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Seismic Evaluation of Multistorey RC Vertical Irregular Buildings with Fixed Base and Laminated Rubber Bearing Base Isolation on Sloping Ground Using Pushover Analysis

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***Abstract*— Base isolation device has been widely adopted structure protection from seismic. It reduces the seismic demand rather than increasing the earthquake resistance capacity of the structure. Building on sloping ground is one of the factors which reduce the capacity of the structure due to the columns in the ground storeys are of different heights which leads the combination of short and long column. In this present study ten storied vertical irregular building models on 11^o sloping ground is considered. The models with fixed base and base isolated building analysis are done by using ETABS 2015 software. The laminated rubber bearing is considered to study the effect of building with fixed base and base isolation on sloping ground by using equivalent static method, response spectrum method and pushover analysis as per IS 1893 (Part 1): 2002. The results like time period, base shear, displacement, storey drift, and performance point, location of hinges, ductility ratio and safety ratio were discussed by comparing fixed base and base isolated buildings.**

***Keywords*— Base Isolation, Fundamental Natural Time Period, Bash Shear, Displacement, Storey Drift, Performance Point and Location of Hinges, Ductility Ratio, Safety Ratio , Equivalent Static Method, Response Spectrum Method, Pushover Analysis**

I. INTRODUCTION

In general structures are constructed on level ground. In some areas most grounds are slope and also difficult to level the ground and excavate. It costs more to level and excavate the ground so engineers choose to construct buildings on sloppy ground [1]. Base isolation of structure is one of the most important techniques used to protect structure from earthquake forces. The term base isolation have two word first is 'base' its meaning is a part that supports from underneath or perform as a foundation of a structure, and second is 'isolation' its meaning of the state of being disparate. The effective decrease of inter storey drift in the floor of base isolation system can ensure the least harm to amenities and also human protection [2]. Earthquake occurs due to sudden movement of the tectonic plates as a results it release large amount of energy in a few seconds. The impact of this function affects large locality and which occurs suddenly and unpredictable. It causes large scale loss of life and property. It damages services like communication, power, transport and water supply etc. The result leads to weaken the financially viable and social structure of the country. To overcome from the problem we need to find out the seismic performance and lateral stability of the building structure [1].

II. DESCRIPTION OF THE BUILDING

In this present study, 3D ten storey RC vertical irregulars building on sloping ground. The plan and elevation of the building models were are shown in Fig 1, Fig 2, Fig 3, Fig 4, Fig 5, Fig 6, Fig 7, Fig 8, Fig 9, Fig 10 and Fig 11. The floor height for each storey is considered as 3.2m. Bay width in longitudinal direction and transverse direction is considered as 4m respectively. The building is assumed to locate in Zone III. M25 grade of concrete and Fe500 grade of steel are considered. Sloping ground were considered as 11^o. The density of concrete and concrete block is considered as 25kN/m^3 and 22kN/m^3. Young's modulus of concrete is considered as 25000 MPa. The ten analytical models are developed, (i) Model 1: ten storey RC vertical regular building on sloping ground with fixed base (ii) Model 2: ten storey RC vertical irregular right side set back building on sloping ground with fixed base (iii) Model 3: ten storey RC vertical irregular left side set back building on sloping ground with fixed base (iv) Model 4: ten storey RC vertical irregular on both left and right side set back building on sloping ground with fixed base

(v) Model 5: ten storey RC vertical irregular T-shaped building on sloping ground with fixed base (vi) Model 6: ten storey RC vertical regular building on sloping ground with laminated rubber bearing at base (vii) Model 7: ten storey RC vertical irregular right side set back building on sloping ground with laminated rubber bearing at base (viii) Model 8: ten storey RC vertical irregular left side set back building on sloping ground with laminated rubber bearing at base (ix) Model 9: ten storey RC vertical irregular on both left and right side set back building on sloping ground with laminated rubber bearing at base (x) Model 10: ten storey RC vertical irregular T-shaped building on sloping ground with laminated rubber bearing at base.

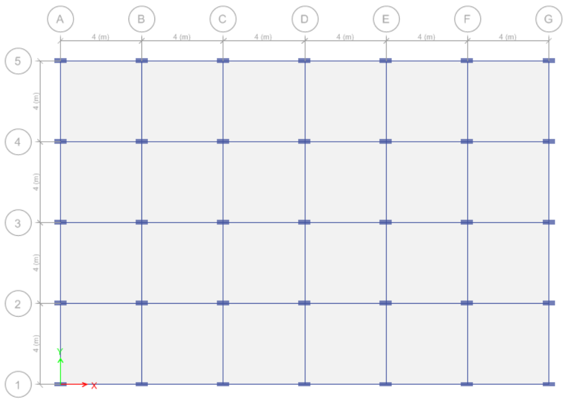

Fig.1 Plan of the building [1]

