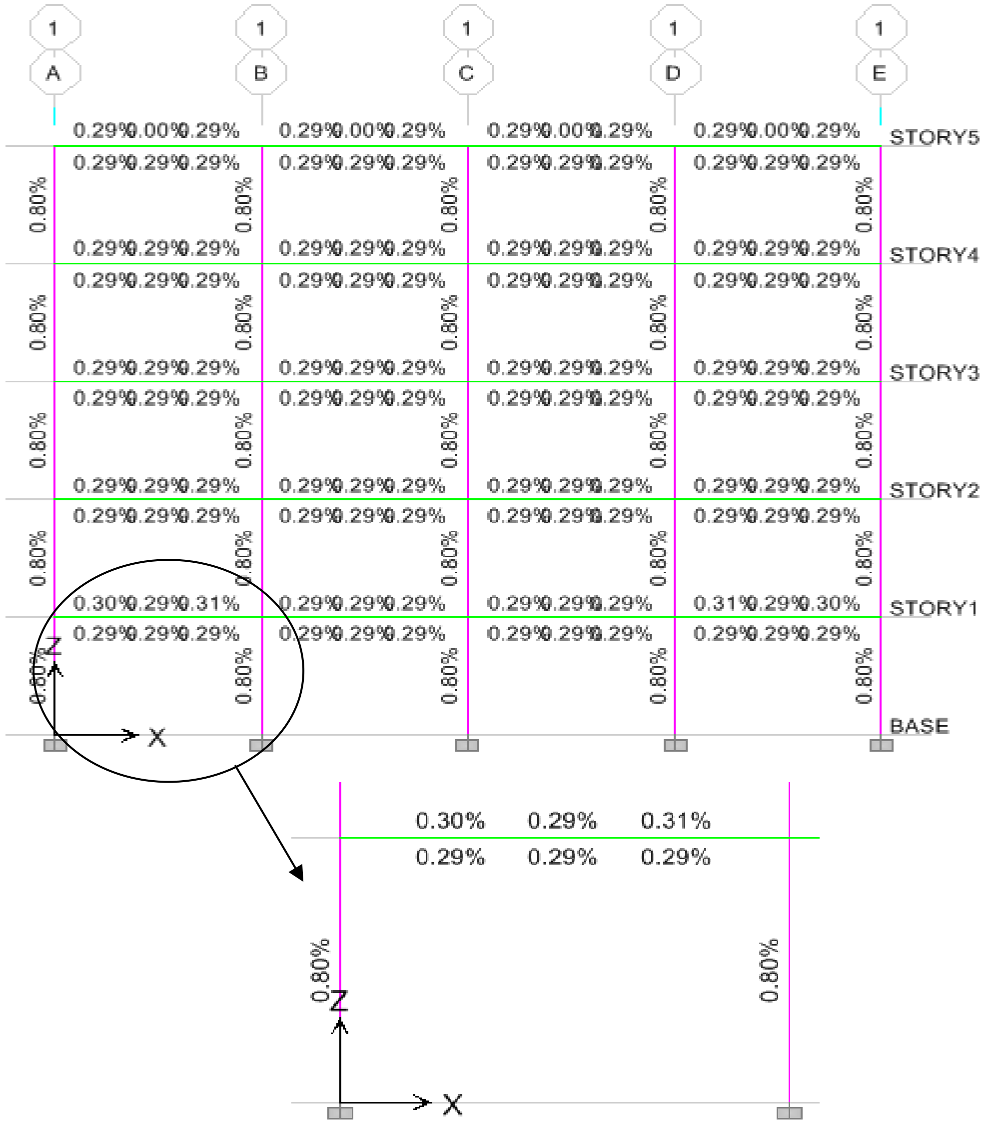


Design is carried out from **Design > Concrete Frame Design > Start Concrete Design**

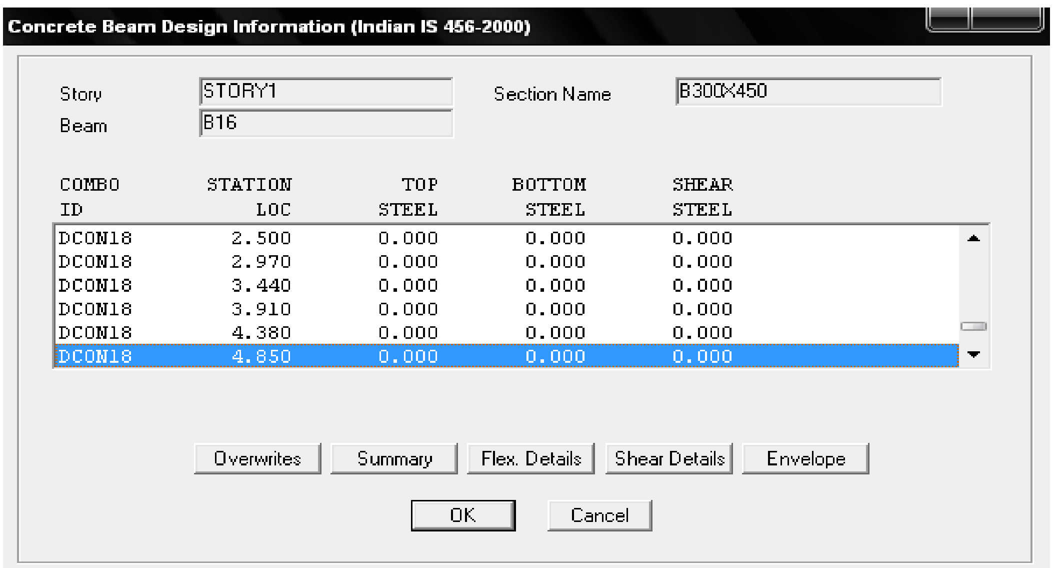


Various results in form of percentage of steel, area of steel in column beam is shown from **Design > Concrete Frame Design > Display Design Information**





Select any beam member and left click to shown below figure

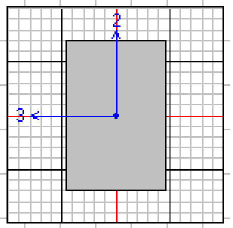


Flexure detailing of beam element is shown in Figure

Concrete Design Information Indian IS 456-2000

File

```
Indian IS 456-2000 BEAM SECTION DESIGN  Type: Ductile Frame  Units: KN-m  (Flexural Details)

Level          : STORY1        L=5.000
Element        : B16           D=0.450          B=0.300          bf=0.300
Section ID     : B300X450      ds=0.000         dct=0.040        dcb=0.040
Combo ID       : DCON18        E=25000000.00    fc=25000.000     Lt.Wt. Fac.=1.000
Station Loc    : 4.850         fy=415000.000    fys=415000.000

Gamma(Concrete): 1.500
Gamma(Steel)   : 1.150

FLEXURAL REINFORCEMENT FOR MOMENT, M3
                       Required  +veMoment  -veMoment  RegularMin  SeismicMin
                          Rebar      Rebar      Rebar       Rebar       Rebar
   Top     (+2 Axis)  4.241E-04      0.000  4.241E-04   3.904E-04   3.904E-04
   Bottom  (-2 Axis)  3.904E-04  5.967E-05      0.000   3.904E-04   3.904E-04

Design Moments, Mu3
                 Design     Design
              +veMoment  -veMoment
                  8.757    -59.106
```

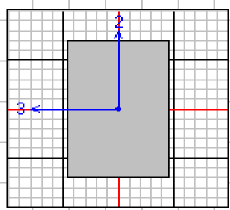


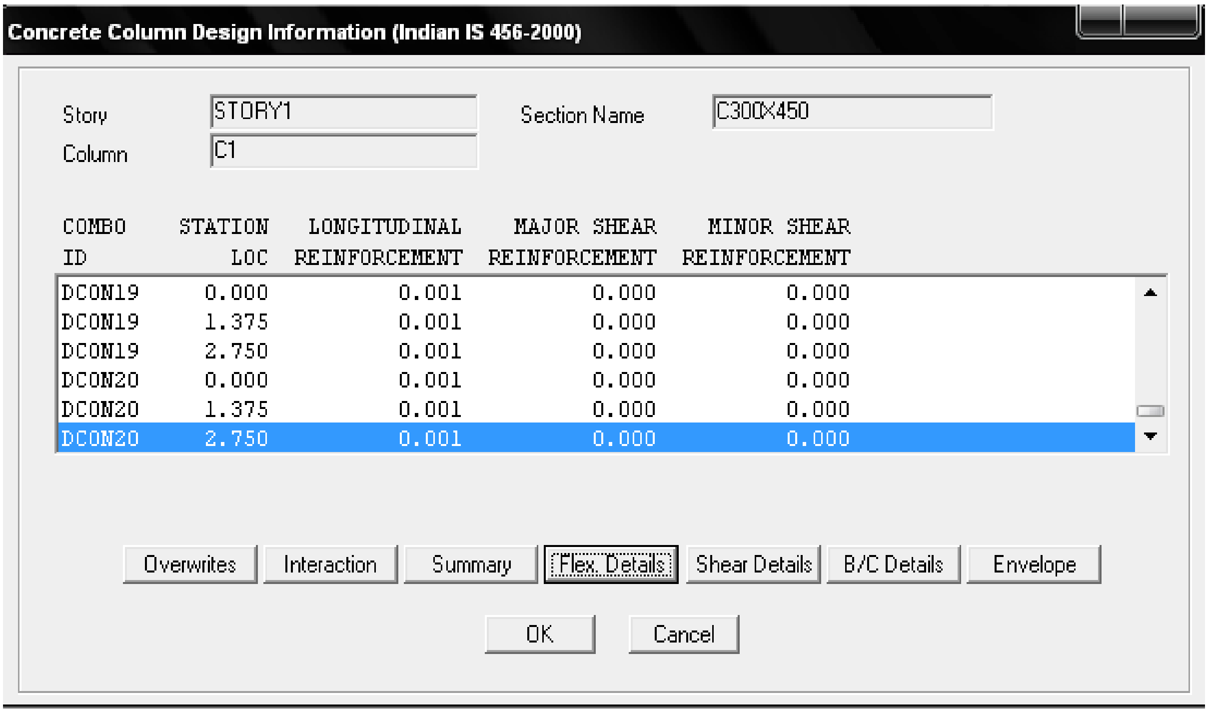
Shear detailing of beam element is shown in Figure

Concrete Design Information Indian IS 456-2000

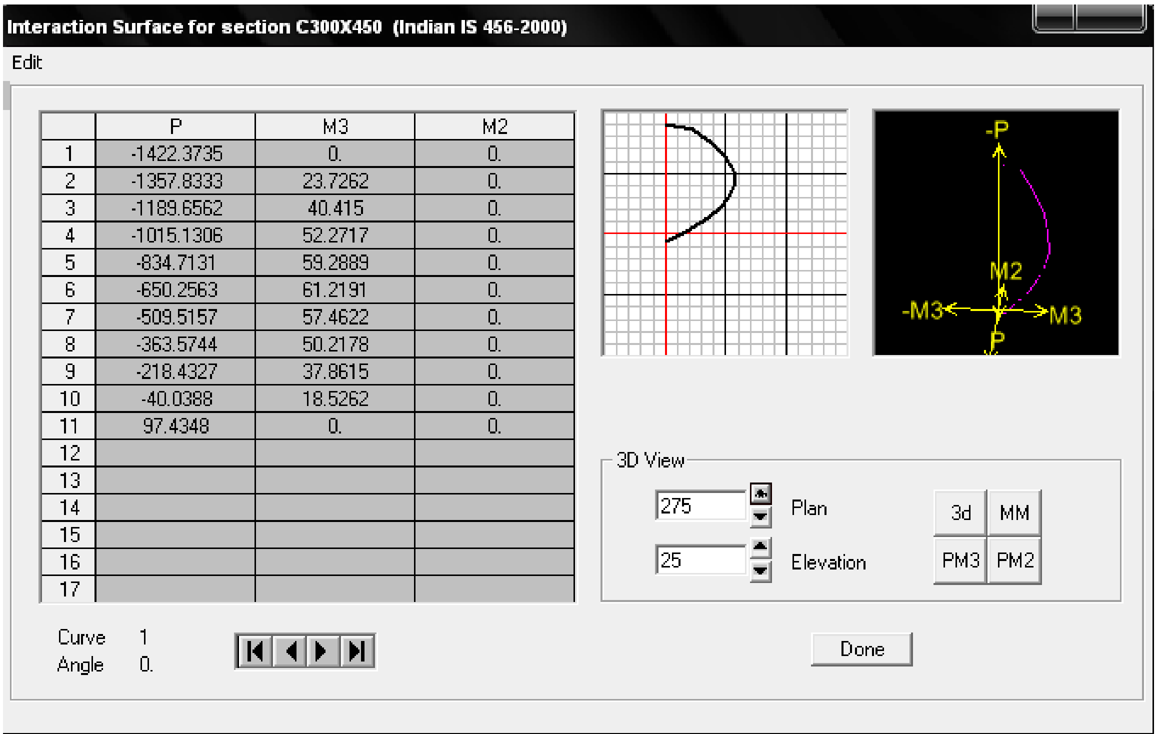
File

```
Indian IS 456-2000 BEAM SECTION DESIGN  Type: Ductile Frame  Units: KN-m  (Shear Details)

Level          : STORY1        L=5.000
Element        : B16           D=0.450          B=0.300          bf=0.300
Section ID     : B300X450      ds=0.000         dct=0.040        dcb=0.040
Combo ID       : DCON18        E=25000000.00    fc=25000.000     Lt.Wt. Fac.=1.000
Station Loc    : 4.850         fy=415000.000    fys=415000.000

Gamma(Concrete): 1.500
Gamma(Steel)   : 1.150

SHEAR DESIGN FOR V2,V3
                  Rebar     Design     Design
                  Asv/s         Vu         Pu
              3.325E-04     64.390      0.000

Design Forces
               Factored   Capacity
                     Vu         Vp
                 46.491     33.891

Capacity Moment (Left)
             Long.Rebar Long.Rebar Cap.Moment Cap.Moment
                As(Bot)    As(Top)       Mpos       Mneg
              3.904E-04  4.035E-04     54.670     56.398

Capacity Moment (Right)
             Long.Rebar Long.Rebar Cap.Moment Cap.Moment
                As(Bot)    As(Top)       Mpos       Mneg
              3.904E-04  4.241E-04     55.390     59.106

Design Basis
            Lt.Wt.Reduc   Strength   Strength       Area
                 Factor         fy        fck         Ag
                  1.000 415000.000  25000.000      0.135

Concrete Capacity
              Conc.Area Tensn.Rein        Ast  Allowable  Allowable CompFactor DepthFactr   Strengh
                     Ac   Area Ast          %   TauC(MPa)      TauC      Delta          k    Factor
                  0.123  3.904E-04      0.317      0.395    395.031      1.000      1.000     1.000

Shear Rebar Design
                 Design     Stress Conc.Cpcty Uppr.Limit RebarArea      Shear      Shear     Shear
                     Vu          v         vc       vmax     Asv/s         Vc         Vs        Vn
                 64.390    523.497    395.031   3100.000 3.325E-04     48.589     49.200    97.789
```





Pu-Mu interaction curve, Flexural detailing, shear detailing and beam/column detailing is shown in figure.



