SEISMIC ANALYSIS OF A MULTISTORIED RC STRUCTURE WITH AND WITHOUT LEAD PLUG RUBBER BEARING (LPRB)

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Abstract:
Base Isolators are thriving all over the world in last few decades. These techniques works effectively on high stiff and midrise buildings. Base Isolators can reduce the effect of earthquake forces by uncoupling the superstructure and foundation. It increases the Natural Period of the structure so that the induced earthquake load greatly reduced. Inter Storey drift reduces as a result there is less damage to non-structural elements. So we can conclude that these techniques are most essential for buildings like structural elements are more economical than structure. Examples of these structures are like Hospitals, Police Stations, Museums, Nuclear Reactors etc.
A G+10 storey of seismic zone V building is modelled & analysed with and without base isolator (LPRB) for Seismic Coefficient Method (SC) and Response Spectrum Method (RSA) in ETABS software. SC and RSA are generated as per IS:1893 2016. Design of Lead Plug Rubber Bearing (LPRB) done for external and internal supports. Various responses of the structure like Story Displacement, Shear, Drift and natural period are compared for SC and RSA with and without LPRB.

Key words : Mid rise buildings, base isolator, storey drift, non-structural elements, Lead Plug Rubber bearing, response spectrum analysis, seismic coefficient method

INTRODUCTION

Earthquake is a natural hazard with can lead to vulnerable condition, which leads to a disaster. Earthquake can be predicted at some times but can't be stopped. The earth zones which are prone to earthquake are more likely to cause disasters often. The life and property can be saved from earthquake by good structural designing practices as the earthquake produces lateral force or huge lateral energy, that energy or force is to be dissipated by Active or Passive control systems, good design and good constructional practices.
Base Isolator belongs to Passive control system of earthquake. These Base Isolators are classified as Elastomeric isolators, Sliding isolators, Low damping Rubber isolator, High damping rubber isolator, Lead Plug Rubber Isolator etc. We are going to see about design and response of a G+10 building with and without LPRB, which is located in Earthquake Zone V by Seismic Coefficient Method and Response Spectrum Analysis (in ETABS) as per IS 1893 2016.

LEAD PLUG RUBBER BEARING (LPRB)

LPRB were invented in 1975 at Newzeland. The mechanism of LPRB is same as Low Damping Rubber Bearing. In LPRB the main components are Steel Shim plates at top and bottom, Rubber layers, Steel Plates which are sandwiched in between rubbers and at middle a Lead rubber core is provided. Lateral flexibility is achieved by rubber layers, Vertical Stiffness is achieved by steel plates, Lead rubber core gives additional yield strength and damping. Lead core deforms almost in pure shear, yields at low shear stresses like 7-10MPa at 20°C temperature. The Lead Plug produces Stable Hysteretic deformation even for number of cycles of load, even it recrystallizes and encounters the fatigue failure. Due to emerging technologies it became easy to analyse and design rubber bearings with high stiffness and high shear deformation

ANALYSIS AND DESIGN OF LPRB

The procedure of design of lead rubber bearing is referred from textbook of "DESIGN OF SEISMIC ISOLATED STRUCTURE ", theory of practice by JAMES M.KELLY and FARZAD NAEIM. As per this we need the base reactions of the structure. To get the base reactions, a model is analysed for gravity loads. Specifications of the model are taken as follows.

Properties Of Material

1) Grade of Conc. (fck) = 30 MPa
2) Elastic Modulus of Conc. (Ec = 5000√fck) = 27386.12788 MPa
3)Grade of Steel (fy) = 550MPa
4)Elastic Modulus of Steel (Es) =200000 MPa
5)Poisons ratio of Conc. (μ conc.) = 0.15
6)Poisons ratio of Steel (μ steel)= 0.3
7)Density of Conc. (γ conc.) = 25kN / m^3
8)Density of Steel (γ steel) =78.5 kN / m^3
9)Coeff. of thermal expansion of Conc. (α conc.) =0.0000055 /c
10)Coeff. of thermal expansion of Steel. (α steel) =0.0000117 /c
11)Density of Brick Masonry (γ w) = 18kN / m^3

Properties Of Sections

1)Size of Beam (b b * Dd) = 0.23m * 0.3m
2)Size of Column (bc * Dc) = 0.3m * 0.45m
3)Thickness of slab (Ds) = 0.15 m
4)Thickness of Wall (Dw) = 0.23 m
5)Height of wall = 3m

Intensity Of Loads

1)Wall Load on frames (Dw * Hw * γ w) = 12.42 kN/m
2)Dead Load on slabs (Ds * γc) = 3.75 kN/m^2
3)Live load on floors (LLf) =4kN/m^2
4)Live load on roof (LLr) =2kN/m^2.