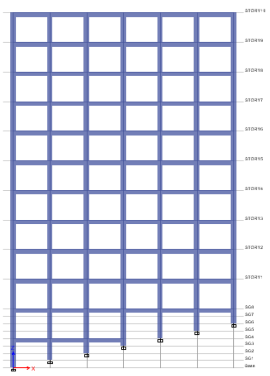

Fig.2 Elevation for model 1

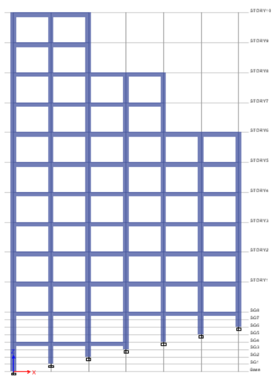

Fig.3 Elevation for model 2

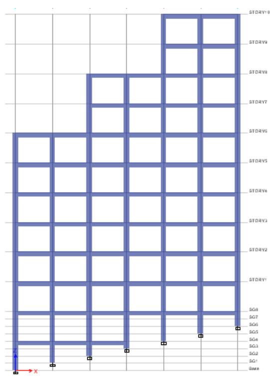

Fig.4 Elevation for model 3

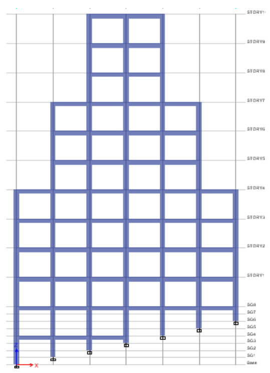

Fig.5 Elevation for model 4

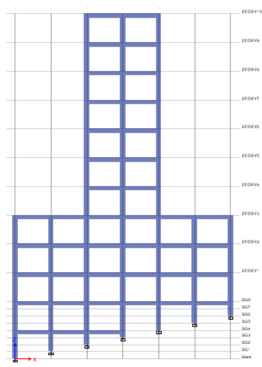

Fig.6 Elevation for model 5

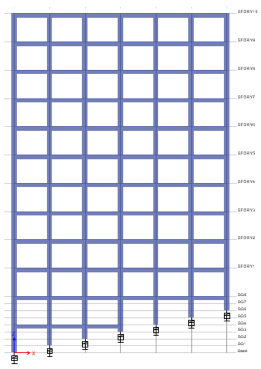

Fig7 Elevation for model 6

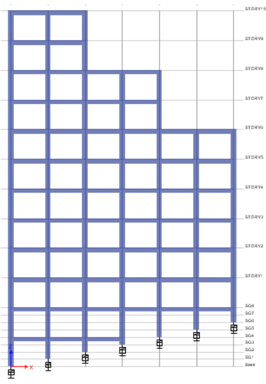
Fig.8 Elevation for model 7

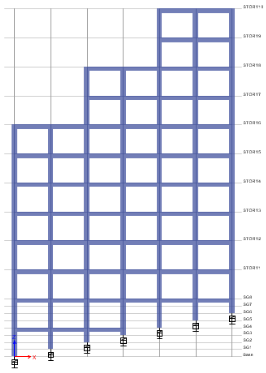
Fig.9 Elevation for model 8

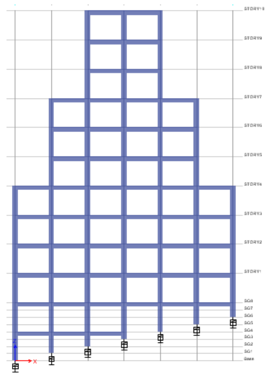
Fig.10 Elevation for model 9

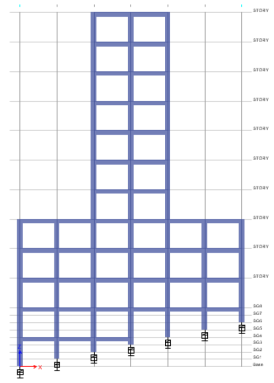
Fig.11 Elevation for model 10

III. METHODOLOGY

A. Base Isolation

Base isolation of structure is defined as protecting structure against seismic forces. It is a devise that is installed between the foundation and base of the building. The base isolator protects the structure from earthquake forces in two ways; (i) by deflecting the seismic energy (ii) by adsorbing the seismic energy. In this present study laminated rubber bearing is used for design

In LBR steel and rubber plate built in to alternate layers. LBR system exhibits high damping capacity, horizontal flexibility and high vertical stiffness [3].