	P	M3	M2
1	-1422.3735	0.	0.
2	-1357.8333	23.7262	0.
3	-1189.6562	40.415	0.
4	-1015.1306	52.2717	0.
5	-834.7131	59.2889	0.
6	-650.2563	61.2191	0.
7	-509.5157	57.4622	0.
8	-363.5744	50.2178	0.
9	-218.4327	37.8615	0.
10	-40.0388	18.5262	0.
11	97.4348	0.	0.
12			
13			
14			
15			
16			
17			

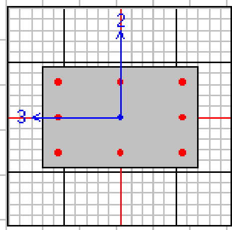
Concrete Design Information Indian IS 456-2000

File

Indian IS 456-2000 COLUMN SECTION DESIGN Type: Ductile Frame Units: KN-m (Flexural Details)

Level : STORY1	L=3.200		
Element : C1	B=0.450	D=0.300	dc=0.045
Section ID : C300X450	E=25000000.00	fc=25000.000	Lt.Wt. Fac.=1.000
Combo ID : DCON20	fy=415000.000	fys=415000.000	
Station Loc : 2.750	RLLF=0.903		

Gamma(Concrete): 1.500
Gamma(Steel) : 1.150



AXIAL FORCE & BIAXIAL MOMENT DESIGN FOR PU, M2, M3

Rebar Area	Rebar %	Design Pu	Design Mu2	Design Mu3
0.001	0.800	118.238	-5.726	-11.830

Factored Biaxial Moments

	Non-Sway Mns	Sway Ms	Factored Mu
Major Bending(M3)	3.896	-14.236	-10.340
Minor Bending(M2)	2.847	-7.579	-4.733

Slenderness Effects and Minimum Biaxial Moments

	EndMoment M1	EndMoment M2	Initial Moment	Additional Moment	Minimum Moment	Minimum Eccentrcty
Major Bending(M3)	31.916	-10.340	15.014	1.490	2.365	0.020
Minor Bending(M2)	25.971	-4.733	13.689	0.994	2.424	0.021

Biaxial Lengths and Length Factors

	K Factor	L Length
Major Bending(M3)	1.000	2.750
Minor Bending(M2)	1.000	2.750

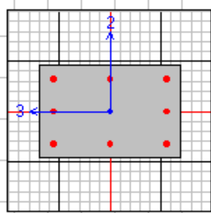
Concrete Design Information Indian IS 456-2000

File

Indian IS 456-2000 COLUMN SECTION DESIGN Type: Ductile Frame Units: KN-m (Shear Details)

Level : STORY1	L=3.200		
Element : C1	B=0.450	D=0.300	dc=0.045
Section ID : C300X450	E=25000000.00	fc=25000.000	Lt.Wt. Fac.=1.000
Combo ID : DCON20	fy=415000.000	fys=415000.000	
Station Loc : 2.750	RLLF=0.903		

Gamma(Concrete): 1.500
Gamma(Steel) : 1.150



SHEAR DESIGN FOR V2,V3

	Rebar Asv/s	Design Vu	Design Pu	Shear Vc	Shear Vs	Shear Vn
Major Shear(V2)	0.000	24.674	257.451	66.938	0.000	66.938
Minor Shear(V3)	0.000	23.918	257.451	68.846	0.000	68.846

Design Forces

	Factored Vu	Factored Pu	Capacity Vp
Major Shear(V2)	19.955	118.238	24.674
Minor Shear(V3)	14.477	118.238	23.918

Capacity Shear

	Shear Vp	Long.Rebar As(Bot)	Long.Rebar As(Top)	Cap.Moment MposBot	Cap.Moment MnegTop	Cap.Moment MnegBot	Cap.Moment MposTop
Major Shear(V2)	24.674	0.800	0.800	41.183	41.183	41.183	41.183
Minor Shear(V3)	23.918	0.800	0.800	63.981	63.981	63.981	63.981

Design Basis

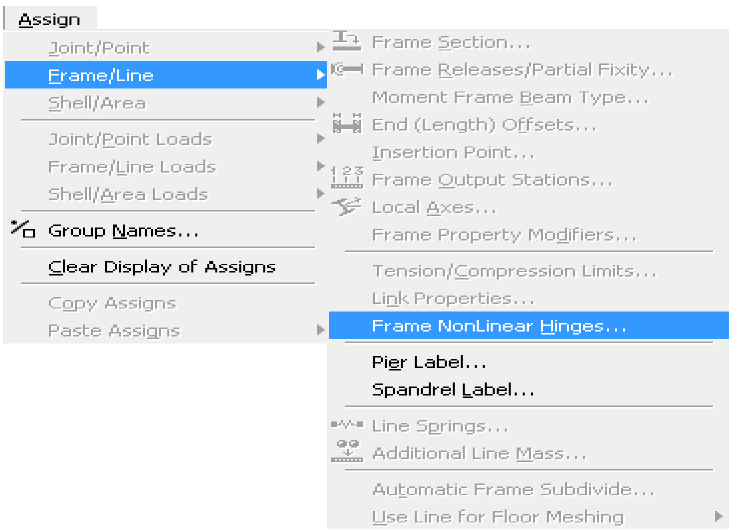
Shr Reduc Factor	Strength fy	Strength fck	Area Ag
1.000	415000.000	25000.000	0.135

Concrete Shear Capacity

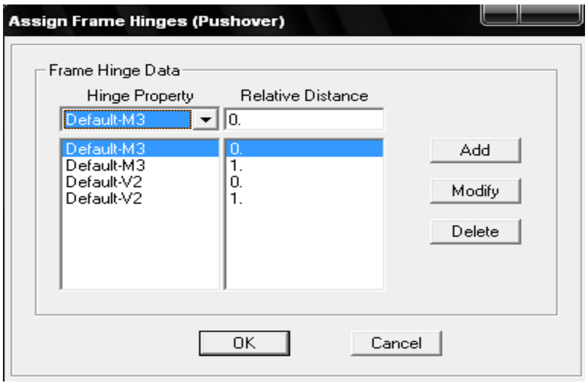
	Conc.Area Ac	Ast %	Allowable TauC(MPa)	Allowable TauC	CompFactor Delta	DepthFactr k	Strengh Factor
Major Shear(V2)	0.115	0.471	0.475	474.706	1.229	1.000	1.000
Minor Shear(V3)	0.122	0.444	0.461	461.111	1.229	1.000	1.000

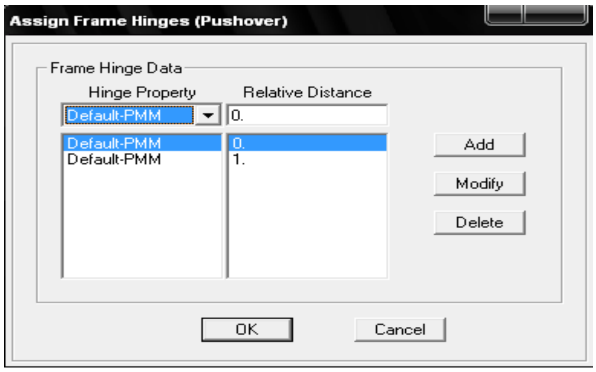
Step 8: Performance based design using pushover analysis

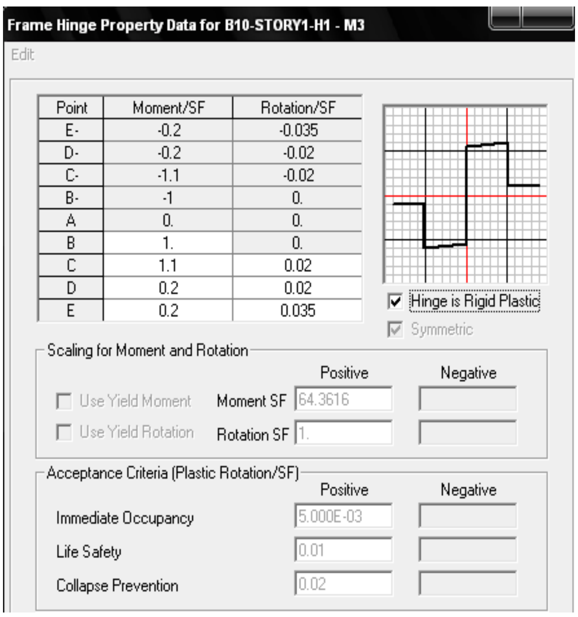
Design is carried out as per IS 456-2000 than select all beam to assign hinge properties from **Assign > Frame/Line > Frame Nonlinear Hinges command**

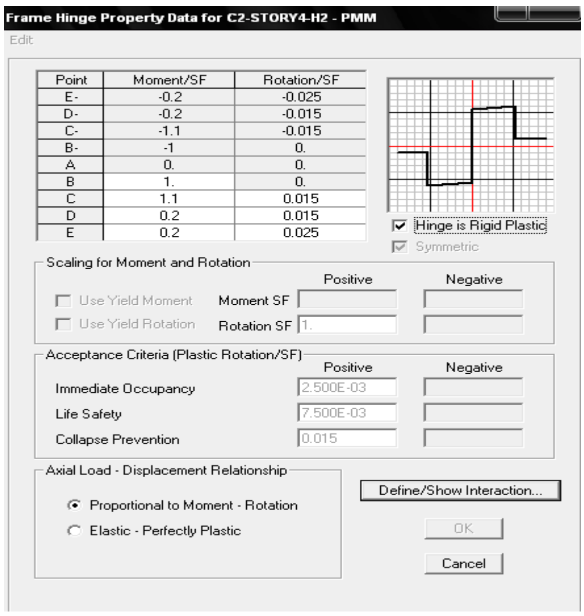


Moment and shear (M & V) hinges are considered for beam element and axial with biaxial moment (P-M-M) hinges are considered for column element as shown in Figure

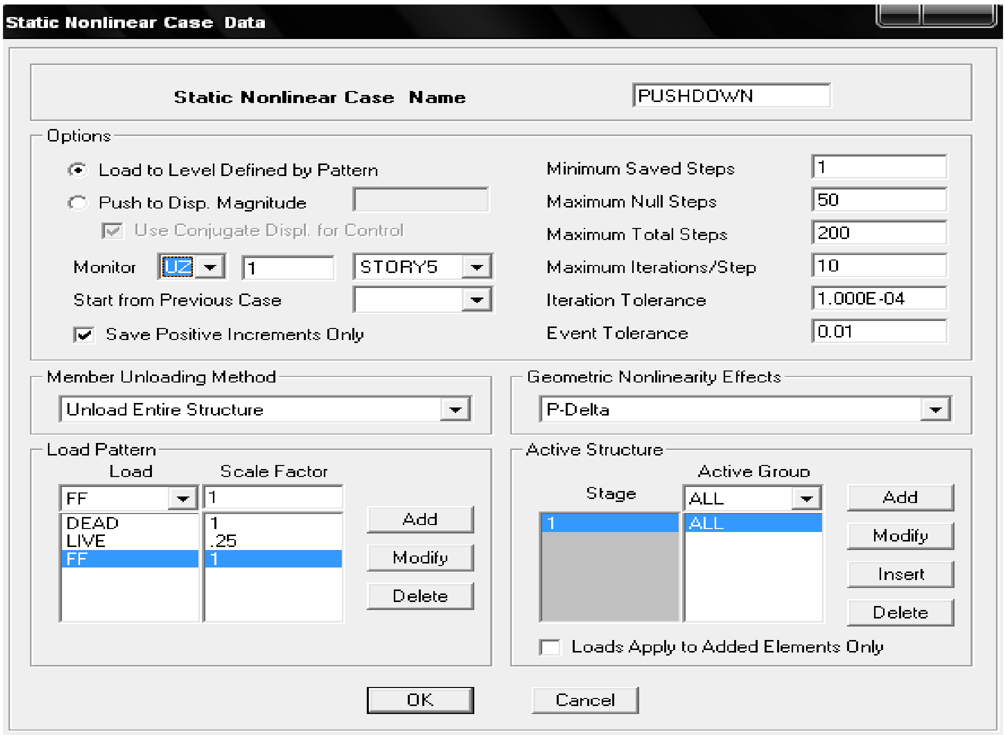




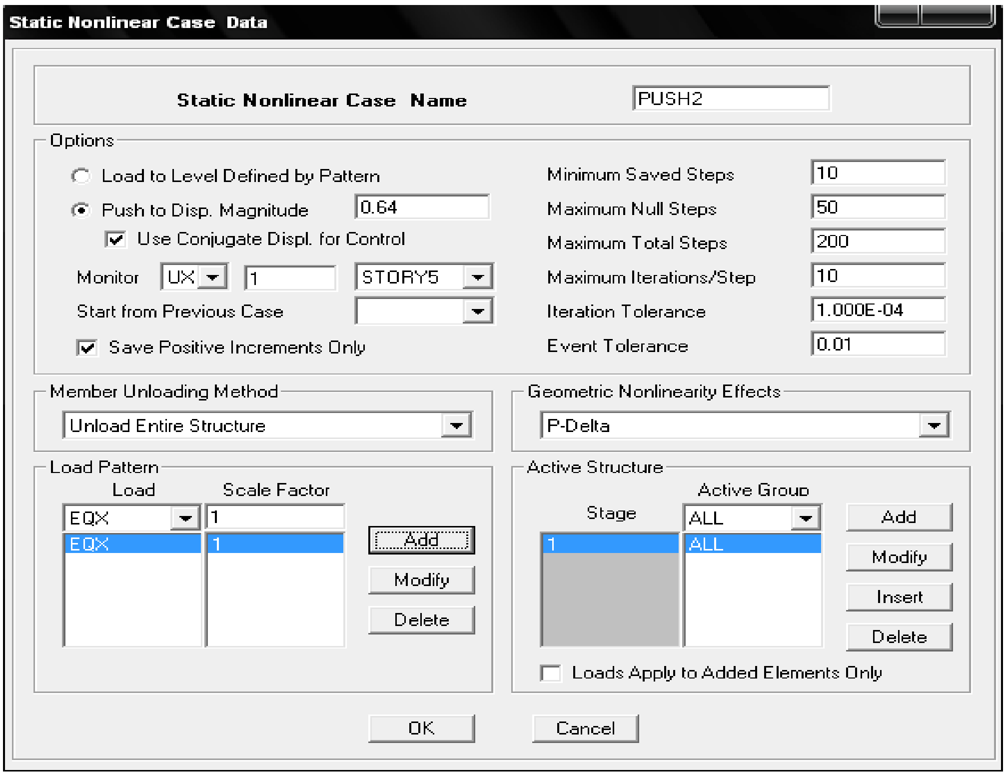




Defining static nonlinear load cases from **Define > Static Nonlinear/Pushover command**. For push over analysis first apply the gravity loading as PUSHDOWN shown in Figure and subsequently use lateral displacement or lateral force as PUSH 2 in sequence to derive capacity curve and demand curve as shown in Figure. Start from previous pushover case as PUSHDOWN for gravity loads is considered for lateral loading as PUSH 2.

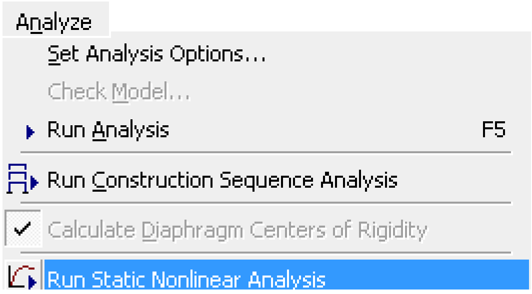


Pushdown a gravity load cases

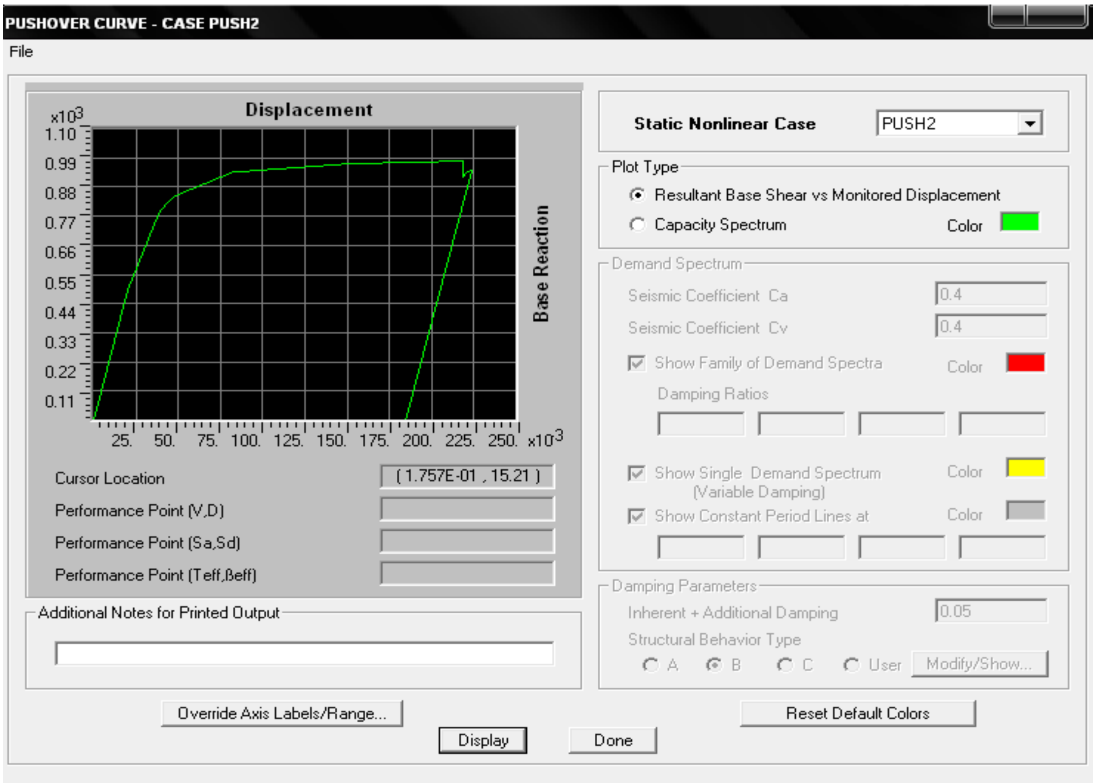


Push2 lateral load cases

Run the Pushover analysis from **Analysis > Run Static Nonlinear Analysis command**.



