Parametric Study on Isolation System used in Earthquake Resistant building

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Abstract – *The earthquake-resistant design of building is currently the focus of attention, especially for buildings that require a high level of seismic protection. To improve the seismic performance of buildings, different innovative techniques have been proposed. It is however necessary to know the efficiency of such techniques. Therefore, the present work attempts to study the effectiveness of Storey isolation system using lead rubber bearings (LRB) over conventional, base and roof isolation system. The case study shall be carried out by using a G+12 RC building, which shall be located in the most seismically active region in India (Zone V). The seismic parameters like base shear, storey displacement, storey drift and fundamental vibration shall be analyzed and studied for optimum position of isolation system using structural analysis software ETABS 2016.*

Key Words: **Roof Isolation, Base Isolation, Storey Isolation, Earthquake resistant structure, Parametric optimization**

1. INTRODUCTION

Structural control systems like seismic isolation (i.e. Base Isolation) and energy dissipation systems (i.e. Fluid dampers, Metallic dampers etc.) has been widely implemented internationally in the last five decades and has been proved to be one of the most prominent strategies to improve the response of structures while earthquake. Seismic isolation system may be defined as a flexible or sliding interface positioned between a structure and its foundation, for the purpose of decoupling the horizontal motions of the ground from the horizontal motions of the structure, thereby reducing earthquake damage to the structure and its contents.

Seismic isolation can have mainly two advantageous effects on the seismic response of a structure. First is reduction of lateral forces in the superstructure and second is concentration of lateral displacements at the isolation interface. This way, large deformations of the building are confined at the isolation level, where seismic isolators have the capacity to accommodate large strains. Inter storey deflections are reduced due to the almost rigid body motion of the superstructure. This seismic isolation technique aims to minimizing the forces induced by earthquakes to low-to-medium rise buildings and mitigating potential structural and non-structural damage.

A limitation of base isolation is the seismic gap which must be provided around the structure to accommodate the large displacements that are expected at the isolation level and another limitation of possibility of poundings with adjacent buildings during strong earthquakes which may result in local structural damages.

There is another version of base isolation that is roof isolation or additional isolated upper floor (AIUF). In roof isolation the above mentioned flexible upper floor will turn into an additional isolated upper floor (AIUF) which act as tuned mass damper or RC tuned mass damper. This earthquake protection system was successfully implemented in the city of "Vanadzor" within the framework of the Armenia Earthquake Zone Reconstruction Project financed by the "World Bank".[2]

The process of isolating upper floor is the upper floor of structure is an attic, the slab of which is envisaged to be separated from the columns then lifted up and seismic isolators installed between them. The mentioned slab is converted into an isolated upper floor (IUF) which will be acting as a reinforced concrete tuned mass damper (TMD) providing earthquake protection for building.

In an effort to extend and enhance the concept of base isolation the present study concerned with the control of particular G+12 building under the earthquake actions of seismic zone V and site class II by introducing seismic isolators at various elevations along the height of the structure (i.e. Storey Isolation).

2. MODELLING

In this research work, actual existing G+12 building is used to modelled as RC rigid frame having structural data as follows.

2.1 Structural data of ETABS

A G+12 storey residential building has plan dimensions as shown in Table 5.1. The building is located in highly active seismic zone V on a site with medium soil. Analysis of the building for seismic loads as per IS 1893 (Part 1): 2016.
General:

1. The building is used for residential purpose only.
2. There are no expansion joints in the building.
3. For simplicity in analysis, the wall is considered for all beams internal and external walls 230 mm thick with 12 mm plaster on both sides are considered. For all the

walls, ACC block is considered to reduce the weight of the structure.

4. Sizes of all columns in upper floors are kept the same; however, for columns up to first floor, sizes are increased.
5. The floor diaphragms are assumed to be rigid.
6. For analysis purpose, the beams are assumed to be rectangular so as to distribute slightly larger moment in columns. Column are assumed to be square with same dimensions, as the design of all isolator is remaining same for all columns.
7. There is no shear wall in the building to present in the building.

2.2 Description of Models

Model 1 - Fixed Base
Model 2 - Base isolated
Model 3 - Roof isolated
Model 4 - Multi storey isolation (Base + Roof isolation)
Model 5 to 16 - Storey isolation

2.3 Structural configuration

Structural data of the building model of G+12 storey building is as follows,

Table -1: Structural data

Type of structure	Multi-storey rigid jointed 3D frame (SMRF)
Seismic zone	V
Zone Factor	0.36
Importance factor	1.2
Response reduction factor	5
Type of soil	Type II (Medium soil)
Dimension of building	36.00 m x 13.65 m
Floor Height	Ground Floor: 3.5 m Typical Floor: 3.3 m
Live load	3 kN/m2 on all floors
Dead load	1.5 kN/m2 on all floor w/o including self-weight
Materials	Concrete (M30) and Reinforcement Fe 415
Beam Dimension	Ground storey: 230 mm x 500 mm Typical storeys: 230 mm x 400 mm
Column Dimension	Ground storey: 700 mm x 700 mm Typical storeys: 600 mm x 600 mm
Number of columns	58
Depth of slab	150 mm
Wall thickness	230 mm