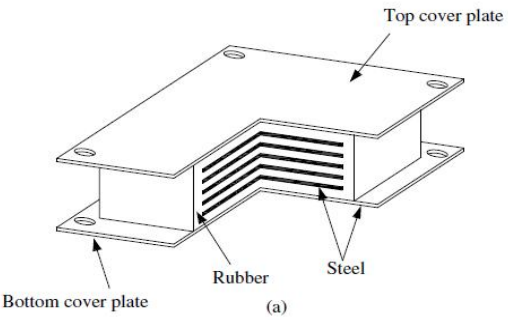

Fig.12 Section and elements of laminated rubber bearing [3]

B. ETABS Input for Laminated Rubber Bearing

ETABS inputs are presented in below tables table I,

TABLE I
PROPERTIES OF LAMINATED RUBBER BEARING BASE ISOLATOR IN ETABS FOR MODEL 6 TO MODEL 10

	Model 6	**Model 7**	**Model 8**	**Model 9**	**Model 10**
Effective Stiffness	493930.71 kN/m	656636.32 kN/m	779629.36 kN/m	1153627.2 kN/m	1153627.2 kN/m
Effective Damping	10%	10%	10%	10%	10%
Linear Properties					
Effective Stiffness	733.330 kN/m	866.670 kN/m	933.330 kN/m	1133.330 kN/m	1133.330 kN/m
Effective Damping	10%	10%	10%	10%	10%
Non-Linear Properties					
Effective Stiffness	7333.3 kN/m	8666.7 kN/m	9333.3kN/m	11333.3 kN/m	11333.3 kN/m
Yield Strength	770.19 kN	910.19 kN	980.19 kN	1190.19 kN	1190.19 kN
Post yield Stiffness ratio	0.1	0.1	0.1	0.1	0.1

C. Pushover Analysis

Pushover analysis is also known as non-linear static analysis. From the state of rest to ultimate failure of structure pushover provides force-displacement curve. The force is representative of equivalent static force of a mode of the structure and may be suitably taken as the total base shear of the structure. Similarly the displacement may represent the displacement of any storey and may be conveniently selected as a top storey displacement.

Pushover analysis can be further divided in to two types,

1) *Force Control method*

2) *Displacement Control method*

For each increment of the force, the stiffness of building may change. In force controlled method total force is applied in increments. The displacement of building at top storey is incremented, such that required horizontal force pushes structure laterally in displacement controlled method.

D. Performance Evaluation of the building

In order to avoid the foremost failure for existing buildings can be retrofitted to make stronger them after evaluating their performance and strength. There for it is compulsory to use pushover analysis to evaluate the performance of the buildings. The most important challenge is to design performance based earthquake design for structure. Demands, force and deformation imposed on structure can be predicted by pushover analysis. In Applied Technology Council (ATC 40) [4] and Federal Emergency Management agency (FEMA 356 and FEMA-440) [5][6] pushover analysis procedure is to determine the displacement demand imposed on a building has been incorporated.

The response spectrum for the seismic design can be determined based on building performance level. The response spectrum provides the maximum acceleration, a structure is likely to experience under the design ground shaking given the structures time period of vibration T. this relation is shown in figure 13 (a)

From the graph, the target displacement represents the maximum displacement in the structure. The target displacement is shown in below figure 13 (b).

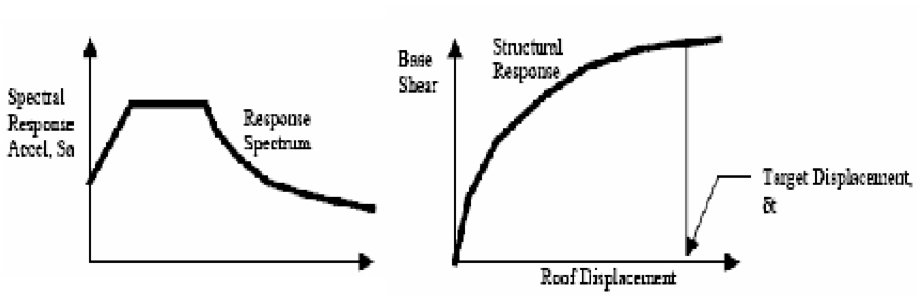

Fig.13 (a) & (b) (a) Response spectrum (b) Target displacement [4]

IV. RESULTS AND DISCUSSION

In this present study, natural time period, base shear, displacement and storey drift were discussed by using equivalent static analysis and response spectrum analysis. And also performance of levels, location of hinges, safety ratio, ductility ratio and global stiffness were discussed by using pushover analysis, for vertical irregular RC building with fixed base and base isolated structure are compared.

A. Time Period

The natural time period is first longest time period of vibration [7]. Below graph represents the time period variation between fixed base building and base isolated building.