Review the pushover analysis results from **Display > Show Static Pushover Curve command**.

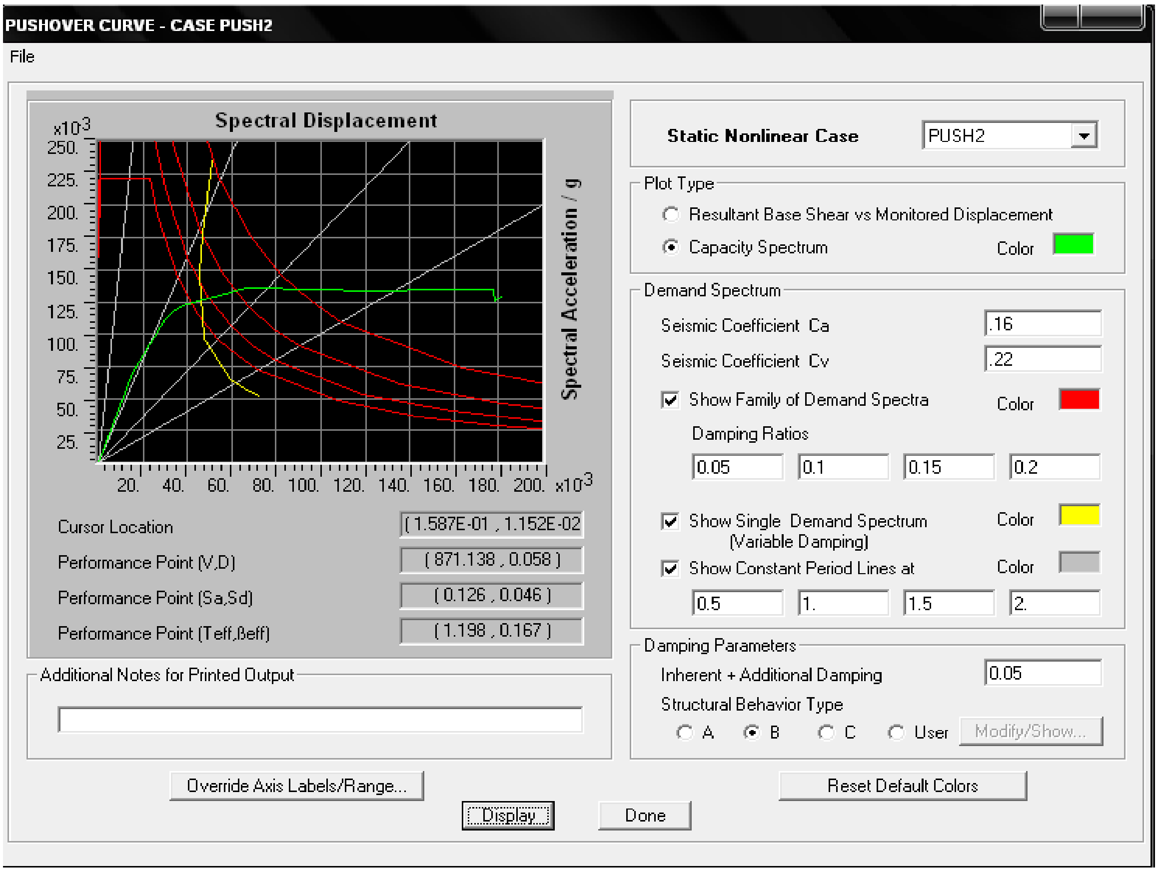


PUSHOVER CURVE

File

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	818	2	0	0	0	0	0	0	820
1	0.0200	489.9547	750	70	0	0	0	0	0	0	820
2	0.0381	778.1516	732	88	0	0	0	0	0	0	820
3	0.0427	818.5428	714	106	0	0	0	0	0	0	820
4	0.0478	845.0795	688	94	38	0	0	0	0	0	820
5	0.0831	936.7535	686	88	46	0	0	0	0	0	820
6	0.0862	939.7776	672	32	50	66	0	0	0	0	820
7	0.1518	965.8489	660	42	18	100	0	0	0	0	820
8	0.1896	974.9493	654	46	4	112	0	4	0	0	820
9	0.2188	979.0764	654	46	4	112	0	0	4	0	820
10	0.2188	919.7686	654	46	4	112	0	0	4	0	820
11	0.2208	935.4454	654	46	4	108	0	4	4	0	820
12	0.2234	944.1318	654	46	4	98	0	2	16	0	820
13	0.1778	-173.1125	820	0	0	0	0	0	0	0	820

Capacity spectrum, demand spectrum and performance point are shown in Figure



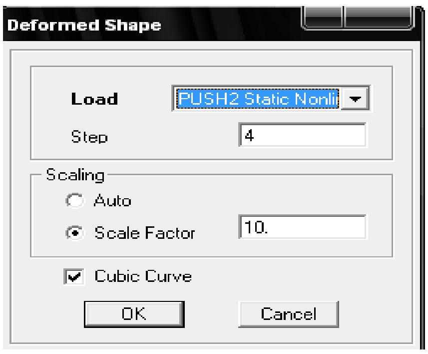
PUSHOVER CAPACITY/DEMAND COMPARISON

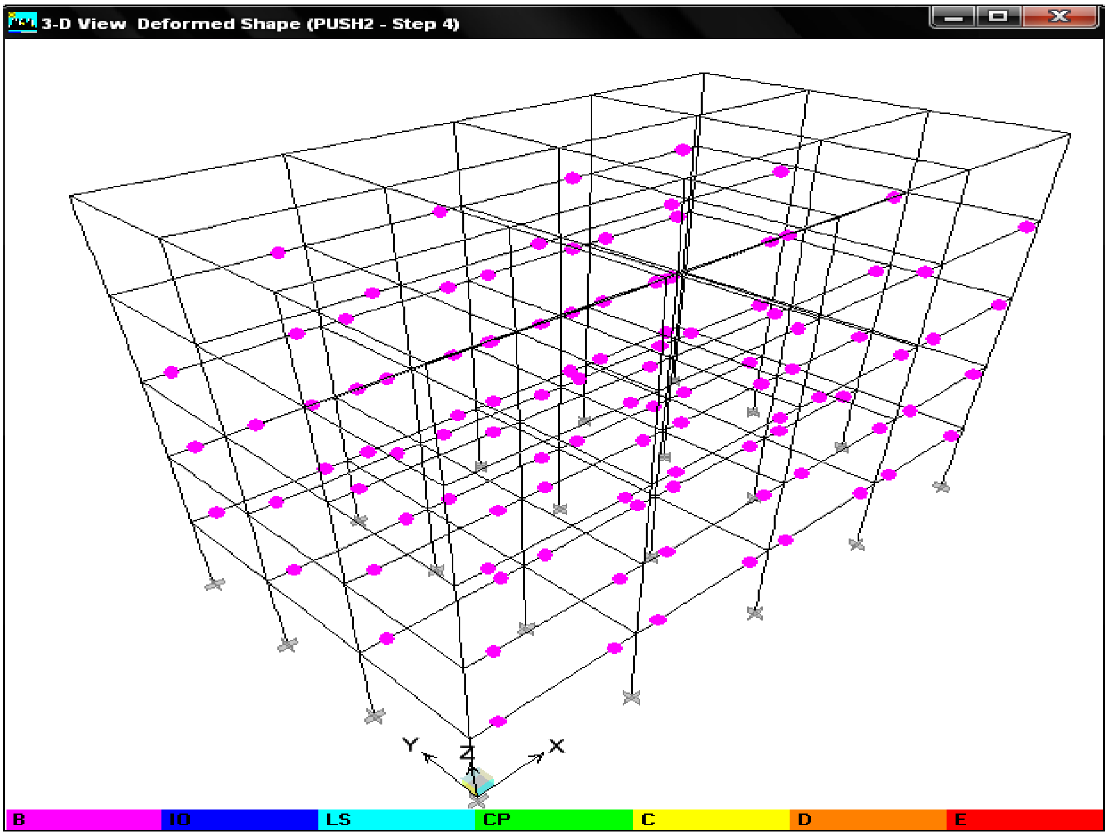
File

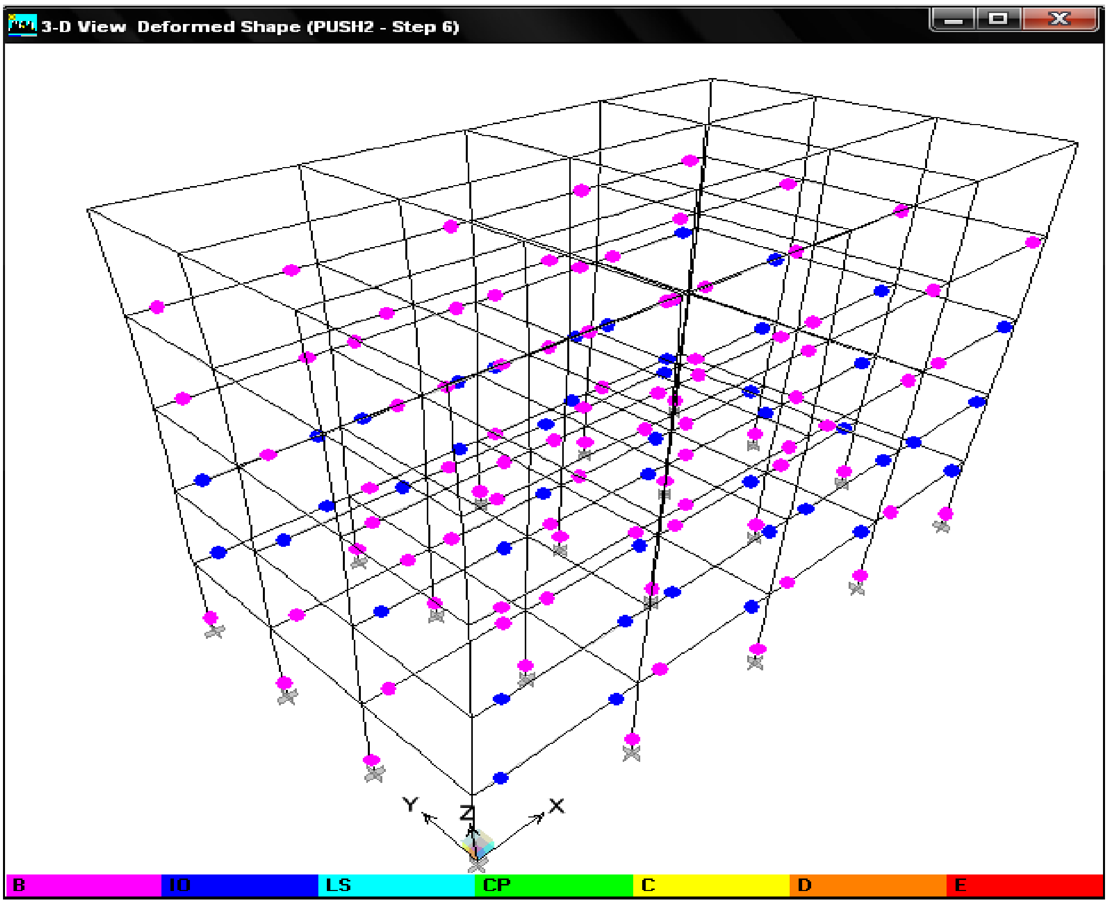
Step	Teff	ßeff	Sd(C)	Sa(C)	Sd(D)	Sa(D)	ALPHA	PF*Ø
0	0.937	0.050	0.000	0.000	0.051	0.235	1.000	1.000
1	0.937	0.050	0.015	0.071	0.051	0.235	0.821	1.299
2	1.034	0.098	0.030	0.112	0.047	0.177	0.821	1.280
3	1.070	0.117	0.034	0.118	0.046	0.162	0.821	1.274
4	1.116	0.141	0.038	0.122	0.045	0.146	0.820	1.268
5	1.406	0.232	0.067	0.136	0.048	0.097	0.816	1.247
6	1.432	0.237	0.069	0.136	0.048	0.094	0.818	1.246
7	1.928	0.292	0.124	0.134	0.059	0.064	0.853	1.229
8	2.150	0.309	0.154	0.134	0.066	0.057	0.858	1.230
9	2.307	0.318	0.178	0.135	0.071	0.053	0.860	1.230
10	2.385	0.331	0.178	0.126	0.073	0.052	0.862	1.228
11	2.377	0.333	0.180	0.128	0.073	0.052	0.863	1.228
12	2.382	0.334	0.182	0.129	0.073	0.052	0.864	1.227

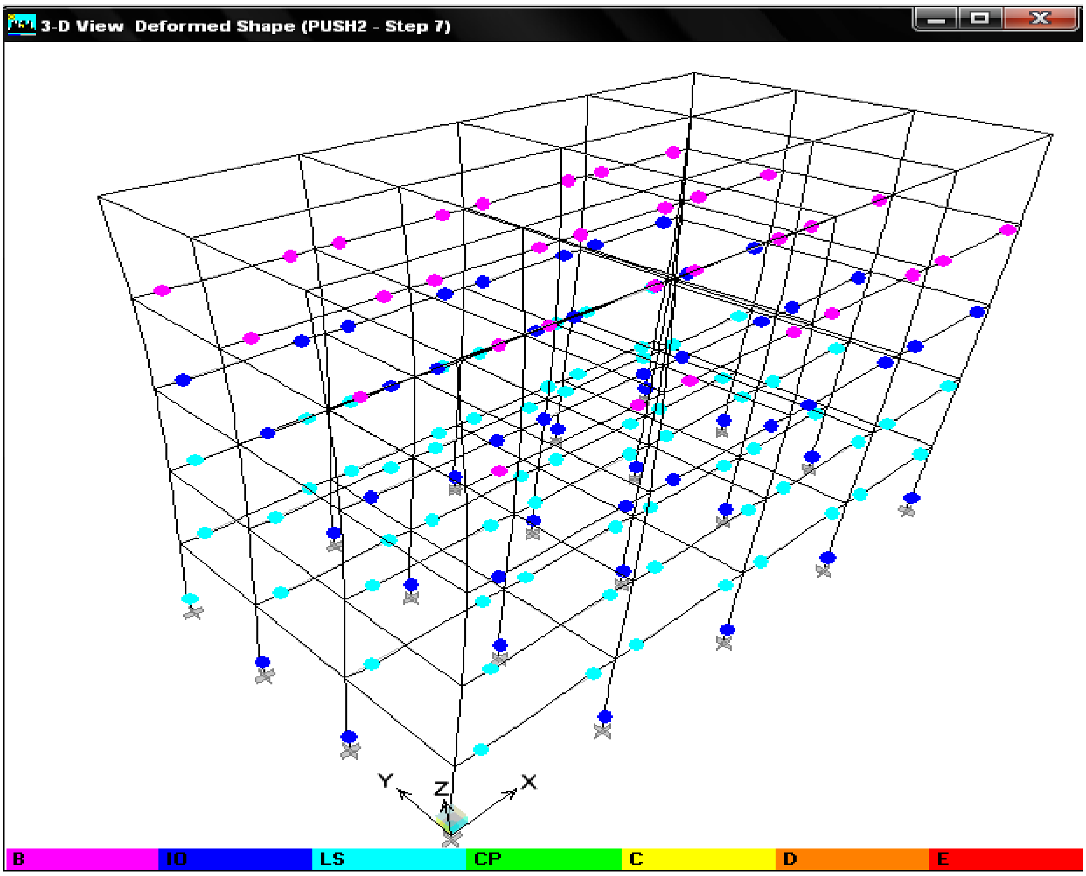
Show the deform shape from **Display > Show Deform shape**