Building Details

1)Structure = RCC (Reinforced Cement Concrete)
2)Structure Type = Regular structure with fixed base.
3)Plan Dimentions = 20 m * 20 m
4)Height of the building =
4)Height of each storey = 3m, base storey= 2m,
5)Number of bays in X- direction = 4 no's
6) Number of bays in Y- direction = 4 no's
7)Spacing between bays in X and Y directions = 5m
8) Number of Storeys = 12

After modelling in ETABS software, section properties, loads, restarins were defined and assigned. Now the structure is Analyzed for Gravity loads and Base reactions are taken.The reactions of periphery columns and inner columns were taken for deigning of LPRB's External and Internal. Base reaction of External Column got 4506.7 kN and Inter Column got 7424.293 kN.

Design Of Internal LPRB

1)Vertical load (R) = 7424.3kN
2)Target Time period of frame taken as (t) = 2.5sec

3)Sesmic Coefficient (Ah) = 0.56
4)Damping coefficient (Eff) = 0.1
5)Damping coefficeient (βeff) = 1.2 (depends on Eff value)
6)Acceleration due to gravity (g) = $9.81m/sec^2$
7)Effective stiffness of isolator**(Keff)=(R/g)(2π/ t)**^{2}= 4775.6kN/m
8)Maximum displacement of isolator (Dd)=**(g*Ah*t)/(4*Bd*π²)**
= 0.291m
as per IS 1893 (part I) : 2002, for 5% damping
9)Calculate the energy dissipation per cycle (Wd)
= (2*π*Keff*Dd²*βeff) = 252.571kNm
10)Approximate short yield force **(Qd) = (Wd/4*Dd)**=217.59 kN
11)Calculate Preyield in rubber **(** Kpre) = (Keff) - (Q / Dd)
= 4025.808kN/m
12)Post yield stiffness to preyield stiffness ratio (n=Kpre/ Kpost)
for Rubber = 0.1
13) n range 0.1 to 0.05 as per Naeim and Kelly et al 1999
* generally taken as 0.1
14)Post yield stiffness in rubber (Kpost = Kpre / n)
= 40258.072 kN/m
15)Calculate displacement (Dy=Q/Kpost-Kpre)) = 0.006 m
16)Correction for first estimation of Qd for Dy, gives yield force (Qr) = Wd / 4*(Dd-Dy) =
222.179 kN
17)The lead Plug Area (Ap) = (Qr / f py) = $0.0222179\ m^2$
18)yield force of lead core (f py) = $10000\ N/m^2$
19)Diameter of plug (d) = 0.168235125mm = 168.236mm
20)Revising rubber stiffness Keff to KeffR = 4009.964kN/m
21)Total thickness of rubber layer (tr)= (Dd / γ) = 0.291m
22)Maximum shear strain (γ)100% = 1
23)Area of Bearing (Alrb) = ((KeffR)*tr / G) = 1.663 m^2
24)Shear modulus (G) = 700kN/m^2
25)Diameter of bearing (φ b) = √(A lrb)*(4/π) = 1.456m
26)Shape factor (S) = (1/2.4)*(fv/fh) = 8.333
27)horizantal frequency (fh) = (1 / T) = 0.5Hz
where "T" = 2 sec
28)vertical frequency (fv) = 10Hz
29)Thickness of single rubber layer (t)=(φ lrb)/(4*S) ≈ 45mm
30)No. of rubber layers (N)= (tr / t) = 6.64722868 = 7no's
31)Provide rubber layers of 45mm thick
32)Provideno. of rubber layers7no's
33) Number of shim plates (Ns) = 6 no's
34)Let thickness of shim plates be (t s) ≈ 2.5 mm
35)Adopt thickness of end plate as (t ep) ≈ 25mm
(Generally end plate thickness is between 19.05 to 38.1)
36)Total height of LRB (h) = (t*N)+(Ns*t s)+(2*t ep) = 380mm
37)Diameter of rubber layer (φ rbl) = N*t = 315mm = 0.315m
38)Area of Rubber layer (A rbl) = (π/4)*(φ rbl) = $0.0779m^2$
39)Compression modulus (EC) = $6GS^2\ (1-(6\ GS^2)/K)$
= $249131.9445kN/m^2$
40)Bulk modulus (K) = 2000Mpa = $2000000kN/m^2$
41)Shear modulus (G) = 0.7 Mpa = $700kN/m^3$
42)Horizontal stiffness (KH) =(G*Alrb)/(tr) = 187.885kN/m