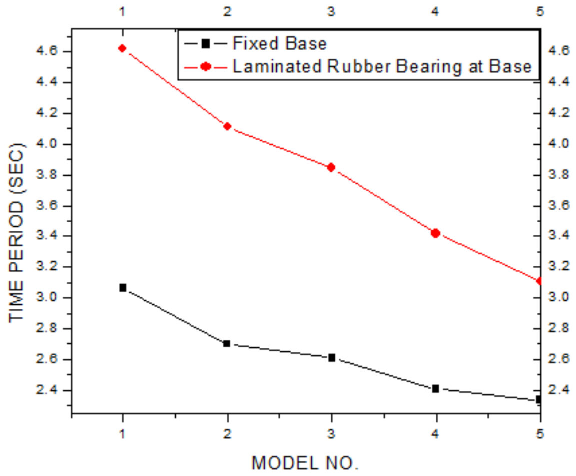

Fig. 14 Fundamental Natural Periods for ten storeyed building models

From the above fig 14 we conclude that, laminated rubber bearing base isolated building models 1, 2, 3, 4 and 5 are 1.51, 1.53, 1.47, 1.42 and 1.33 times longer time period as compare to fixed base building model 1, 2, 3, 4 and 5.

B. Base Shear

Total design lateral force at the base of the structure is defined as Base shear [7] .Base shear and scale factor for the fixed base and base isolated building models were indicated in table II.

TABLE III

BASE SHEAR VALUES FOR FIXED BASE AND BASE ISOLATED BUILDING MODELS

Model No.	**X-direction**			**Y-direction**		
	$\bar{V}_B$ **in kN**	V_B **in kN**	**SF**	$\bar{V}_B$ **in kN**	V_B **in kN**	**SF**
1	1291.78	694.5	1.86	762.15	421.57	1.8
2	1276.18	662.74	1.92	712.26	362.2	1.96
3	1277.1	736.47	1.73	736.47	382.2	1.92
4	1208.54	606.52	1.99	703.94	375.2	1.87
5	895.53	524.5	1.71	573.75	314.96	1.82
6	622.52	379.12	1.64	583.53	340.19	1.7
7	611.65	372.58	1.64	480.22	251.91	1.9
8	628.114	381.41	1.64	499.62	285.35	1.93
9	634.43	385.61	1.64	496.1	289.67	1.71
10	550.9	431.62	1.27	326.16	245.57	1.33

From results we conclude that, In fixed base building along X-direction models 1, 2, 3, 4 and 5 having more base shear as compare to laminated rubber bearing building models 6, 7, 8, 9 and 10 by 51.81%, 52.07%, 50.82%, 47.50% and 38.48% by Equivalent Static Method. Similarly In fixed base building along Y-direction models 1, 2, 3, 4 and 5 having more base shear as compare to laminated rubber bearing building models 6, 7, 8, 9 and 10 by 23.44%, 32.58%, 32.16%, 29.53% and 43.15%by Equivalent Static Method. Similarly, In fixed base building along X-direction models 1, 2, 3, 4 and 5 having more base shear as compare to laminated rubber bearing building models 6, 7, 8, 9 and 10 by 45.41%, 43.78%, 48.21%, 36.42% and 17.17%by Response Spectrum Method. Similarly In fixed base building along Y-direction models 1, 2, 3, 4 and 5 having more base shear as compare to laminated rubber bearing building models 6, 7, 8, 9 and 10 by 19.30%, 30.45%, 25.34%, 22.80% and 22.03%by Response Spectrum Method.

C. Lateral Displacement

Lateral displacement for vertical irregular RC ten storey with fixed base and base isolated structure on sloping ground for various building models by equivalent static analysis and response spectrum analysis were shown in below Fig. 15 to 18.