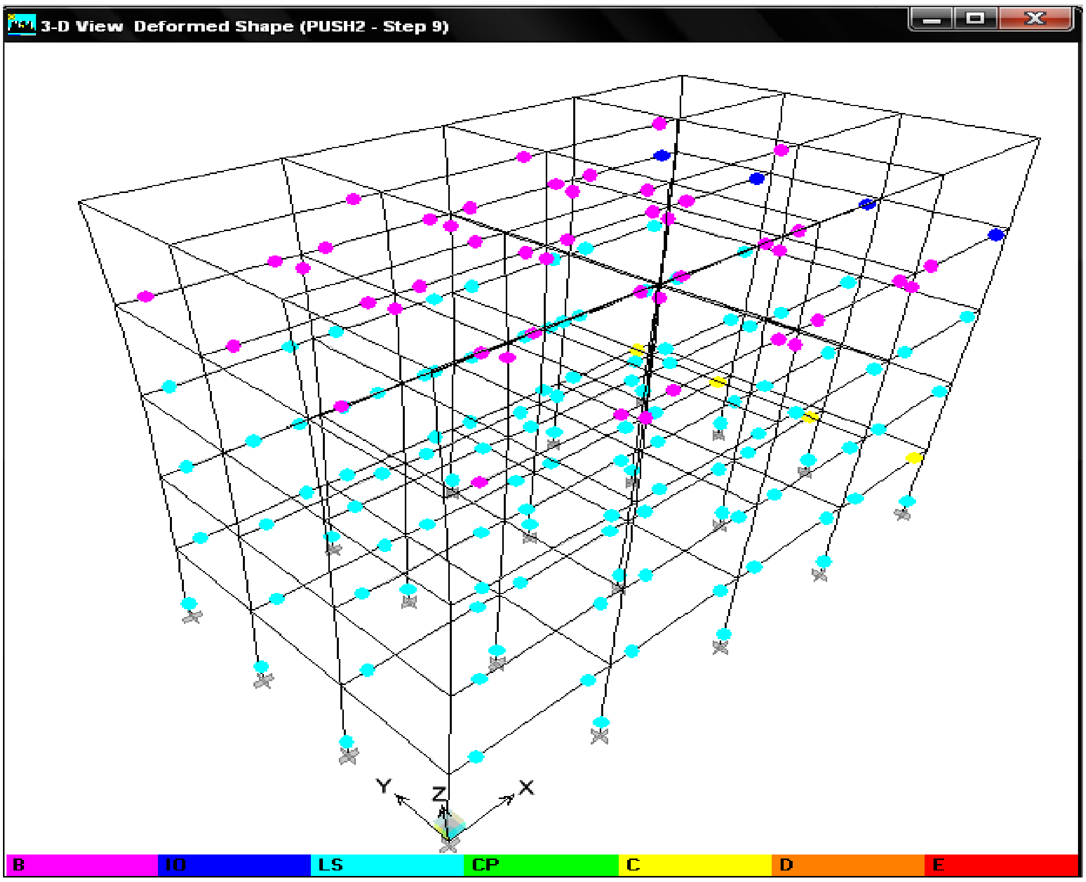
At various stages hinge formation is shown with change the value in **step** box. Step 4 is shown in this Figure.




3-D View Deformed Shape (PUSH2 - Step 4)
Y
Z
X
B
IO
LS
CP
C
D
E


3-D View Deformed Shape (PUSH2 - Step 6)
Y
Z
X
B
IO
LS
CP
C
D
E


3-D View Deformed Shape (PUSH2 - Step 7)
Y
Z
X
B
IO
LS
CP
C
D
E


3-D View Deformed Shape (PUSH2 - Step 9)
Y
Z
X
B
IO
LS
CP
C
D
E

Illustrative Example

For the illustration purpose the data is taken from SP 22 for analysis of a 15 storey RC building as shown in fig. 1(a). The live load on all the floors is 200 kg/m^2 and soil below the building is hard. The site lies in zone V. All the beams are of size 40 × 50 cm and slabs are 15 cm thick. The sizes of columns are 60 × 60 cm in all the storeys and wall alround is 12 cm thick.

Analysis of the building

(a) Calculation of dead load, live load and storey stiffness: Dead loads and live loads at each floor are computed and lumped. Stiffness in a storey is lumped assuming all the columns to be acting in parallel with each column contributing stiffness corresponding to $K_c = 12EI/L^3$, where I is the moment of inertia about bending axis, L is the column height, and E the elastic modulus of the column material. The total stiffness of storey is thus ΣK_c. The lumped mass at all floor level is 52.43 (t-s^2/m) and at roof level is 40 (t-s^2/m). The values of I, K_c and ΣK_c for all the floors / storeys are 1.08×10^8 cm^4, 9024 t/m and 180480 t/m, respectively. The value of modulus of elasticity of column material considered is 1880000 t/m^2.

(b) For undamped free vibration analysis the building is modeled as spring mass model. As the building is regular one degree of freedom can be considered at each floor level. Total degrees of freedom are 15. So mass and stiffness matrix are having size 15 × 15 given as in Table 1.

Table 1: Stiffness and mass matrix

Stiffness matrix [k]	Mass matrix [m]
360960 -180480 0 0 0 0 0 0 0 0 0 0 0 0 0	52.43 0 0 0 0 0 0 0 0 0 0 0 0 0 0
-180480 360960 -180480 0 0 0 0 0 0 0 0 0 0 0 0	0 52.43 0 0 0 0 0 0 0 0 0 0 0 0 0
0 -180480 360960 -180480 0 0 0 0 0 0 0 0 0 0 0	0 0 52.43 0 0 0 0 0 0 0 0 0 0 0 0
0 0 -180480 360960 -180480 0 0 0 0 0 0 0 0 0 0	0 0 0 52.43 0 0 0 0 0 0 0 0 0 0 0
0 0 0 -180480 360960 -180480 0 0 0 0 0 0 0 0 0	0 0 0 0 52.43 0 0 0 0 0 0 0 0 0 0
0 0 0 0 -180480 360960 -180480 0 0 0 0 0 0 0 0	0 0 0 0 0 52.43 0 0 0 0 0 0 0 0 0
0 0 0 0 0 -180480 360960 -180480 0 0 0 0 0 0 0	0 0 0 0 0 0 52.43 0 0 0 0 0 0 0 0
0 0 0 0 0 0 -180480 360960 -180480 0 0 0 0 0 0	0 0 0 0 0 0 0 52.43 0 0 0 0 0 0 0
0 0 0 0 0 0 0 -180480 360960 -180480 0 0 0 0 0	0 0 0 0 0 0 0 0 52.43 0 0 0 0 0 0
0 0 0 0 0 0 0 0 -180480 360960 -180480 0 0 0 0	0 0 0 0 0 0 0 0 0 52.43 0 0 0 0 0
0 0 0 0 0 0 0 0 0 -180480 360960 -180480 0 0 0	0 0 0 0 0 0 0 0 0 0 52.43 0 0 0 0
0 0 0 0 0 0 0 0 0 0 -180480 360960 -180480 0 0	0 0 0 0 0 0 0 0 0 0 0 52.43 0 0 0
0 0 0 0 0 0 0 0 0 0 0 -180480 360960 -180480 0	0 0 0 0 0 0 0 0 0 0 0 0 52.43 0 0
0 0 0 0 0 0 0 0 0 0 0 0 -180480 360960 -180480	0 0 0 0 0 0 0 0 0 0 0 0 0 52.43 0
0 0 0 0 0 0 0 0 0 0 0 0 0 -180480 180480	0 0 0 0 0 0 0 0 0 0 0 0 0 0 40.00

The first three natural frequencies and the corresponding mode shape are determined using solution procedure of Eigen value problem i.e. $Det([k] - \omega^2 [m]) = \{0\}$. Time periods and mode shape factors are given in table 2.

(c) The next step is to obtain seismic forces at each floor level in each individual mode as per IS 1893. These calculations are shown in Table 3.

Table 2. Periods and modes shape coefficients at various levels for first three modes

Mode No.	1	2	3
Period in seconds	1.042	0.348	0.210
Mode shape coefficient at various floor levels			
$\phi_1^{(r)}$	0.037	0.108	0.175
$\phi_2^{(r)}$	0.073	0.206	0.305
$\phi_3^{(r)}$	0.108	0.285	0.356
$\phi_4^{(r)}$	0.143	0.336	0.315
$\phi_5^{(r)}$	0.175	0.356	0.192
$\phi_6^{(r)}$	0.206	0.342	0.019
$\phi_7^{(r)}$	0.235	0.296	-0.158
$\phi_8^{(r)}$	0.261	0.222	-0.296
$\phi_9^{(r)}$	0.285	0.127	-0.355
$\phi_{10}^{(r)}$	0.305	0.019	-0.324
$\phi_{11}^{(r)}$	0.323	-0.089	-0.208
$\phi_{12}^{(r)}$	0.336	-0.190	-0.039
$\phi_{13}^{(r)}$	0.347	-0.273	0.140
$\phi_{14}^{(r)}$	0.353	-0.330	0.283
$\phi_{15}^{(r)}$	0.356	-0.355	0.353

As per clause 7.8.4.4 of IS 1893, if the building does not have closely spaced modes, the peak response quantity due to all modes considered shall be obtained as per SRSS method. In this example as shown below, the frequencies in each mode differ by more than 10%, so building is not having closely spaced modes and so, SRSS method can be used.

Mode	Time period	Natural frequency 2π / T
1	1.042	6.03
2	0.348	18.06
3	0.210	29.92

The comparison of storey shear using SRSS method and CQC method is shown in table 3.

As per clause 7.8.2 of IS 1893 the design base shear (V_B) shall be compared with base shear ($\bar{V}_B$) calculated using a fundamental period Ta . When V_B is less than $\bar{V}_B$, all the response quantities (e.g. member forces, displacements, storey forces, storey shear and base reactions) shall be multiplied by $\bar{V}_B/V_B$.

For this example

$T_a = 0.075\ h^{0.75}$ for RC frame building

$T_a = 0.075\ (45)^{0.75} = 1.3031$ sec

For hard soil $Sa/g = 1.00/T_a = 1/1.3031 = 0.7674$

$\bar{V}_B = A_h\ W$

$W = 514.34 \times 14 + 392.4 = 7593.16$ t

$A_h = (Z\ I\ S_a) / (2\ R\ g)$

$Z = 0.36$ (for zone V)

$I = 1.0$

$R = 5.0$ (considering SMRF)

$A_h = (0.36 \times 1 \times 0.7674) / (2 \times 5.0) = 0.0276$

Base shear $\bar{V}_B = 0.0276 \times 7593.16 = 209.77$ t

Base shear from dynamic analysis $V_B = 229.9$ t

So, $V_B > \bar{V}_B$, response quantities need not required to be modified.

The storey shear distribution along the height is shown in fig. 1 (c).

Table 3: Calculation of Seismic forces

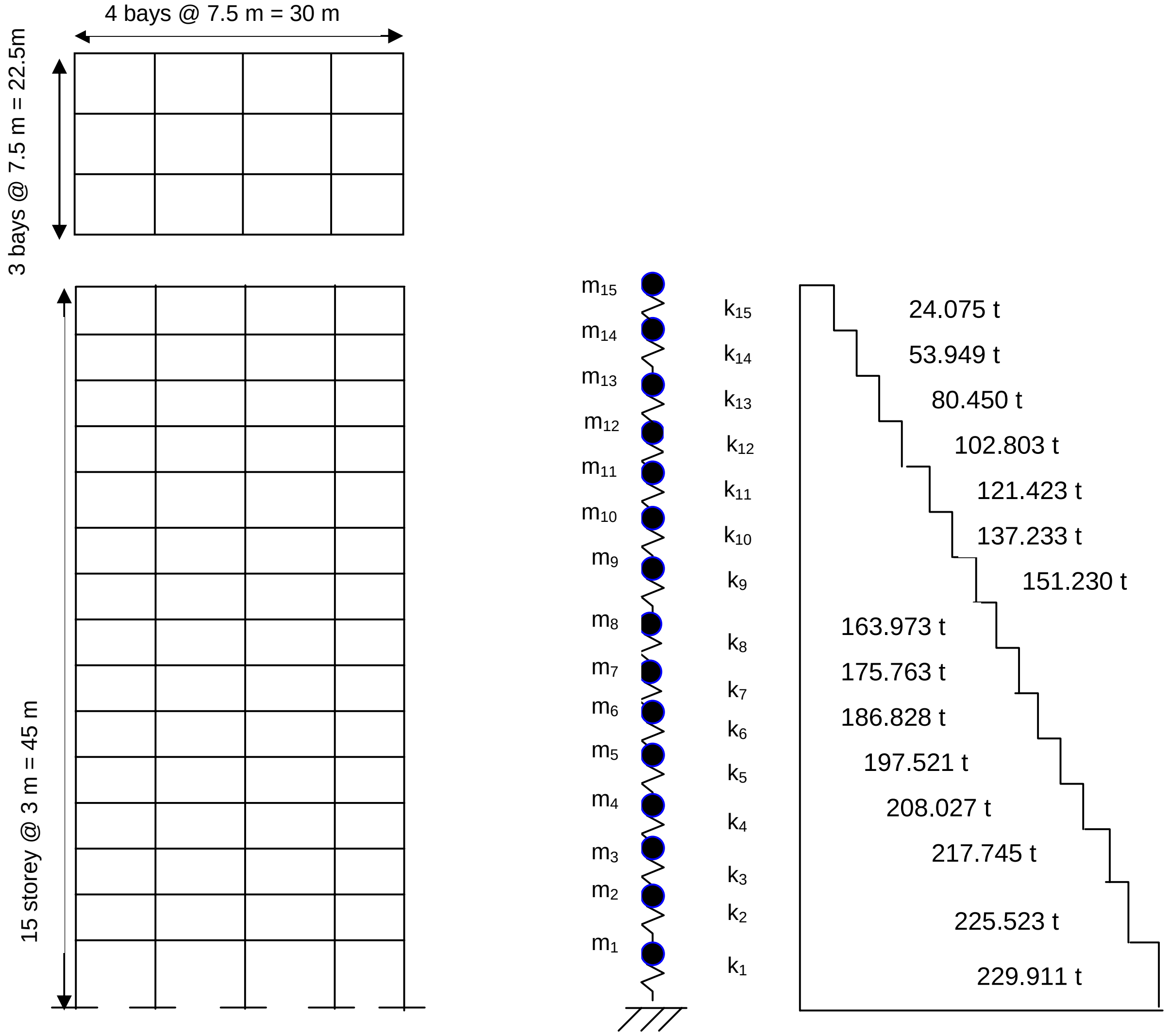
Floor No.	Weight W_i (t)	Mode coefficients			$W_i\phi_{ik}$			$W_i\phi_{ik}^2$		
		ϕ_{i1}	ϕ_{i2}	ϕ_{i3}	$W_i\phi_{i1}$	$W_i\phi_{i2}$	$W_i\phi_{i3}$	$W_i\phi_{i1}^2$	$W_i\phi_{i2}^2$	$W_i\phi_{i3}^2$
1	514.34	0.037	0.108	0.175	19.030	55.548	90.009	0.704	5.999	15.751
2	514.34	0.073	0.206	0.305	37.546	105.953	156.873	2.740	21.826	47.846
3	514.34	0.108	0.285	0.356	55.548	146.586	183.104	5.999	41.777	65.185
4	514.34	0.143	0.336	0.315	73.550	172.817	162.016	10.517	58.066	51.035
5	514.34	0.175	0.356	0.192	90.009	183.104	98.752	15.751	65.185	18.960
6	514.34	0.206	0.342	0.019	105.953	175.903	9.772	21.826	60.159	0.185
7	514.34	0.235	0.296	-0.158	120.869	152.244	-81.265	28.404	45.064	12.839
8	514.34	0.261	0.222	-0.296	134.242	114.183	-152.244	35.037	25.348	45.064
9	514.34	0.285	0.127	-0.355	146.586	65.320	-182.590	41.777	8.295	64.819
10	514.34	0.305	0.019	-0.324	156.873	9.772	-166.645	47.846	0.185	53.993
11	514.34	0.323	-0.089	-0.208	166.131	-45.776	-106.982	53.660	4.074	22.252
12	514.34	0.336	-0.190	-0.039	172.817	-97.724	-20.059	58.066	18.567	0.782
13	514.34	0.347	-0.273	0.140	178.475	-140.414	72.007	61.930	38.333	10.081
14	514.34	0.353	-0.330	0.283	181.561	-169.731	145.557	64.091	56.011	41.192
15	392.40	0.356	-0.355	0.353	139.694	-139.301	138.517	49.731	49.452	48.896
Total					1778.890	588.486	346.824	498.085	498.346	498.886