43)Vertical Stiffness (KV)= (Ec* Alrb)/(tr)= 1427157.273 kN/m
44)Yield strength (Qy) = (Qr + (keff * Dy)) = 250.8572kN
45)Rotational inertia1(I =(π*(φb - φlpg)⁴)/ 64) =0.13461kN/m

Table 1: Dimensions of Internal LPRB

Diameter of bearing (φ b) cm	145.524
Diameter of plug (d) cm	16.82351
Total height of LRB (h) cm	38
Thickness of 1 rubber layer (t) cm	4.5
No. of rubber layers (N) no's	7
Thickness of shim plates be (t s) cm	2.5
Number of shim plates (Ns) no's	7
Thickness of end plate as (t ep) cm	2.5

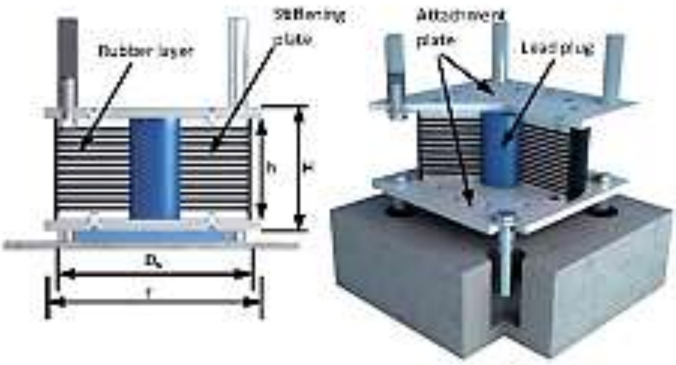


Figure no. 1 : Cross Sectional view of LPRB

Design Of External LPRB

1)Vertical load (R) = 4506.7 kN
2)Target Time period of frame (t) = 2.5sec
3)Sesmic Coefficient (Ah) = 0.56
4)Damping coefficient (Eff) = 0.1
5)Damping coefficeient (βeff) = 1.2
6)acceleration due to gravity (g) = 9.81 m/sec^2
7)Efeective stiffness of isolator (Keff) = (R/g)(2π/ t)^2
= 2898.87 kN/m
8) Maximum displacement of isolator (Dd)
= (g*Ah*t)/(4*Bd*π²) = 0.290199 m
9) Calculate the energy dissipation per cycle
(Wd) = (2*π*Keff*Dd²*βeff) = 153.32 kNm
10) Approximate short yield force (Qd) = (Wd / 4*Dd)
= 132.077 kN
11) Calculate Preyield in rubber (Kpre) = (Keff - (Q/Dd))
= 2443.75 kN/m
12) Post yield stiffness to preyield stiffness ratio
(n = Kpre/ Kpost) for Rubber= 0.1
13) n range 0.1 to 0.05 as per Naeim and Kelly et al 1999
*generally taken as 0.1
14) Post yield stiffness in rubber (Kpost) = Kpre / n
= 24437.484kN/m
15) Calculate displacement (Dy = Q/(Kpost - Kpre)) = 0.006m