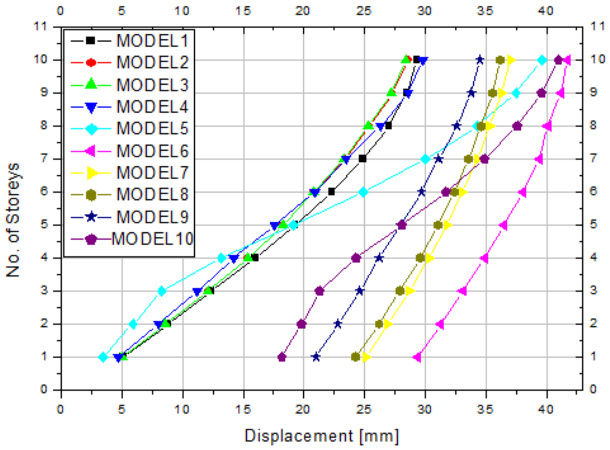

Fig. 15 Displacements along X-direction by ESM

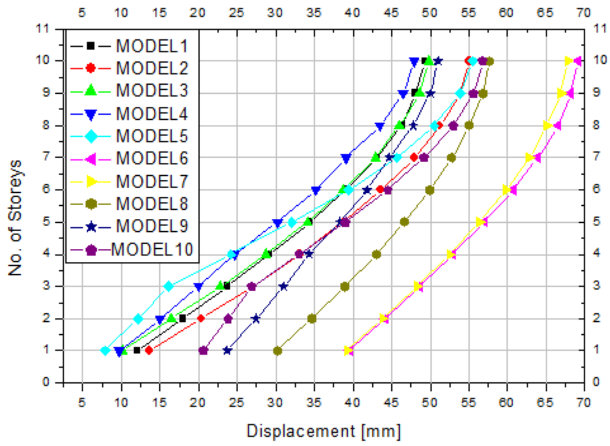

Fig.16 Displacements along Y-direction by ESM

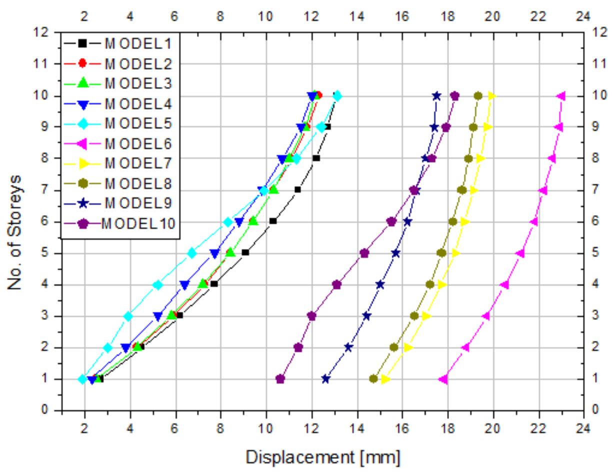

Fig. 17 Displacements along X-direction by RSM

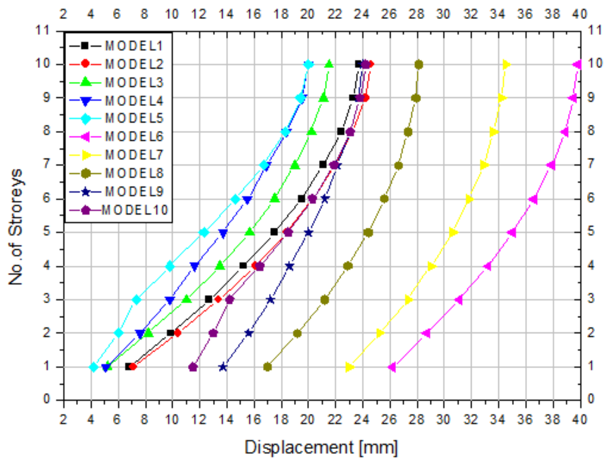

Fig. 18 Displacements along Y-direction by RSM

From the above figure 15, it clearly shows that, vertical irregular RC building on sloping ground with laminated rubber bearing building models 6, 7, 8, 9 and 10 having more lateral displacement as compared to fixed base building models 1, 2, 3, 4 and 5 at roof by 29.74%, 22.70%, 21.55%, 13.62% and 3.41% and similarly at bottom storey by 82.65%, 80.08%, 79.42%, 77.62% and 81.32% by equivalent static method along X-direction.

From figure 16, it clearly shows that, vertical irregular RC building on sloping ground with laminated rubber bearing building models 6, 7, 8, 9 and 10 having more lateral displacement as compared to fixed base building models 1, 2, 3, 4 and 5 at roof by 28.51%, 18.73%, 13.69%, 6.08% and 2.29% and similarly at bottom storey by 69.37%, 65.31%, 66.56%, 59.07% and 61.65% by equivalent static method along Y-direction.

From figure 17, it clearly shows that, vertical irregular RC building on sloping ground with laminated rubber bearing building models 6, 7, 8, 9 and 10 having more lateral displacement as compared to fixed base building models 1, 2, 3, 4 and 5 at roof by 43.04%, 38.19%, 37.31%, 31.43% and 28.42% and similarly at bottom storey by 84.83%, 83.55%, 82.99%, 81.75% and 82.08% by response spectrum method along X-direction.

From the above figure 18, it clearly shows that, vertical irregular RC building on sloping ground with laminated rubber bearing building models 6, 7, 8, 9 and 10 having more lateral displacement as compared to fixed base building models 1, 2, 3, 4 and 5 at roof by 40.45%, 28.70%, 23.49%, 16.67% and 17.36% and similarly at bottom storey by 74.05%, 69.13%, 69.41%, 62.77% and 63.48% by response spectrum method along Y-direction.