Table 3: Calculation of Seismic forces (Continued)

	Mode 1	Mode 2	Mode 3
Mode participation factor $P_k = \Sigma W_i\phi_{ik}$ / Σ Wi(ik2	3.571456	1.180878	0.695197
Modal mass Mk = ((Wi(ik)2/ (Wi(ik2	6353.23	694.91	241.37
% of total mass = Mk / (Mk	83.67 %	9.15 %	3.18 %
Time Period (Tk)	1.042 Sec	0.348 Sec	0.210 Sec
Sa/g	0.9596	2.5	2.5
	Z = 0.36 (zone V), I = 1.0, R = 5.0, Hard soil		
Design horizontal spectrum value Ak = (Z I Sa) / (2 R g)	0.0345456	0.09	0.09
Base Reaction	219.44	62.54	21.72

Table 3: Calculation of Seismic forces (Continued)

Floor No.	$Q_{ik} = A_k\phi_{ik} P_kW_i$			$V_{ik} = \Sigma Q_{ik}$			Combination of storey shear		
	Q_{i1}	Q_{i2}	Q_{i3}	V_{i1}	V_{i2}	V_{i3}	SAV	SRSS	CQC
1	2.348	5.903	5.631	219.497	62.543	21.699	303.741	229.263	229.911
2	4.6328	11.260	9.815	217.149	56.640	16.068	289.857	224.989	225.523
3	6.854	15.579	11.456	212.516	45.379	6.253	264.148	217.397	217.745
4	9.075	18.366	10.137	205.662	29.800	-5.203	240.665	207.875	208.027
5	11.106	19.460	6.178	196.586	11.433	-15.340	223.360	197.515	197.521
6	13.073	18.694	0.611	185.480	-8.026	-21.519	215.026	186.897	186.828
7	14.914	16.180	-5.084	172.406	-26.721	-22.130	221.258	175.863	175.763
8	16.564	12.135	-9.525	157.492	-42.901	-17.045	217.440	164.119	163.973
9	18.087	6.942	-11.424	140.928	-55.037	-7.520	203.486	151.481	151.230
10	19.356	1.038	-10.426	122.841	-61.979	3.903	188.724	137.646	137.233
11	20.498	-4.865	-6.693	103.484	-63.017	14.330	180.833	122.007	121.423
12	21.323	-10.386	-1.255	82.985	-58.152	21.024	162.162	103.491	102.803
13	22.022	-14.923	4.505	61.661	-47.766	22.279	131.707	81.118	80.450
14	22.402	-18.038	9.107	39.639	-32.843	17.773	90.257	54.460	53.949
15	17.236	-14.804	8.666	17.236	-14.804	8.666	40.708	24.318	24.075



(a) Plan and Elevation of Building

(b) Spring and mass model of Building

(c) Storey shear distribution along

Fig. 1

Above mention 15 storey example solved in ETABS is describe follow:

(1) Generate model: Material properties are assign as per Indian Code. Beam, column and slab are define as per given above dimension. 3D model of 15 story building is shown in Fig. 2.

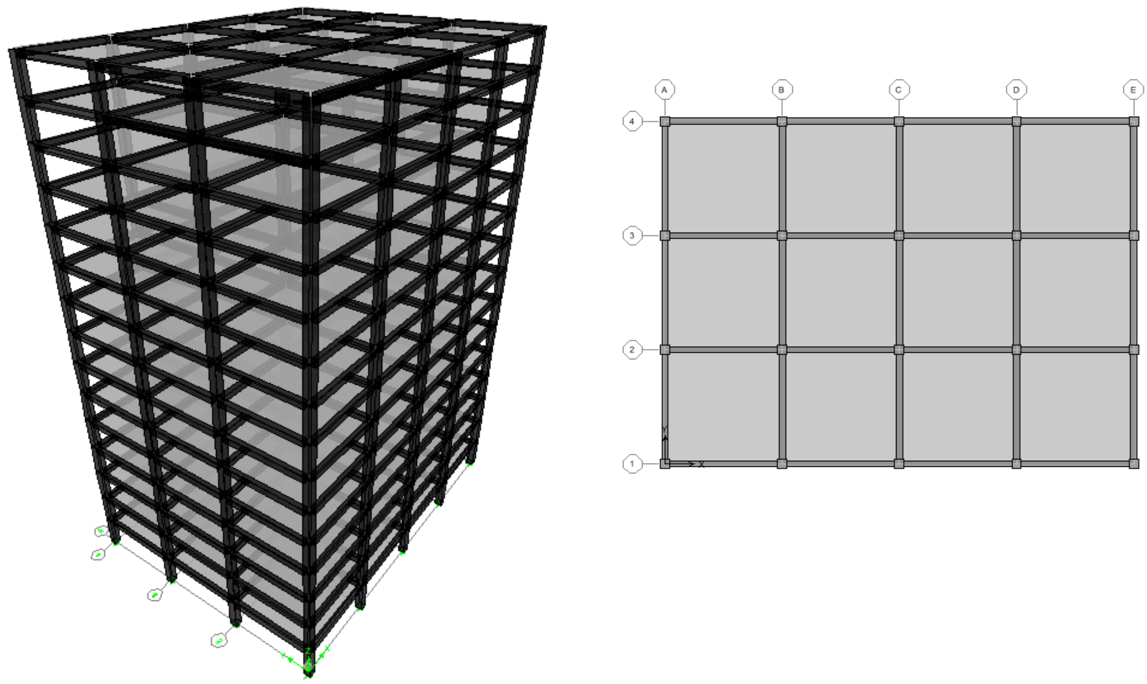


Fig. 2 3D model of 15 storey building

(2) Static analysis load case: Loading parameters are defined as per Indian Code as shown in Fig. 3 and 4. Consider dead load and live load as a gravity load in vertical downward direction and earthquake load as lateral load in horizontal direction. Earthquake load is defined as per IS 1893-2002.

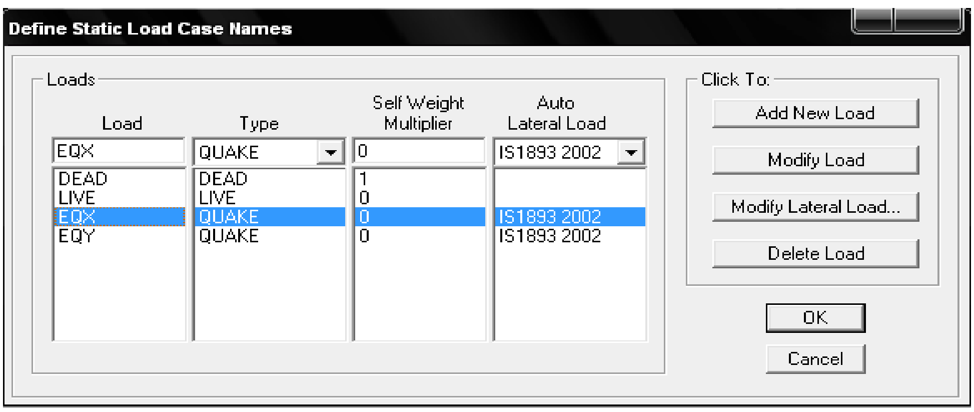


Fig. 3 Define static load case

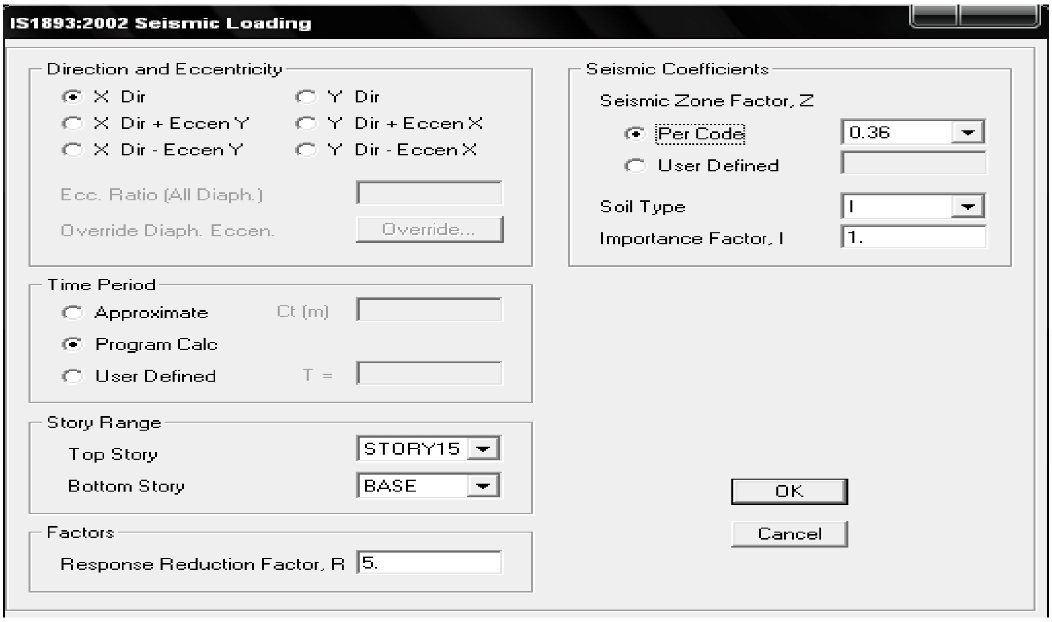
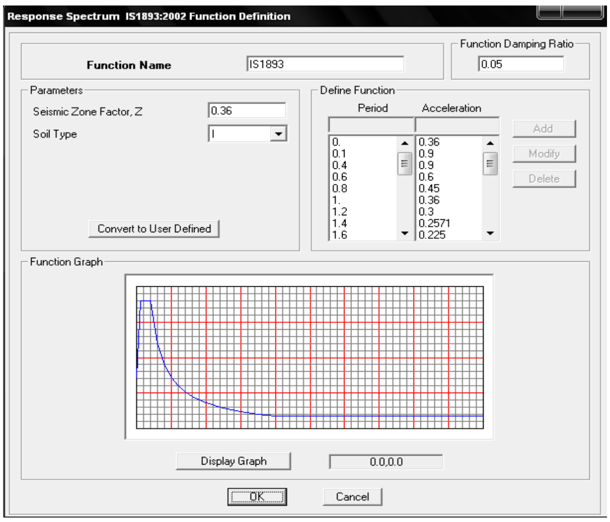


Fig. 4 Define a seismic loading as per IS: 1893-2002

(3) Dynamic analysis: IS 1893 response spectrum curve for zone V is shown in Fig. 5. The damping value of 5% is specified to generate the response spectrum curve. The scale factor of 9.81 (i.e. g) is assigned as shown in Fig. 6.



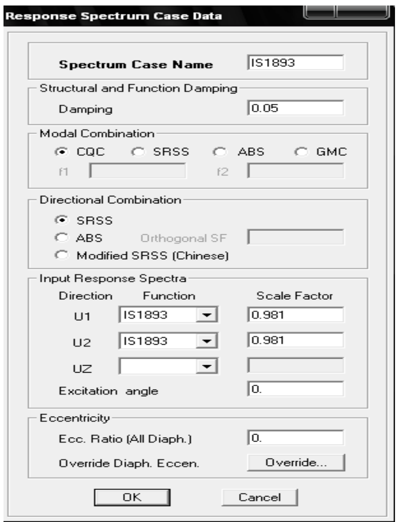


Fig. 5 IS 1893 response Spectra Graphs

Fig. 6 Response Spectra Case Data

(4) The design acceleration time history for passport office site is given as input in Define menu > Time History Function. The time history load cases are defined from the Time History Cases option as shown in the Fig. 7. The acceleration time history of Passport office site as defined in ETABS is shown in Fig. 8.

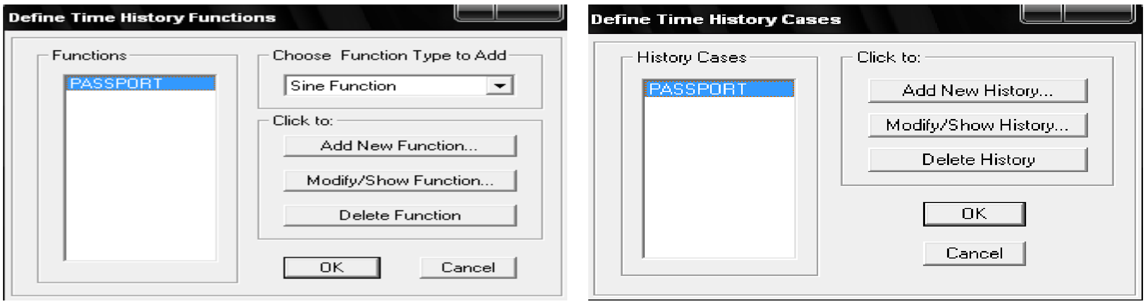


Fig. 7 Time History Options

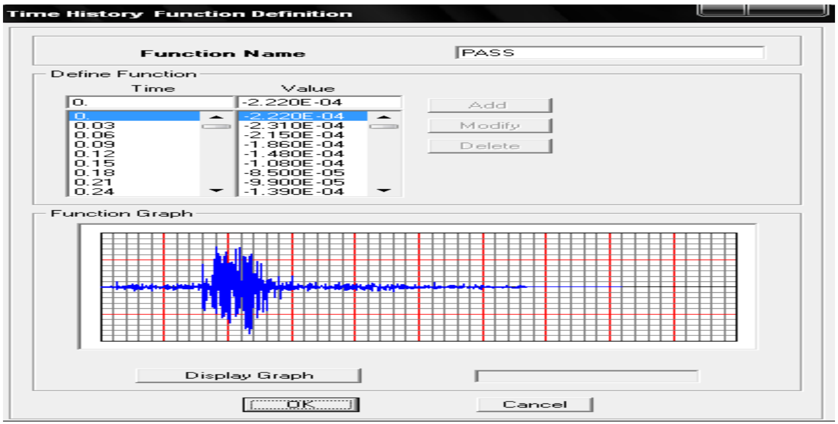


Fig. 8 Time History Graphs

Time history case data is defined for simplicity of analysis. Number of output time steps is 300. Linear analysis case and two direction acceleration load case are considered. The scale factor 9.81 i.e. gravitational acceleration (m/sec^2) and 5% damping are defined as shown in Fig. 9.