16) Correction for first estimation of Qd for Dy, gives yield force (Qr) = Wd / 4*(Dd-Dy) = 134.867kN
17) The lead Plug Area (Ap) = (Qr / f py) = 0.0134867 m^2
18) yield force of lead core (f py) = 10000 N/m^2
19) Diameter of plug (d) = 0.131075m = 131.075 mm
20) Revising rubber stiffness Keff to KeffR = 2434.133 kN/m
21)Total thickness of rubber layer (tr)= (Dd / γ) =0.29012 m
22)Maximum shear strain (γ)100% = 1
23)Area of Bearing (Alrb) = ((KeffR)*tr / G)= 1.01 m^2
24)Shear modulus (G) = 700kN/m^2
25)Diameter of bearing **(φ b) = √(A lrb)*(4/π) =**1.1338m
26)Shape factor (S) = (1/2.4)*(fv/fh)= 8.333
27)horizantal frequency (fh) = (1 / T) =0.5Hz
where "T" = 2 sec
28)vertical frequency (fv) = 10Hz
29)Thickness of single rubber layer **(t) =(φ lrb)/(4*S)** ≈ 35mm
30)No. of rubber layers (N)= (tr / t) = 8.54 ≈ 9no's
31)Provide rubber layers of 35mm thick
32)Provideno. of rubber layers 9 no's
33)Number of shim plates (Ns) = 8 no's
34)Let thickness of shim plates be (t s) = 2.5mm
35)Adopt thickness of end plate as (t ep)25mm
(End plate thickness is between 19.05 to 38.1)
36)Total height of LRB (h) = **(t*N)+(Ns*t s)+(2*t ep)** = 385 mm
37)Diameter of rubber layer (φ rbl) =N*t = 31mm=0.315 m
38)Area of Rubber layer (A rbl) =(π/4)*(φ rbl)= 0.0779m^2
39)Compression modulus (EC)=$6GS^2$ (1-($6GS^2$)/K)
= 249131.9444 kN/m^2
40)Bulk modulus (K) = 2000Mpa = 2000000 kN/m^2
41)Shear modulus (G) = 0.7 Mpa = 700 kN/m^3
42)Horizontal stiffness (KH)=(G*Alrb)/(tr) = 187.8851kN/m
43)Vertical Stiffness **(KV)=(Ec* Alrb)/(tr) =** 866314.367kN/m
44)Yield strength (Qy) = (Qr + (keff * Dy)) = 152.275245kN
45)Rotational inertia 1 (I = (π*(φb - φlpg)^4)/ 64) = 0.05 kN/m

Table 2 : Dimensions of External LPRB :

Diameter of bearing (φ b)	113.38 cm
Diameter of plug (d)	13.1074 cm
Total height of LRB (h)	38.5 cm
Thickness of single rubber layer (t)	3.5 cm
No. of rubber layers (N)	9 cm
Let thickness of shim plates be (t s)	2.5 cm
Number of shim plates (Ns)	9 cm
Adopt thickness of end plate as (t ep)	2.5 cm

Modelling And Analysis Of The Structure With Lprb

As we want to compare the Storey Responses of the structure with and without LPRB for RSA (Response Spectrum Analysis) and Seismic Coefficient method, the previous model responses are noted for Seismic Coefficient method (EQ X, EQ Y) and RSA (RS X, RS Y). LPRB External and Internal generated and assigned by removing fixed support. Then the response of the structure with LPRB for Seismic Coefficient (EQX, EQY) and RSA (RSX, RSY) are noted for comparison.

Response Spectrum Function is generated in ETABS as per IS 1893 2016.

Specifications for Seismic Coefficient method and RSA are as follows for the model.

1)Zone factor (Z) = 0.36 (for Zone V)
2)Importance Factor (I) = 1.5
3)Response Reduction Factor (R) = 5
4)Soil Type = Medium (II)
5)Seismic Zone = V
6)Damping = 0.05 i.e 5%