D. Story Drift

The storey drift for all building models were calculated by using equivalent and response spectrum method. Below graph Fig 19 to Fig 22 Shows the storey drift values.

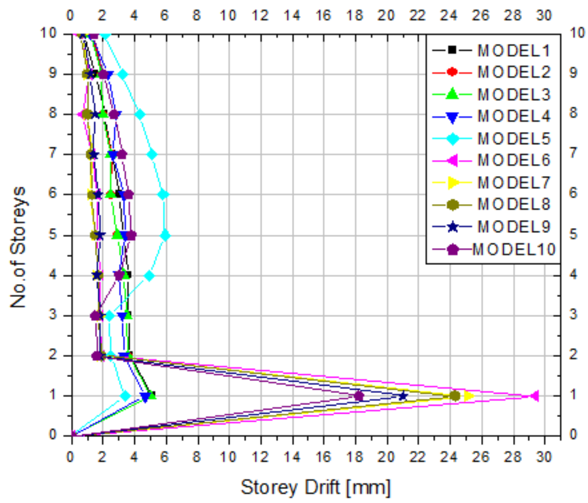

Fig. 19 Story drifts values along X-direction by ESM

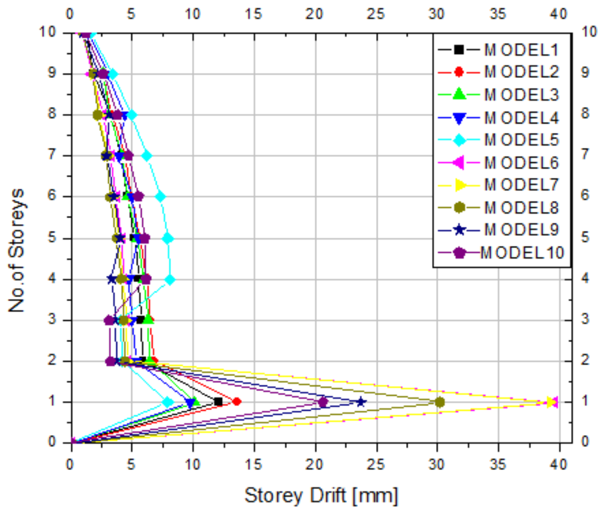

Fig. 20 Story drifts values along Y-direction by ESM

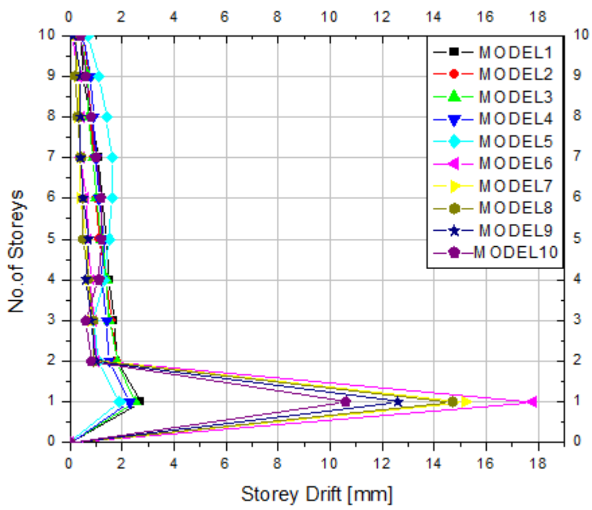

Fig. 21 Story drifts values along X-direction by RSM

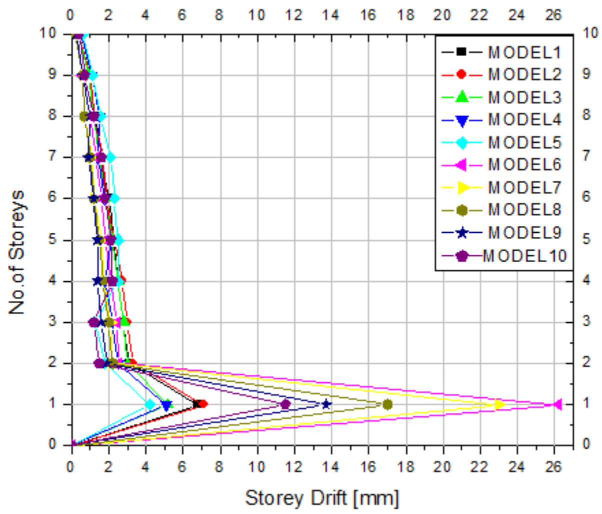

Fig. 22 Story drifts values along Y-direction by RSM

As per IS 1893 (Part 1): 2002 with clause of 7.11.1 storey drift should be within the 0.004 times the each story height [7] i.e. 12.8 mm for each storey. For fixed base buildings and base isolated buildings storey drift values were within limits. From the above Figure 17 and Figure 18, we can conclude that, storey drift values are within the limits for fixed base building models. For base isolated building storey drift is more than the limit (12.8mm) only at bottom storey and upper storeys are within the limit.