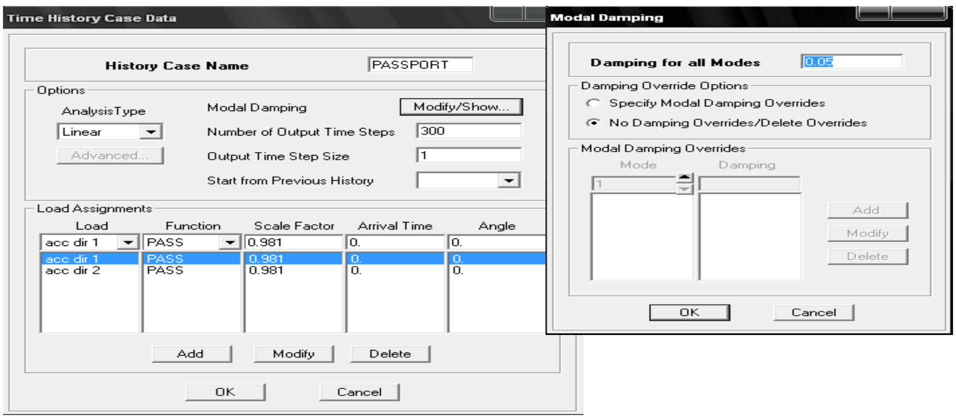


Fig. 9 Time History Case Data

(5) Mass source is defined in modeling as shown in Fig. 10. As per IS: 1893-2002, 25% live load (of 200 kg/m^2) is considered on all floor of building except at roof level.

(6) In building, slab is considered as a single rigid member during earthquake analysis. ETABS has a facility to create rigid diaphragm action for slab. For that, all slabs are selected first and apply diaphragm action for rigid or semi rigid condition.

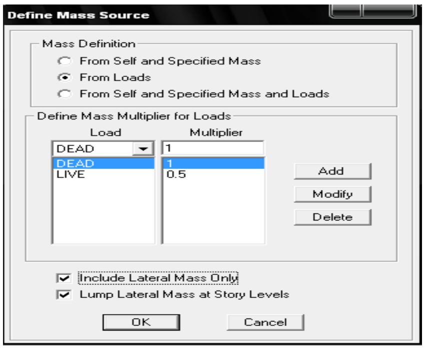


Fig. 10 define mass source

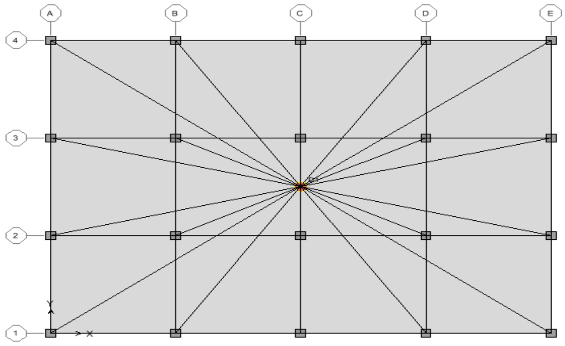
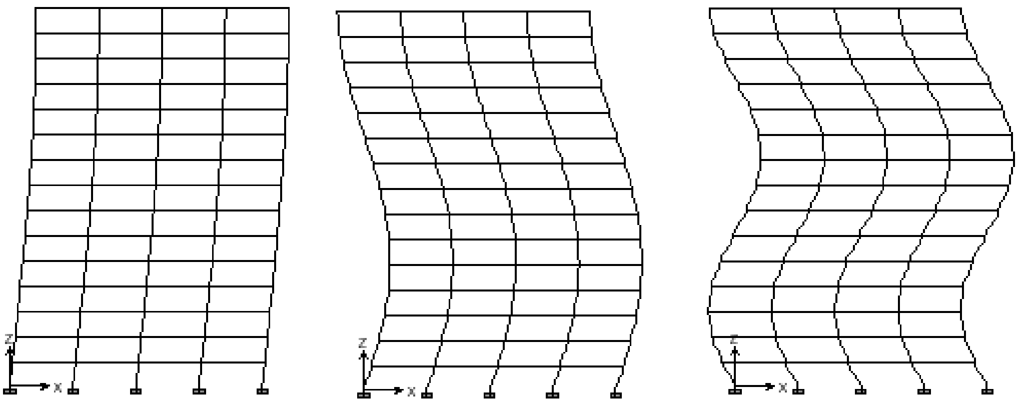


Fig. 11 Rigid diaphragm in plan

Results of Static and Dynamic analysis



1.1097 sec   0.3712 sec   0.2243 sec

Fig. 12 Time Period of different mode

Table 4 percentage of total seismic mass

Mode	Period	UX	UY	UZ
1	1.109689	83.6450	0.0000	0.0000
2	0.371229	9.1628	0.0000	0.0000
3	0.224349	3.2049	0.0000	0.0000

Table 5 Base reaction for all modes

Mode	Dir	F1	F2	F3
1	U1	2109.86	0.00	0.00
2	U1	635.94	0.00	0.00
3	U1	222.43	0.00	0.00
All	All	2221.54	0.00	0.00

Compare manual static and dynamic results with ETABS static and dynamic results

Table 6. Periods and modes shape coefficients at various levels for first three modes

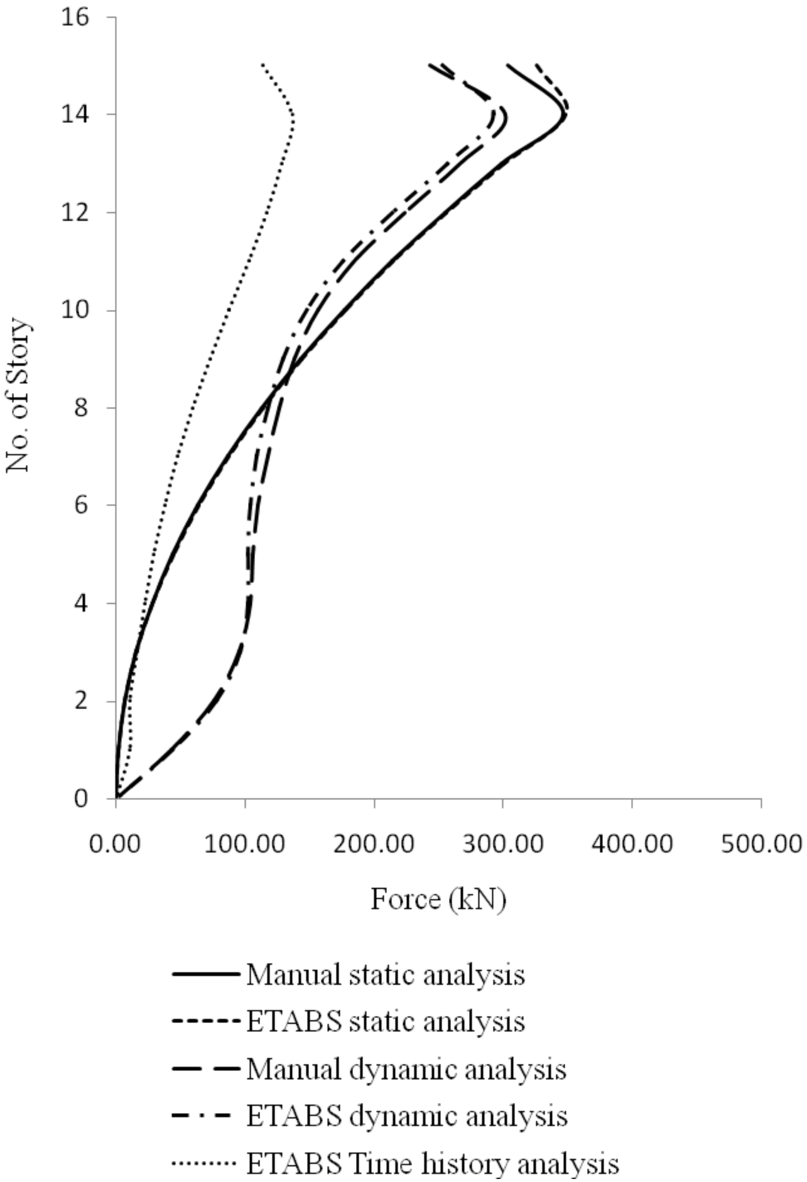
	Manual analysis			ETABS Analysis		
Mode No.	1	2	3	1	2	3
Period in seconds	1.042	0.348	0.210	1.109	0.371	0.224
Mode shape coefficient at various floor levels						
$\phi_1^{(r)}$	0.037	0.108	0.175	0.036	0.109	0.175
$\phi_2^{(r)}$	0.073	0.206	0.305	0.073	0.206	0.304
$\phi_3^{(r)}$	0.108	0.285	0.356	0.109	0.283	0.356
$\phi_4^{(r)}$	0.143	0.336	0.315	0.143	0.336	0.315
$\phi_5^{(r)}$	0.175	0.356	0.192	0.175	0.356	0.195
$\phi_6^{(r)}$	0.206	0.342	0.019	0.206	0.342	0.023
$\phi_7^{(r)}$	0.235	0.296	-0.158	0.234	0.297	-0.154
$\phi_8^{(r)}$	0.261	0.222	-0.296	0.261	0.224	-0.290
$\phi_9^{(r)}$	0.285	0.127	-0.355	0.283	0.129	-0.354
$\phi_{10}^{(r)}$	0.305	0.019	-0.324	0.304	0.023	-0.327
$\phi_{11}^{(r)}$	0.323	-0.089	-0.208	0.322	-0.086	-0.213
$\phi_{12}^{(r)}$	0.336	-0.190	-0.039	0.336	-0.186	-0.045
(13 (r)	0.347	-0.273	0.140	0.345	-0.270	0.134
(14 (r)	0.353	-0.330	0.283	0.351	-0.327	0.277
(15 (r)	0.356	-0.355	0.353	0.356	-0.354	0.351

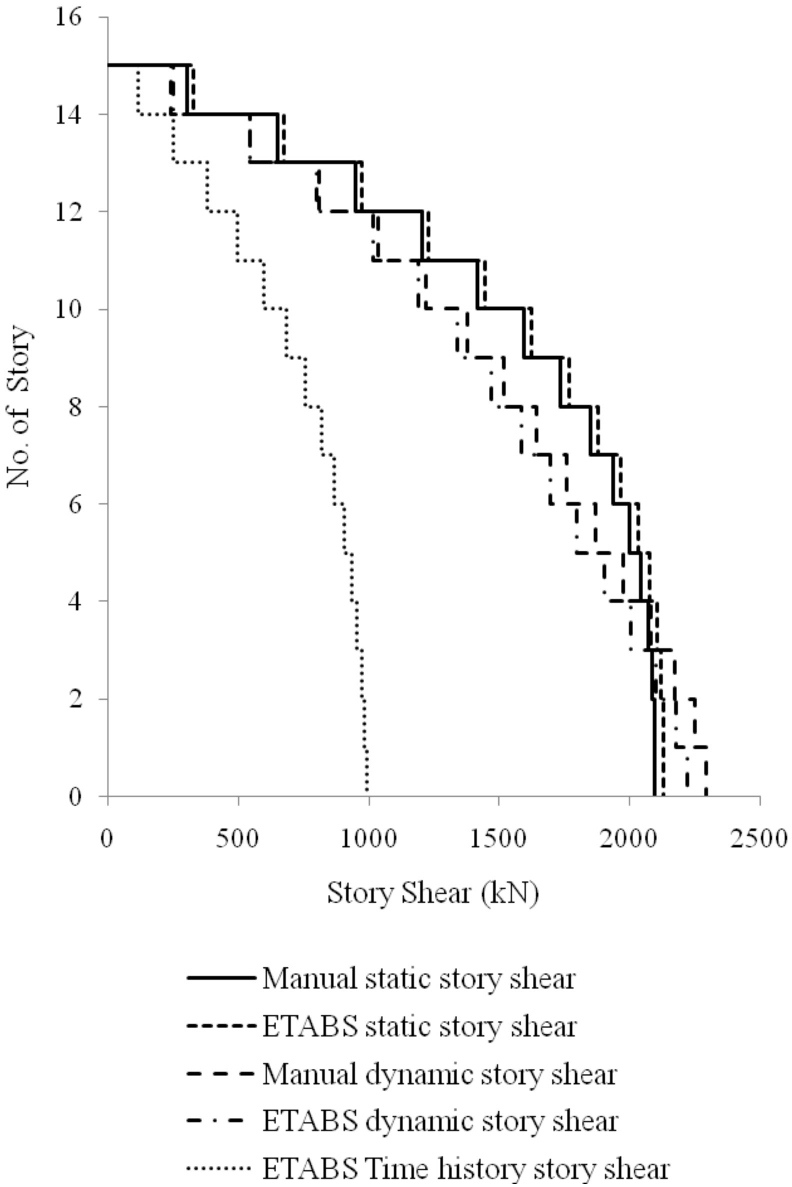
Table 7. Compare the time period, mass participation and base reaction

Mode	Time period (sec)		Percentage of Total Seismic Mass		Base reaction (kN)	
	Manual	ETABS	Manual	ETABS	Manual	ETABS
1	1.042	1.109	83.67	83.64	2194.40	2109.86
2	0.348	0.371	9.15	9.16	625.43	635.94
3	0.210	0.224	3.18	3.20	217.21	222.43

Table 8 comparison of Static Dynamic and Time history analysis

Story No.	Static Analysis				Dynamic Analysis				Passport office Site Time History Analysis	
	Story Shear (kN)		Story Force (kN)		Story Shear (kN)		Story Force (kN)		Story Shear (kN)	Story Force (kN)
	Manual	ETABS	Manual	ETABS	Manual	ETABS	Manual	ETABS	ETABS	ETABS
15	303.55	325.46	303.55	325.46	243.10	252.87	243.10	252.87	114.15	114.15
14	650.00	673.89	346.46	348.43	544.60	545.14	301.50	292.27	250.58	136.43
13	948.73	974.33	298.73	300.44	811.10	801.74	266.50	256.60	378.82	128.24
12	1203.27	1230.33	254.54	256.00	1034.90	1015.87	223.80	214.13	495.44	116.62
11	1417.16	1445.43	213.88	215.10	1220.00	1191.48	185.10	175.61	598.18	102.74
10	1593.92	1623.21	176.76	177.78	1376.40	1338.91	156.40	147.43	686.07	87.89
9	1737.10	1767.20	143.18	143.99	1514.80	1468.49	138.40	129.58	759.32	73.25
8	1850.23	1880.98	113.13	113.78	1641.10	1586.46	126.30	117.97	819.05	59.73
7	1936.84	1968.09	86.61	87.11	1758.60	1695.82	117.50	109.36	866.9	47.85
6	2000.48	2032.09	63.64	64.00	1868.90	1799.56	110.30	103.74	904.69	37.79
5	2044.67	2076.53	44.19	44.44	1975.10	1901.64	106.20	102.08	934.11	29.42
4	2072.95	2104.97	28.28	28.44	2078.70	2003.54	103.60	101.90	956.48	22.37
3	2088.86	2120.97	15.91	16.00	2173.90	2099.83	95.20	96.29	972.71	16.23
2	2095.93	2128.09	7.07	7.12	2249.80	2177.58	75.90	77.75	983.34	10.63
1	2097.70	2129.86	1.77	1.77	2292.60	2221.55	42.80	43.97	993.82	10.48
0	2097.70	2130.00	0.00	0.00	2292.60	2221.60	0.00	0.00	993.82	0


16
14
12
10
8
6
4
2
0
No. of Story
0.00
100.00
200.00
300.00
400.00
500.00
Force (kN)
Manual static analysis
ETABS static analysis
Manual dynamic analysis
ETABS dynamic analysis
ETABS Time history analysis


16
14
12
10
8
6
4
2
0
No. of Story
0
500
1000
1500
2000
2500
Story Shear (kN)
Manual static story shear
ETABS static story shear
Manual dynamic story shear
ETABS dynamic story shear
ETABS Time history story shear

TORSION ANALYSIS OF BUILDING

EXAMPLE: A four storeyed building (with load 300 kg/m^2) has plan as shown in Fig. 1 and is to be designed in seismic zone III. Work out the seismic shears in the various storeys of the proposed building. The foundation is on hard soil and importance factor is 1.0 (Data from SP- 22 : 1982)

As building is having height 12 m and is in zone III, earthquake forces can be calculated by seismic coefficient method using design spectrum.