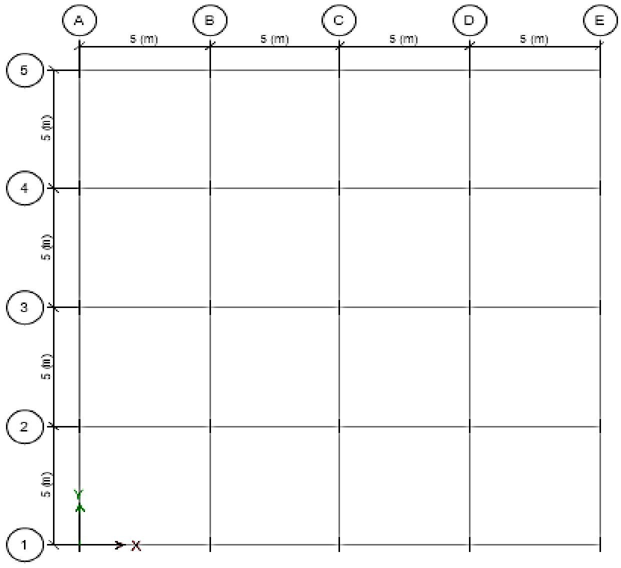


Fig. no. 2 : Plan Grid of building

Table 3 : Input values for LPRB External and Internal

Input Values in ETABS:	INT. LPRB	EXT. LPRB
Rotational inertia 1 (I) kN/m	0.134608	0.0496
Vertical Stiffness (KV) kN/m	1427157	866314
Effective Stiffness (Keff) kN/m	4775.572	2898.97
Damping (Eeff)	10%	10%
yield displacement (Dy) m	0.006005	0.00601
Post yield stiffness (Kpost) kN/m	40258.07	24437.5
Yield strength (Qy) kN	250.8572	152.275
Post yield stiffness ratio	0.1	0.1
Horizontal Stiffness (KH) kN/m	187.8851	187.885

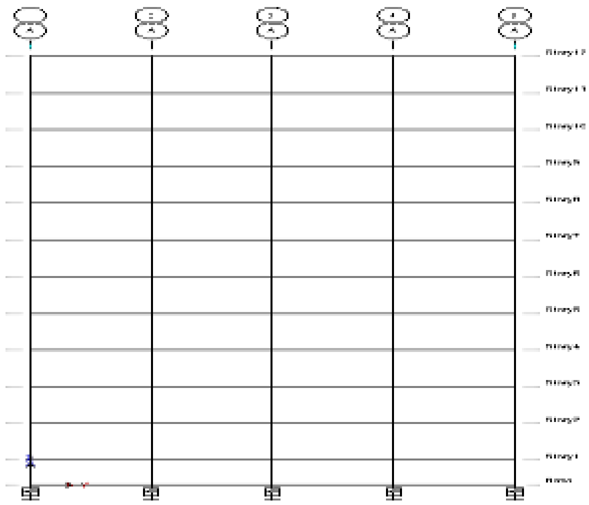


Fig. no. 3 : Elevation of building

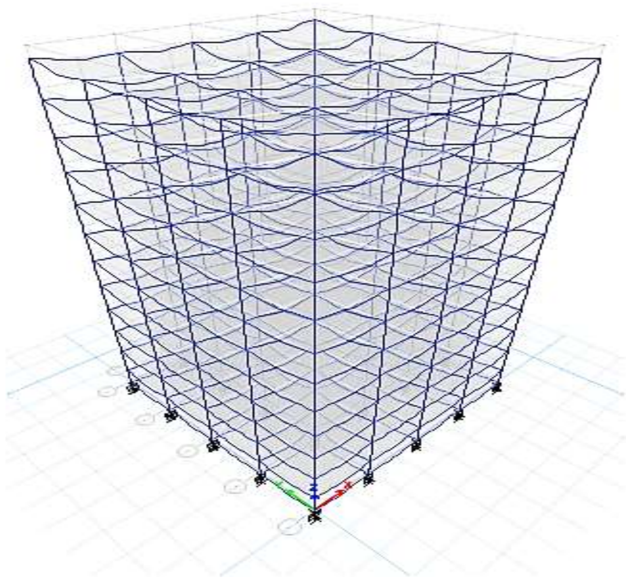


Fig. no. 4 : Displacement of building

Fig. no. 2 and 3 are the Grid Plan and Elevation view of the structure before analysis with LPRB and fig. no.4 shows the response of the structure (i.e., Dispacement) in z direction.
At the base, beams and slab is assigned and analyzed for structure with LPRB in RSA.

Results / Response

Results shown in this paper are Storey Displacemant, Storey Drift and Storey Shear for Structure with and without LPRB in both SC (EQX, EQY) and RSA (RSX, RSY). We know that RSA results are good and perfect when compared with SC results. So, RSA results are lesser than SC results.

Storey Displacement

The Results of Storey Displacement of the structure with and without LPRB in SC and RSA are shown in table 4 and results compared are shown in fig. 5 and 6. Though the RSX and RSY of with and without LPRB initially slightly higher than EQX, EQY of with LPRB but at final storey it got reversed. We can conclude that structure with LPRB has displacements but they are in considerable range where non structural elements are not going to be damaged severely.