From the above figure 19 to figure 22, we can conclude that, storey drift values are within the limits for fixed base building models. For base isolated building storey drift is more than the limit (12.8mm) only at bottom storey and upper storeys are within the limit.From above figure 19 to 22, we conclude that, in base isolated building compared to fixed base building at base (footing) level storey drift shows more. And also we can conclude that in base isolated building storey drift shows less at roof level compare to fixed base building.

E. Performance Point and Location of Hinges

The location of hinges at the performance point for performance levels along X and Y directions for all building models are presented in table III and table IV.

TABLE IIIII PERFORMANCE POINT AND LOCATION OF HINGES FOR FIXED BASE AND BASE ISOLATED BUILDINGS ALONG X-DIRECTION BY PUSHOVER ANALYSIS

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	35.9	2196.58	4526	250	0	0	0	4776
	Ultimate	87.2	2661.76	4052	724	0	0	0	4776
2	Yield	34.56	2289.9	3914	190	0	0	0	4104
	Ultimate	67.21	2710.16	3558	546	0	0	0	4104
3	Yield	39.26	2426.48	3734	370	0	0	0	4104
	Ultimate	77.38	2778.42	3398	706	0	0	0	4104
4	Yield	53.6	2659.9	3258	510	0	0	0	3768
	Ultimate	430.55	3240.78	2708	390	650	10	10	3768
5	Yield	49.14	2089.8	3084	124	0	0	0	3208
	Ultimate	276.9	2842.24	2326	752	130	0	0	3208
6	Yield	58.12	1956.81	4776	0	0	0	0	4776
	Ultimate	151.91	2380.26	4086	640	50	0	0	4776
7	Yield	46	1898.1	3804	300	0	0	0	4104
	Ultimate	133.1	2452.98	3500	554	50	0	0	4104
8	Yield	60.3	2074.01	3684	420	0	0	0	4104
	Ultimate	160	2548.2	3398	512	194	0	0	4104
9	Yield	90.7	2348.78	3228	540	0	0	0	3768
	Ultimate	506.4	2674.92	2718	510	380	130	30	3768
10	Yield	63.2	2002.51	2828	380	0	0	0	3208
	Ultimate	211.1	2484.47	2428	730	50	0	0	3208

TABLE IVV PERFORMANCE POINT AND LOCATION OF HINGES FOR FIXED BASE AND BASE ISOLATED BUILDINGS ALONG Y-DIRECTION BY PUSHOVER ANALYSIS

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	Yield	43.7	926.22	4774	2	0	0	0
	Ultimate	Ultimate	66.3	1363.84	4654	122	0	0	0
2	Yield	Yield	71.6	1411.34	3938	164	0	0	2
	Ultimate	Ultimate	85.25	1526.69	3816	280	0	0	8
3	Yield	Yield	63.1	1394.07	3968	134	0	0	2
	Ultimate	Ultimate	91.25	1590.78	3736	330	12	0	26
4	Yield	Yield	67.05	1458.75	3610	158	0	0	0
	Ultimate	Ultimate	111.86	1654.08	3358	376	30	0	4
5	Yield	Yield	76.9	1419.28	3062	144	0	0	2
	Ultimate	Ultimate	141.03	1659.29	2746	434	18	0	10
6	Yield	Yield	71.43	1119.95	4690	86	0	0	0
	Ultimate	Ultimate	78.17	1173.03	4632	144	0	0	0
7	Yield	Yield	80.6	1165.38	3986	118	0	0	0
	Ultimate	Ultimate	80.6	1165.41	3986	118	0	0	0
8	Yield	Yield	75.8	1221.48	3944	160	0	0	0
	Ultimate	Ultimate	85.8	1269.41	3918	172	10	0	4
9	Yield	Yield	62.4	1125.96	3684	84	0	0	0
	Ultimate	Ultimate	100	1324.56	3544	194	26	0	4
10	Yield	Yield	73.9	1142.24	3114	94	0	0	0
	Ultimate	Ultimate	87.6	1234.1	3050	158	0	0	0

From the above table III and IV we conclude that, In fixed base building along X-direction model 1, 2, 3, 4 and 5 having more base force as compare to laminated rubber base building (base isolated building) model 6, 7, 8, 9 and 10 by 10.58%, 9.49%, 8.29%, 17.46% and 12.59% at ultimate stage by pushover analysis.