(a) Lumped mass Calculation

Total weight of beams in a storey = 27 × 7.5 × 0.4 × 0.5 × 2.4 = 97.2 t

Total weight of columns in a storey = 18 × 3 × 0.4 × 0.6 × 2.4 = 31.10 t

Total weight of slab in a storey = (22.5 × 15 + 15 × 15) × 0.15 × 2.4 = 202.5 t

Total weight of walls = (22.5 + 15 + 7.5 +30 + 15 + 15 – 6 × 0.6 – 8 × 0.4) × 0.2 × 3 × 2.0 = 117.8 t

Live load in each floor = (22.5 × 15 + 15 × 15) × 0.3 × 0.25 = 42.18 t

Lumped weight at floor 1, 2 and 3 = Dead load + Live load

= (97.2 + 31.10 + 202.5 + 117.8) + 42.18 = 490.8 t

Lumped weight at roof floor = Dead load

(97.2 + 31.10/2+ 202.5 + 117.8/2) = 374.17 t

Total weight of building W = 490.8 × 3 + 374.17= 1846.57 t

(b) Base shear calculation:

Base shear $V_B = A_h W$

$A_h = (Z\ I\ S_a) / (2\ R\ g)$

Z = 0.16 (Zone III)

I = 1.0

R = 5 (considering SMRF)

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

$= 0.075 \times 12^{0.75} = 0.4836$ sec

$S_a/g = 1/0.4836 = 2.07$

$A_h = (0.16 \times 1.0 \times 2.07) / (2 \times 5) = 0.033$

$V_B = 0.033 \times 1846.57 = 60.94$ t

(c) Shear force in various storeys

Calculation of storey shear distribution along height is shown in Table 1.

(d) Calculation of eccentricity

Assuming mass is uniformly distributed over the area

Horizontal distance of center of mass

$X_m = (15 \times 22.5 \times 7.5 + 15 \times 15 \times 22.5) / (15 \times 22.5 + 15 \times 15) = 13.5$ m

Vertical distance of center of mass

$Y_m = (15 \times 22.5 \times 11.25 + 15 \times 15 \times 7.5) / (15 \times 22.5 + 15 \times 15) = 9.75$ m

As columns are of equal size their stiffness are also same. So horizontal distance of center of rigidity,

$X_r = (4 \times 7.5 + 4 \times 15 + 3 \times 22.5 + 3 \times 30) / 18 = 13.75$ m

Vertical distance of center of rigidity,

$Y_r = (5 \times 7.5 + 5 \times 15 + 3 \times 22.5) / 18 = 10$ m

Static eccentricity in X direction = $e_{si} = X_r - X_m = 13.75 - 13.5 = 0.25$m

Design eccentricity in X direction = $1.5 \times 0.25 + 0.05 \times 30 = 1.875$ m

Or = $0.25 - 1.5 = -1.25$ m

Static eccentricity in Y direction = $e_{si} = Y_r - Y_m = 10.00 - 9.75 = 0.25$m

Design eccentricity in Y direction = $1.5 \times 0.25 + 0.05 \times 22.5 = 1.5$ m

Or = $0.25 - 1.125 = -0.875$ m

The center of mass and center of rigidity and design eccentricity are shown in Fig. 2.

Total rotational stiffness $Ip = \Sigma(K_x y^2 + K_y x^2)$

K_x = Stiffness of one column in X direction = $12 EI / L^3$

$= 12 \times 1880000 \times (0.6 \times 0.4^3/12)/3^3 = 2673.78$ t/m

K_y = Stiffness of one column in Y direction = $12 EI / L^3$

$= 12 \times 1880000 \times (0.4 \times 0.6^3/12)/3^3 = 6016.00$ t/m

$K_x y^2 = 2673.78 \times (5(10^2) + 5(2.5^2) + 5(5^2) + 3(12.5^2)) = 3008002.5$

$K_y x^2 = 6016.0 \times (4(13.75^2) + 4(6.25^2) + 4(1.25^2) + 3(8.75^2) + 3(16.25^2))$

$= 11674799.0$

$I_p = 3008002.5 + 11674799.0 = 14682802.5$

(e) Torsional due to seismic force in X direction

Torsional moment T at various floors is considering seismic force in X direction only is shown in Table 3.

Torsional shear at each column line is worked out as follows using following equation:

$V_x = (T/I_p) \times y \times K_{xx}$

$K_{xx} = 5 \times K_x$ (for column line 1, 2, 3)

$= 3 \times K_x$ (for column line 4)

$K_{yy} = 4 \times K_y$ (for column line A, B, C)

$= 3 \times K_y$ (for column line D, E)

Additional shear due to torsional moments in columns at various floor levels are shown in Table 4.

(f) Torsional due to seismic force in Y direction

Torsional moment T at various floors is considering seismic force in Y direction only is shown in Table 5.

Torsional shear at each column line is worked out as follows using following equation:

$V_y = (T/I_p) \times x \times K_{yy}$

Additional shear due to torsional moments in columns at various floor levels are shown in Table 6.

As per the codal provisions only positive values or additive shear should be considered. This shear is to be added in to shear force resisted by columns due to seismic force in respective directions.

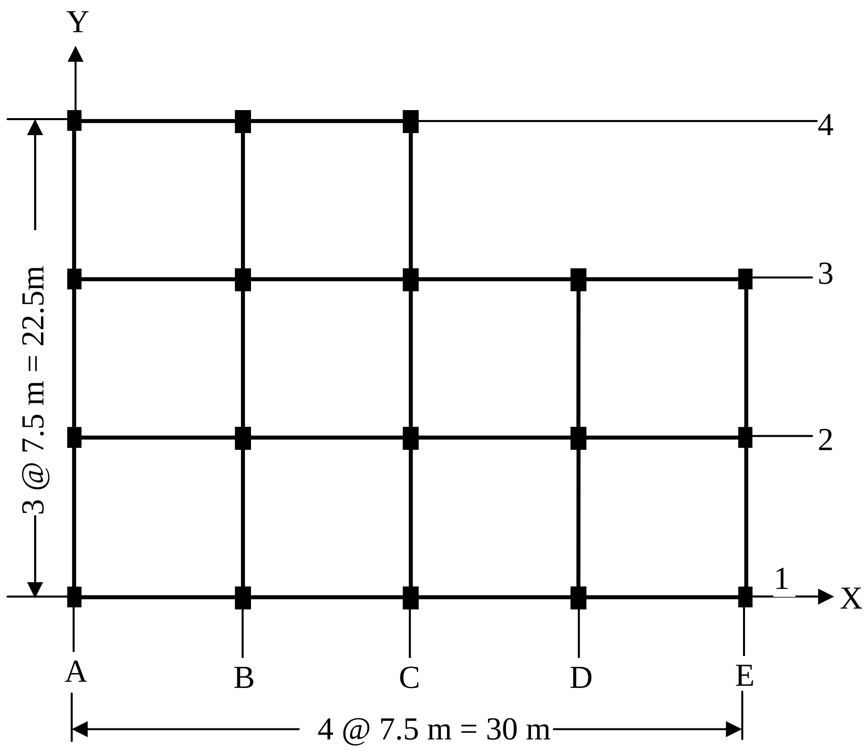


Fig. 1 Example

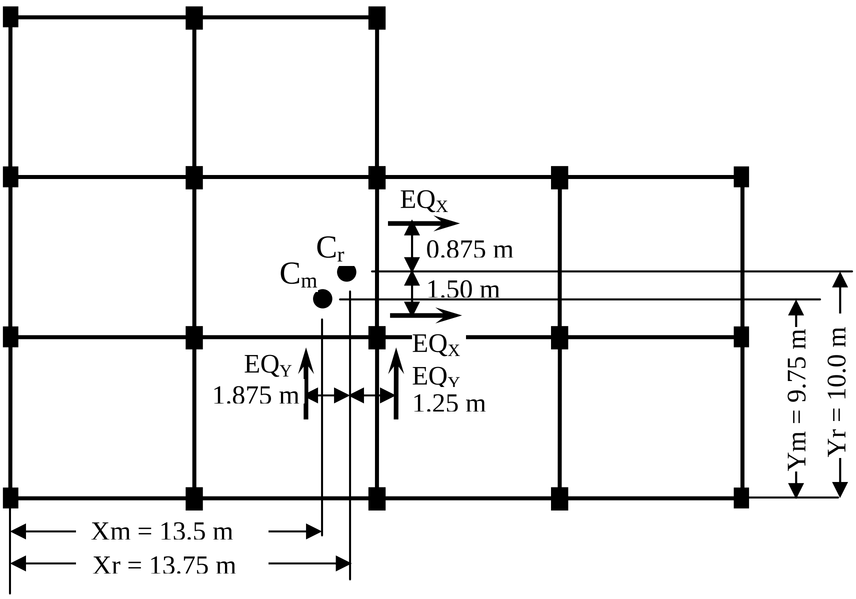


Fig. 2 Position of Center of Mass, Center of Rigidity and Design Eccentricities

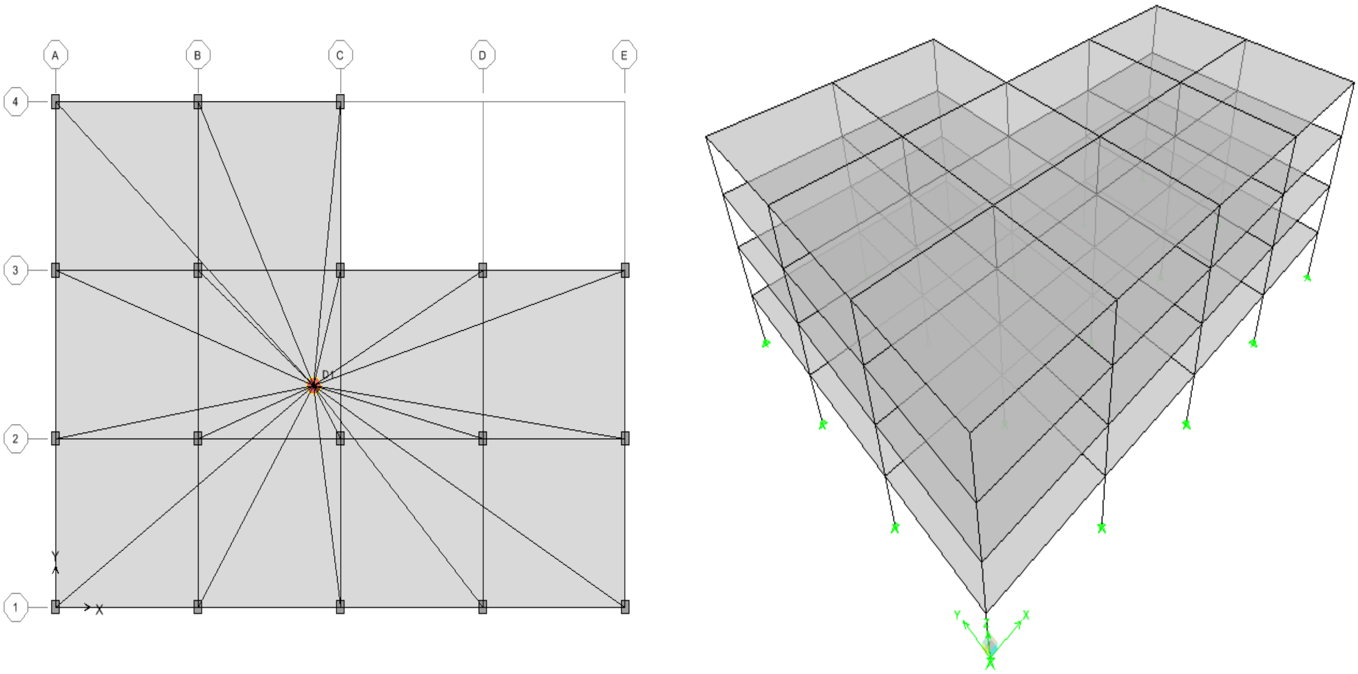


Fig. 3 Plan and 3D view of modeled building in ETABS

Table:1 Storey shear at various floors (manual)

Floor	W_i t	h_i m	$W_ih_i^2$	Q_i t	V_i t
1	490.8	3	4417.20	2.32	60.94
2	490.8	6	17668.80	9.30	58.61
3	490.8	9	39754.80	20.93	49.30
4	374.17	12	53880.48	28.37	28.37
			1157212.80		

Table: 2 Storey shear (tone) from ETABS

Floor	Weight of each storey	height	Storey shear
1	487.55	3.00	59.90
2	487.55	6.00	57.66
3	487.55	9.00	48.70
4	388.13	12.00	28.54

Story Shears

Edit View

Story	Load	Loc	P
STORY4	DL025LL	Top	3570.30
STORY4	DL025LL	Bottom	3881.34
STORY3	DL025LL	Top	8445.77
STORY3	DL025LL	Bottom	8756.81
STORY2	DL025LL	Top	13321.23
STORY2	DL025LL	Bottom	13632.27
STORY1	DL025LL	Top	18196.70
STORY1	DL025LL	Bottom	18507.74

18507.74 - 13632.27 =4875.5 kN (seismic weight of first storey)

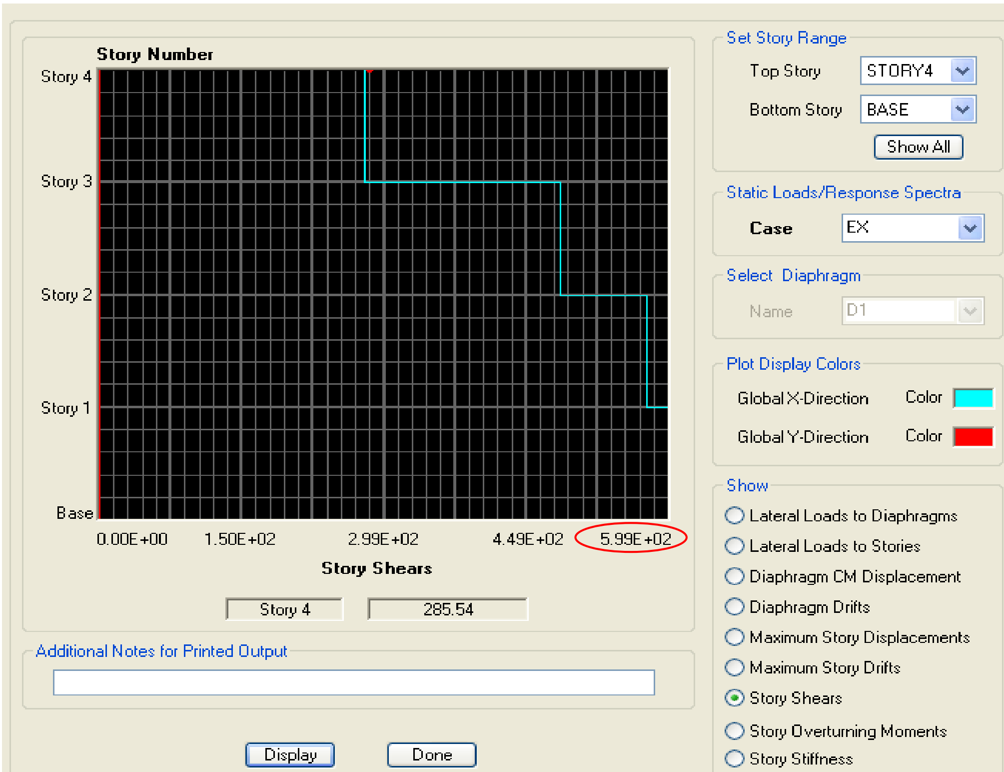


Fig. 4 Storey shear (kN) in ETABS for earthquake in X direction

Center Mass Rigidity

Edit View

Center Mass Rigidity

Story	Diaphrag	MassX	MassY	XCM	YCM	CumMassX	CumMassY	XCCM	YCCM	XCR	YCR
STORY4	D1	373.3691	373.3691	13.606	9.854	373.3691	373.3691	13.606	9.854	13.376	9.760
STORY3	D1	490.6002	490.6002	13.640	9.889	863.9693	863.9693	13.626	9.874	13.410	9.776
STORY2	D1	490.6002	490.6002	13.640	9.889	1354.5696	1354.5696	13.631	9.879	13.457	9.802
STORY1	D1	490.6002	490.6002	13.640	9.889	1845.1698	1845.1698	13.633	9.882	13.560	9.868