Table 4 : Storey Displacement response with and without LPRB

Storey	Without LPRB				With LPRB			
	EQX	EQY	RSX	RSY	EQX	EQY	RSX	RS Y
Base	0	0	0	0	24.897	26.412	21.054	22
Storey01	5.116	7.649	3.84	5.786	38.567	41.757	31.804	34.195
Storey02	24.557	34.992	18.202	26.225	65.224	75.095	52.496	60.268
Storey03	49.065	66.631	35.756	49.239	94.01	110.519	74.274	87.264
Storey04	74.684	98.252	53.424	71.45	122.577	144.997	95.201	112.72
Storey05	99.854	128.662	70.137	92.047	149.99	177.718	114.542	135.996
Storey06	123.80	157.297	85.436	110.695	175.734	208.259	131.971	156.833
Storey07	146.004	183.681	99.057	127.168	199.388	236.216	147.317	175.091
Storey08	165.958	207.313	110.832	141.309	220.525	261.133	160.454	190.649
Storey09	183.177	227.632	120.63	152.971	238.692	282.481	171.284	203.389
Storey10	197.179	244.034	128.349	162.019	253.437	299.685	179.758	213.232
Storey11	207.605	255.942	133.979	168.387	264.428	312.189	185.916	220.156
Storey12	214.573	263.184	137.731	172.202	271.824	319.858	190.021	224.337