From the above table III and IV we conclude that, In fixed base building along Y-direction model 1, 2, 3, 4 and 5 having more base force as compare to laminated rubber base building (base isolated building) model 6, 7, 8, 9 and 10 by 13.99%, 23.66%, 20.20%, 19.92% and 25.62% at ultimate stage by pushover analysis.

F. Ductility Ratio

Ductility ratio is defined as the ratio of collapse yield to (CY) to the initial yield (IY) [8]. Below table V shows the values of ductility ratio for fixed base and base isolated buildings.

TABLE V
DUCTILITY RATIO FOR FIXED BASE AND BASE ISOLATED BUILDING MODELS ALONG X AND Y DIRECTION BY PUSHOVER ANALYSIS

Model No.	**X-direction**			**Y-direction**		
	IY	**CY**	**DR**	**IY**	**CY**	**DR**
1	35.9	87.2	2.4	43.7	66.3	1.5
2	34.56	67.21	1.9	71.6	85.25	1.2
3	39.26	77.38	2	63.07	91.25	1.4
4	53.6	430.55	8	67.05	111.9	1.7
5	67.08	276.9	4.1	76.9	141.03	1.8
6	58.12	151.91	2.61	71.43	78.17	1.09
7	46	133.1	2.89	80.6	80.6	1
8	60.3	160	2.65	75.8	85.8	1.13
9	90.7	506.4	5.58	62.4	100	1.6
10	63.2	211.1	3.34	73.9	87.6	1.18

For vertical irregular RC building on sloping ground with fixed base for ten storied building models, along X-direction, model 4 and 5 are more than the targeted value 3. Similarly in Y –direction Model 1 to 5 are within the targeted value 3. For vertical irregular RC building on sloping ground with laminated rubber bearing for ten storied building models, along X-direction, model 4 and 5 are more than the targeted value 3. Similarly in Y –direction Model 1 to 5 are within the targeted value 3. From table V, it shows that, ductility ratio having more in model 1, 2 and 3 as compared to model 6, 7 and 8 by 8.05%, 34.26% and 24.53%. And also Ductility ratio more in model 4 and 5 as compared to model 9 and 10 by 30.25% and 18.54% along X-direction. Similarly ductility ratio having more in model 1, 2, 3, 4 and 5 as compare to model 6, 7, 8, 9 and 10 by 27.33%, 16.67%, 19.29%, 5.88% and 34.44% along Y-direction

G. Safety Ratio

The ratio of base force at performance point at ultimate stage to the base shear by equivalent static method is called as safety ratio [8]. If the safety ratio value is equal to one or more than one the structure is said to be safer. If safety ratio values comes less than one then the structure is not safe [8].

TABLE VI

SAFETY RATIO FOR FIXED BASE AND BASE ISOLATED BUILDING MODELS ALONG X AND Y-DIRECTION BY PUSHOVER ANALYSIS

Model No.	X- direction			Y-direction		
	Base force at pushover method	**Base force at ESM**	**Safety ratio**	**Base force at pushover method**	**Base force at ESM**	**Safety ratio**
1	2661.76	1291.78	2.06	1363.84	762.15	1.79
2	2710.16	1276.18	2.12	1526.69	712.26	2.14
3	2778.42	1277.1	2.18	1590.78	736.47	2.16
4	3240.48	1208.54	2.68	1654.1	703.94	2.35
5	2842.24	895.53	3.17	1659.29	573.99	2.89
6	2380.26	622.52	3.82	1173.03	583.53	2.01
7	2452.98	611.65	4.01	1165.38	480.22	2.43
8	2548.2	628.114	4.06	1269.41	499.62	2.54
9	2674.92	634.43	4.22	1324.56	496.1	2.67
10	2484.47	550.9	4.51	1234.1	326.16	3.78

From table VI, it shows that, base isolated building models are 1.85, 1.89, 1.86, 1.57 and 1.42 times safer than the fixed base buildings along X-direction. Similarly in Y-direction base isolated buildings are 1.12, 1.14, 1.18, 1.14 and 1.31 times safer than the fixed base buildings.

V. CONCLUSIONS

Natural time periods are increased after providing laminated rubber bearing (base isolation devise). And time period reduced in fixed base building. When compared with fixed base structure, base shear is reduced in base isolated structure. After providing base isolator to the building displacements are increased compare to the fixed base building. The story drift is found to be within the limits for all buildings. Fixed base building shows more base force at performance point compared to base isolated building. In pushover analysis method at the ultimate state flexural hinges are found within life safety. In base isolated building ductility ratio found more than fixed base building. Base isolated building is safer than the fixed base building. Fixed base building is stiffer than the base isolated building. The response of building is good in base isolated structures than fixed base structures. After providing laminated rubber bearing as base isolation system, it increases the structure stability against earthquake. Safety ratio is more in base isolated building compare to fixed base building.

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