Fig. 5 Centre of mass and centre of rigidity at each storey in ETABS

Table: 3 Torsional moment due to seismic force in X direction

Torsional moment in	e_{di} = 1.5 m	e_{di} = -0.875 m
Storey 1 T_1	60.94× 1.5 = 91.41	-53.32
Storey 2 T_2	58.61× 1.5 = 87.92	-51.28
Storey 3 T_3	49.30× 1.5 = 73.96	-43.14
Storey 4 T_4	28.37× 1.5 = 42.56	-24.82

Table: 4 Additional shear due to seismic force in X direction

Column line	First storey (shear in one column)			Total shear from ETABS	Second storey (shear in one column)			Total shear from ETABS	Third storey (shear in one column)			Total shear from ETABS	Fourth Storey (shear in one column)			Total shear from ETABS
	Direct	Torsional Shear V_x	Total		Direct	Torsional Shear V_x	Total		Direct	Torsional Shear V_x	Total		Direct	Torsional Shear V_x	Total	
1 y = 10 m	3.39	+ 0.83	4.22	16.79	3.26	0.80	4.06	16.30	2.74	+0.67	3.41	13.63	1.58	+0.39	1.97	7.86
		(-0.49)	2.90			(-0.47)	2.79			(-0.39)	2.35			(-0.23)	1.35	
2 y = 2.5 m	3.39	+0.21	3.60	16.80	3.26	0.20	3.46	16.45	2.74	+0.17	2.91	13.70	1.58	+0.10	1.68	7.92
		(-0.12)	3.27			(-0.12)	3.14			(-0.10)	2.64			(-0.06)	1.52	
3 y = 5 m	3.39	-0.42	2.97	16.80	3.26	-0.40	2.86	16.55	2.74	-0.34	2.40	13.75	1.58	-0.19	1.39	7.96
		(+0.24)	3.63			(+0.23)	3.49			(+0.20)	2.94			(+0.11)	1.69	
4 y = 12.5 m	3.39	-0.62	2.77	9.48	3.26	-0.60	2.66	8.28	2.74	-0.51	2.23	7.36	1.58	-0.29	1.29	4.10
		(+0.36)	3.75			(+0.35)	3.61			(+0.29)	3.03			(+0.17)	1.75	
			62.18	59.87			59.81	57.58			50.28	48.43			29.00	27.85
			60.17				57.86				48.73				27.98	

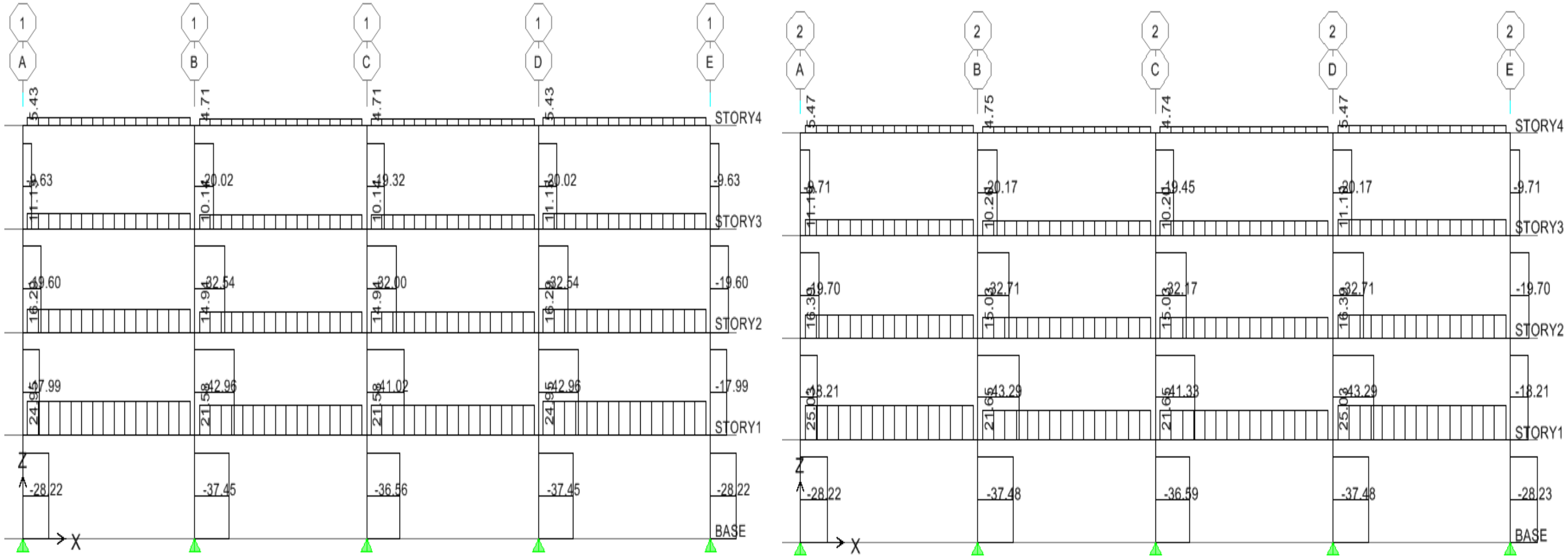


Fig. 6 Shear force (kN) in column line 1 and line 2 due to earthquake force in X direction

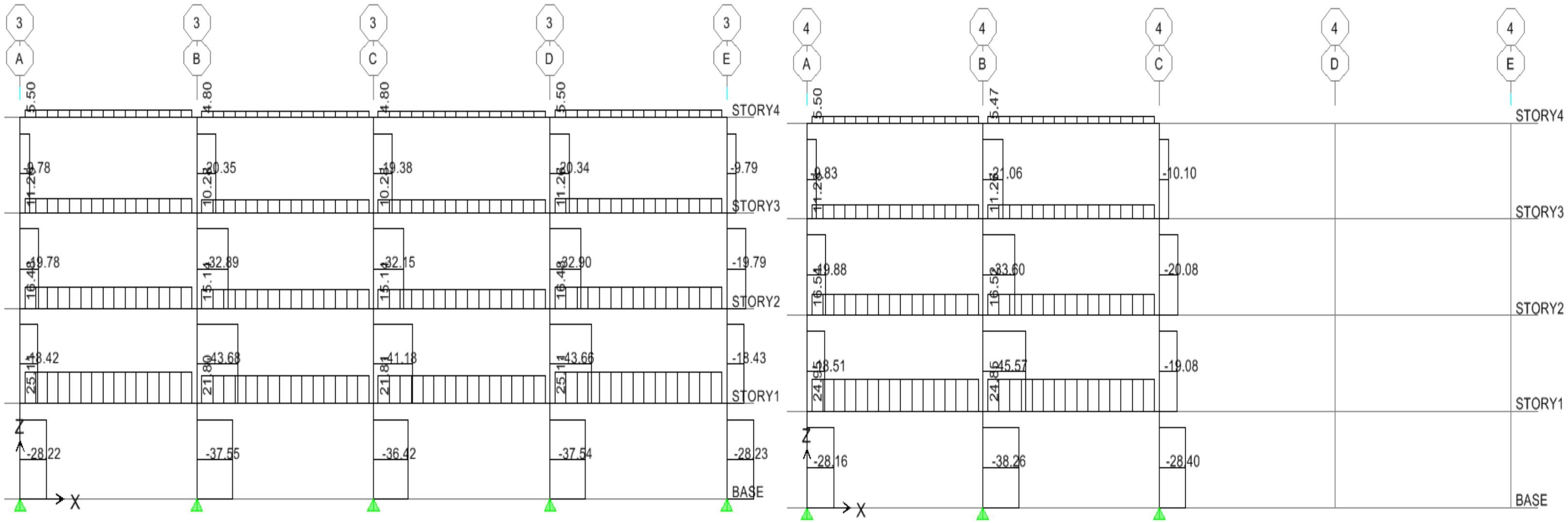


Fig. 7 Shear force (kN) in column line 3 and line 4 due to earthquake force in X direction

Table: 5 Torsional moment due to seismic force in Y direction

Torsional moment in	e_{di} = 1.875 m	e_{di} = -1.25 m
Storey 1 T_1	60.94 × 1.875 = 114.26	-76.18
Storey 2 T_2	58.61 × 1.875 = 109.90	-73.27
Storey 3 T_3	49.30 × 1.875 = 92.45	-61.64
Storey 4 T_4	28.37 × 1.875 = 53.20	-35.47

Table: 6 Additional shears due to seismic force in Y direction

Column line	First storey (shear in one column)			Total shear from ETABS	Second storey (shear in one column)			Total shear from ETABS	Third storey (shear in one column)			Total shear from ETABS	Fourth Storey (shear in one column)			Total shear from ETABS
	Direct	Torsional Shear V_y	Total		Direct	Torsional Shear V_y	Total		Direct	Torsional Shear V_y	Total		Direct	Torsional Shear V_y	Total	
A x = 13.75 m	3.39	+2.57	5.96	13.44	3.26	+2.48	5.74	12.88	2.74	+2.08	4.82	10.87	1.58	+1.20	2.78	6.25
		(-1.72)	1.67			(-1.65)	1.61			(-1.39)	1.35			(-0.80)	0.78	
B x = 6.25 m	3.39	+1.17	4.56	13.485	3.26	+1.13	4.39	13.16	2.74	+0.95	3.69	11.00	1.58	+0.54	2.12	6.38
		(-0.78)	2.61			(-0.75)	2.51			(-0.63)	2.11			(-0.36)	1.22	
C x = 1.25 m	3.39	-0.23	3.16	13.514	3.26	-0.22	3.04	13.40	2.74	-0.19	2.55	11.11	1.58	-0.11	1.47	6.50
		(+0.16)	3.55			(+0.15)	3.41			(+0.13)	2.87			(+0.07)	1.65	
D x = 8.75 m	3.39	-1.23	2.16	9.707	3.26	-1.18	2.08	8.99	2.74	-0.99	1.75	7.69	1.58	-0.57	1.01	4.33
		(+0.82)	4.21			(+0.79)	4.05			(+0.66)	3.40			(+0.38)	1.96	
E x = 16.25 m	3.39	-2.28	1.11	9.721	3.26	-2.20	1.06	9.15	2.74	-1.85	0.89	7.77	1.58	-1.06	0.52	4.40
		(+1.52)	4.91			(+1.46)	4.72			(+1.23)	3.97			(+0.71)	2.29	
			64.48	59.87			62.03	57.58			52.15	48.43			30.00	27.85
			58.63				56.36				47.42				27.28	

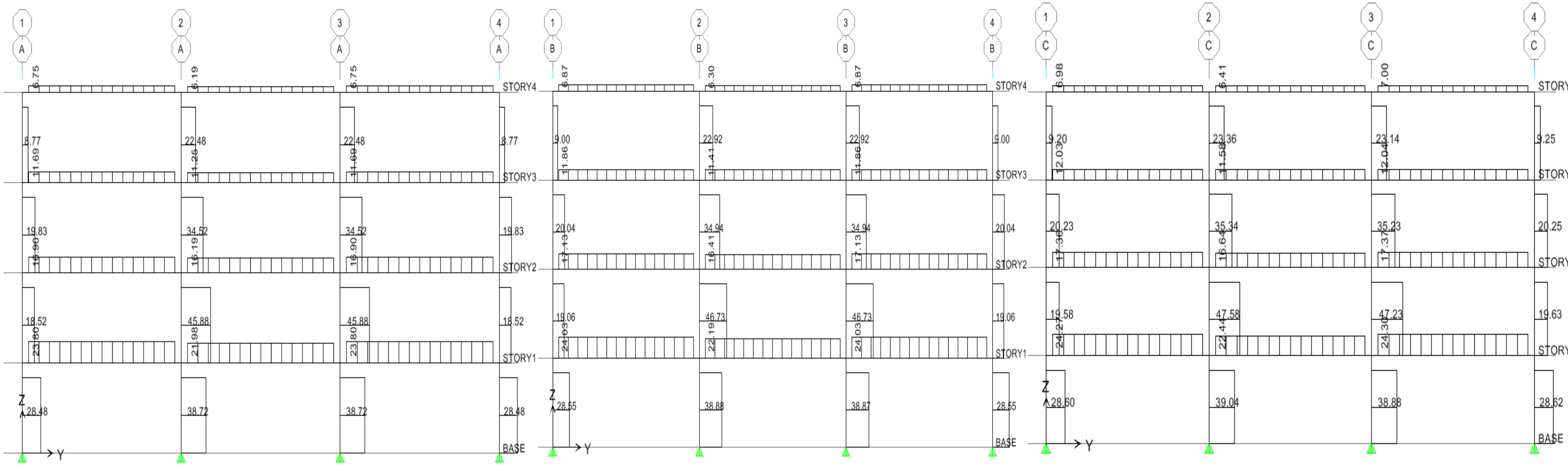


Fig. 8 Shear force (kN) in column line A, B and C due to earthquake force in Y direction

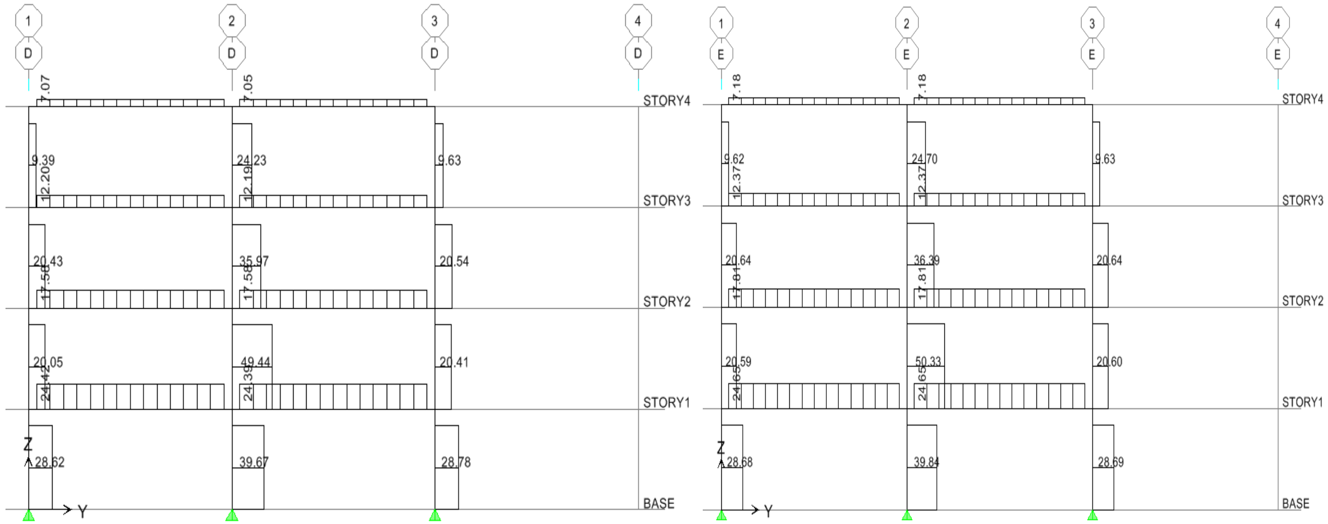


Fig. 9 Shear force (kN) in column line D and E due to earthquake force in Y direction