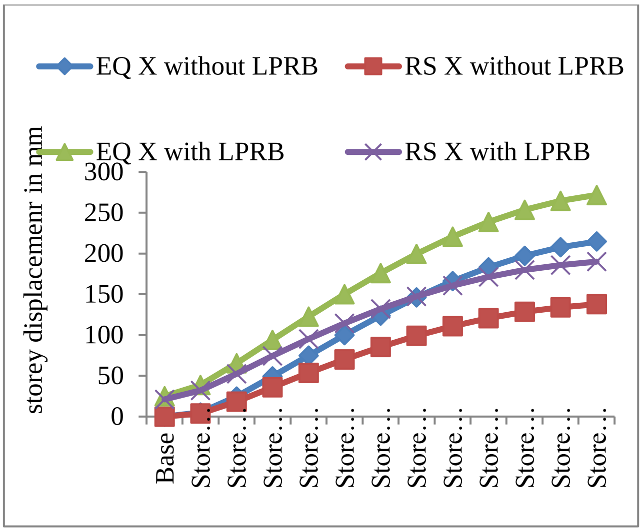


Fig. 5. Storey Displacement with and without LPRB for SC & RSA - X axis

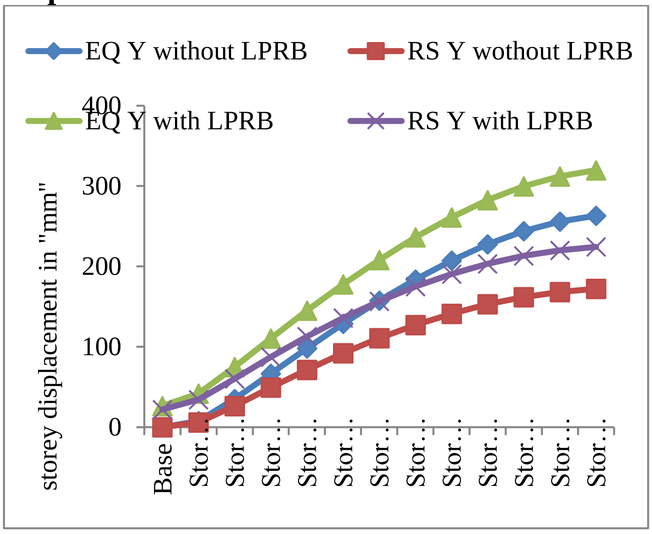


Fig. 6. Story displacement with and without LPRB for SC & RSA - Y axis

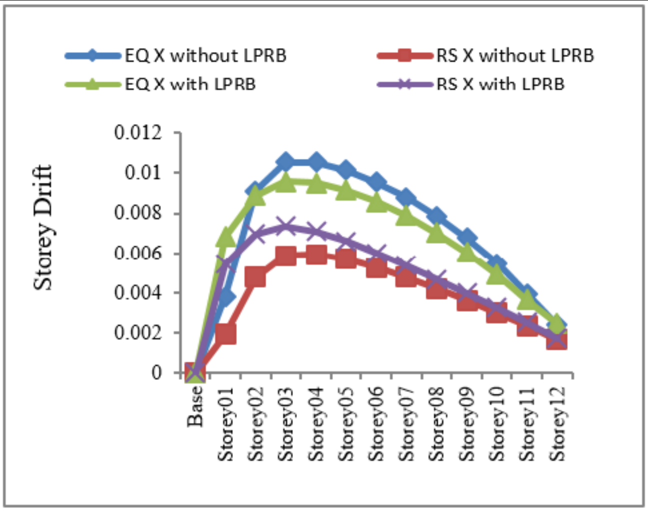
Storey Drift

The Results of Storey Drift of the structure with and without LPRB in SC and RSA are shown in table 5 and results compared are shown in fig. 7 and 8. Though the RSX and RSY of with and without LPRB initially slightly higher than EQX, EQY of with LPRB but at final storey it got reversed. We can conclude that structure with LPRB RSX,RSY has drift values slightly varying with RSX and RSY without LPRB.

Table 5 : Storey Drift with and without LPRB for EQ X, EQ Y, RS X and RS Y

Storey	Without LPRB				With LPRB			
	EQX	EQY	RSX	RSY	EQX	EQY	RSX	RS Y
Base	0	0	0	0	0	0	0	0
Storey01	0.003825	0.002558	0.00192	0.002893	0.006849	0.007687	0.005457	0.006149
Storey02	0.009114	0.00648	0.004788	0.006814	0.00889	0.011116	0.006977	0.008755
Storey03	0.010547	0.008171	0.005869	0.007693	0.009596	0.011809	0.007362	0.0091
Storey04	0.01054	0.00854	0.005957	0.007484	0.009522	0.011493	0.007107	0.008624
Storey05	0.010137	0.00839	0.005701	0.007008	0.009138	0.010907	0.00661	0.007927
Storey06	0.009545	0.007984	0.005279	0.0064	0.008581	0.01018	0.006018	0.007159
Storey07	0.008795	0.007399	0.004774	0.005731	0.007885	0.009319	0.005376	0.00636
Storey08	0.007877	0.006652	0.004226	0.005024	0.007046	0.008305	0.004686	0.005507
Storey09	0.006773	0.005739	0.003623	0.004247	0.006056	0.007116	0.003973	0.004618

Storey10	0.005467	0.004667	0.002994	0.003441	0.004915	0.005734	0.003264	0.003743
Storey11	0.003969	0.003475	0.002355	0.002611	0.003664	0.004168	0.002522	0.002817
Storey12	0.002415	0.002324	0.001673	0.001674	0.002466	0.002557	0.001752	0.001782



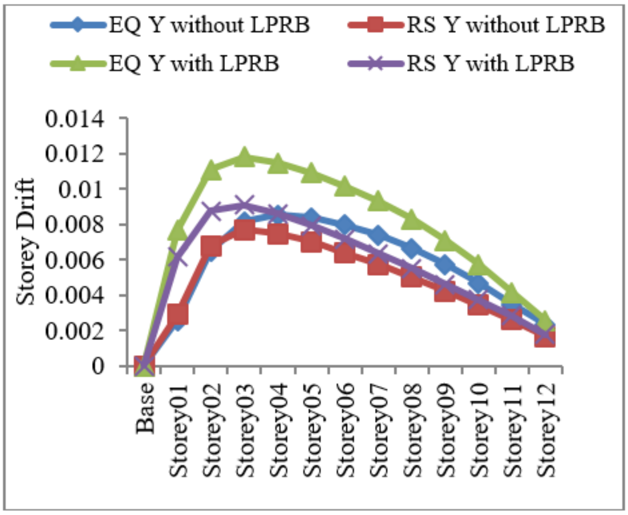


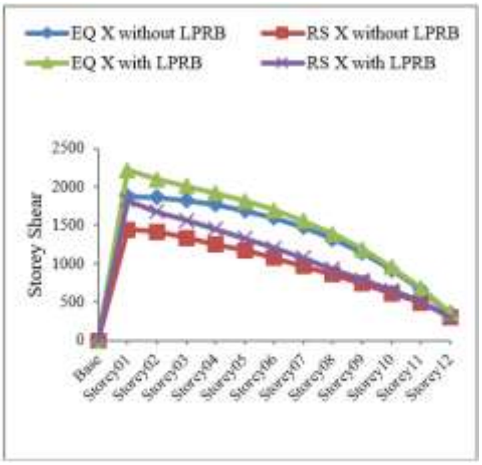
Fig. 7. Storey Drift withand without LPRB for SC & RSA - X axis
Fig. no. 8 Storey Drift with and without LPRB for SC & RSA - Y axis

Storey Shear

The Results of Storey Shear of the structure with and without LPRB in SC and RSA are shown in table 6 and results compared are shown in fig. 8 and 9. The RSX and RSY with LPRB is slightly higher than RSX RSY without LPRB at Storey1 but the values got reversed at Storey12. So the Storey Shear RSX and RSY got reduced as the Storey increased.

Table 6 : Storey Shear with and without LPRB for EQ X, EQ Y, RS X and RS Y

Storey	Without LPRB				With LPRB			
	EQX	EQY	RSX	RSY	EQX	EQY	RSX	RS Y
Base	0	0	0	0	0	0	0	0
Storey01	1877.9505	2015.1733	1444.0593	1540.718	2220.1893	2355.4287	1820.4032	1916.8656
Storey02	1860.7709	1989.9954	1414.5612	1507.7292	2097.4346	2222.5974	1673.4774	1766.5467
Storey03	1823.0528	1939.0122	1334.0375	1426.1261	2008.023	2120.6388	1562.671	1646.6418
Storey04	1767.4201	1869.4245	1251.122	1337.2629	1916.684	2016.1842	1449.4523	1524.6696
Storey05	1692.7847	1781.1717	1172.7019	1243.4391	1814.3768	1900.9232	1325.6947	1389.5057
Storey06	1596.4541	1671.7631	1073.3039	1129.0164	1695.2858	1769.2447	1200.0492	1250.0856
Storey07	1474.9696	1537.758	966.7395	1008.7444	1554.3878	1616.187	1071.7388	1109.8939
Storey08	1324.4918	1375.307	861.8422	886.7749	1386.9456	1437.0413	930.9036	957.7902
Storey09	1140.9856	1180.3734	737.8075	747.0702	1188.3609	1227.2355	786.3615	798.8086
Storey10	920.3124	948.8333	612.0607	606.2713	954.117	982.2875	653.2148	650.9394
Storey11	658.2693	676.5214	494.2758	469.3983	679.7444	697.7793	505.315	493.8132
Storey12	350.5899	359.2415	306.8501	275.9891	360.779	369.328	291.1538	278.3962



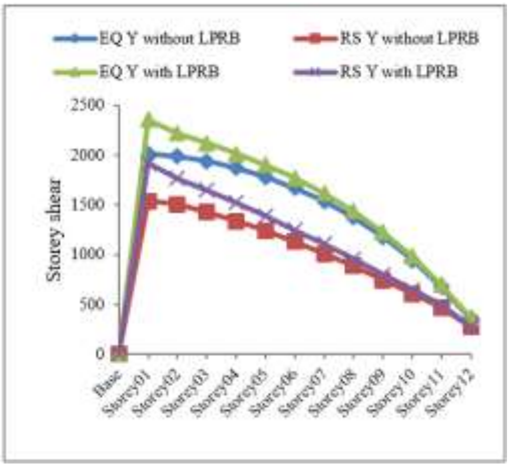


Fig. no. 9 Storey Shear with and without LPRB for SC & RSA - X axis

Fig. no. 10 Storey shear with and without LPRB for SC & RSA - Y axis

CONCLUSION

We got results of Sesmic coefficient Method (SC) analysis (EQ X, EQ Y) with and without LPRB as well as RSA (RS X, RS Y) with and without LPRB. The following conclusions can be drawn from the results.

1) RSA(RS X, RS Y) results are lower than SC (EQ X, EQ Y) results in both With LPRB and without LPRB i.e RS X < EQ X and RS Y < EQ Y.
2) Storey displacement values SC (EQX, EQ Y) With LPRB are more compared with Without LPRB in both X and Y directions.
3) Storey Displacement value of RSA with LPRB is slightly higher than RSA without LPRB and lower than others, with this can conclude that storey displacement an be reduced slightly with LPRB.
4) Storey Drift of RSA with LPRB is lower than SC results with and without LPRB and it is slightly higher than RSA without LPRB.
5) Storey Drift reduces as the elevation increases which results in structures safety against earthquake.
6) Base Shear of RSA with LRB is less than the SC with and without LPRB. This makes structure to be stable during earthquake.
7) Fundamental natural period got increased, which is helpful for less natural period stuctures in earthquake to withstand against collapse without damaging the non-structural elements.

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