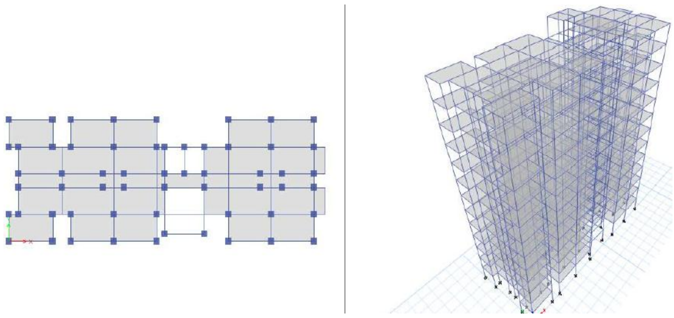


Fig -1: Fixed base building model

2.4 Load application details

1. Self-Weight of the Building

2. Slab load:
   Dead Load = 1.5 kN/m2
   Live Load = 3 kN/m2

3. Wall load on Beams:
   Dead Load = 3.4 kN/m2

4. Load of Roof Slab of Lift:
   Machine Load (D.L.) = 7.5 kN/m2
   Live Load = 1.5 kN/m2

5. Staircase load on Beams:
   Dead Load = 3.75 kN/m2
   Live Load = 3 kN/m2

6. Earthquake static load:
   Zone factor (Z) =0.36
   Soil type II (Medium soil)
   Importance factor (I) =1.2
   Response reduction factor (R) =5

3. DESIGN OF LEAD RUBBER BEARING

In present, there is no such Indian code to design isolation devices and design seismic isolated structure. Hence, for the design of seismic isolated structure, we are relying on the ASCE chapter 17 code, IBC-200 and UBC-97 code of design.

In this study LRB design is based on ASCE code of Chapter 17. For properties of LRB two excel sheets are prepared.

The first part of excel spread sheet presents a procedure to determine the geometry of an LRB required to achieve the designed bilinear model and the maximum total displacement. In the second part of spared sheet used to determine the input property of LRB for the given geometry which is used in ETABS structural software.

Code provisions regarding the specification of site classification, specification of hazard, design response spectrum, ductility classification, response reduction factors and minimum design base shear are taken Equivalent to Indian code.[3]

4. RESULTS

Result of scaled response spectrum for highly seismic zone V and medium soil type is applied to all 16 models.

4.1 Model Period

Table -2: Modal period (in sec) of main models

Model	Fixed Base	Base Isolation	Roof Isolation	Base + Roof
Mode 1	2.07	3.08	1.15	1.59
Mode 2	1.96	2.93	1.12	1.54
Mode 3	1.87	2.82	1.07	1.48

Table - 3: Modal period (in sec) of Storey Isolated models

Mode	12th Storey Isolated	11th Storey Isolated	10th Storey Isolated	9th Storey Isolated	8th Storey Isolated	7th Storey Isolated	6th Storey Isolated	5th Storey Isolated	4th Storey Isolated	3th Storey Isolated	2th Storey Isolated	1th Storey Isolated
Mode 1	1.067	1.058	1.088	1.181	1.305	1.444	1.587	1.723	1.852	1.955	2.023	2.054
Mode 2	1.033	1.026	1.055	1.143	1.260	1.391	1.524	1.649	1.768	1.862	1.923	1.949
Mode 3	0.986	0.976	1.001	1.084	1.195	1.320	1.447	1.567	1.681	1.770	1.828	1.855

4.2 Storey displacement

Table - 4: Storey displacement (in mm) of main models

Storey No	Elevation	Fixed Base	Base Isolation	Roof Isolation	Base + Roof
Cabin	46	82.44	121.14	25.32	23.49
13	43.1	79.48	118.74	32.65	31.93
12	39.8	76.37	115.74	36.18	36.46
11	36.5	75.66	112.05	40.14	42.15
10	33.2	70.93	107.65	43.14	47.59
9	29.9	65.36	105.21	44.54	52.22
8	26.6	59.01	102.58	44.06	55.73
7	23.3	51.93	96.86	41.64	57.93
6	20.0	44.17	90.54	37.38	58.73
5	16.7	35.76	83.65	31.50	58.08
4	13.4	26.82	76.22	24.34	56.01
3	10.1	17.64	68.27	16.37	52.57
2	6.8	8.98	59.85	8.47	47.87
1	3.5	2.57	50.87	2.46	42.03
Base	0	0	40.85	0	34.98

Table - 5: Storey displacement of Storey Isolated models

Storey No	Elevation	12th Storey Isolated	11th Storey Isolated	10th Storey Isolated	9th Storey Isolated	8th Storey Isolated	7th Storey Isolated	6th Storey Isolated	5th Storey Isolated	4th Storey Isolated	3th Storey Isolated	2th Storey Isolated	1th Storey Isolated
Cabin	46	26.57	34.38	42.57	48.45	52.92	56.86	60.86	65.00	68.72	79.01	74.25	75.68
13	43.1	32.90	41.30	50.27	56.35	60.86	64.58	68.40	72.29	75.96	76.12	81.07	82.11
12	39.8	33.25	39.21	46.74	52.45	57.08	61.03	65.05	69.11	72.97	72.33	78.20	79.19
11	36.5	35.60	37.22	42.16	47.16	51.93	56.24	60.61	64.92	69.04	71.95	74.46	75.41
10	33.2	38.74	37.26	37.49	40.81	45.52	50.26	55.08	59.72	64.14	67.60	69.79	70.72
9	29.9	40.87	38.19	35.05	34.64	38.44	43.41	48.66	53.62	58.34	61.98	64.26	65.17
8	26.6	41.28	38.23	33.88	30.88	31.86	36.18	41.55	46.73	51.73	55.56	57.94	58.84
7	23.3	39.69	36.72	32.24	28.70	27.72	29.48	34.07	39.17	44.37	48.40	50.88	51.78
6	20.0	36.12	33.48	29.44	26.31	25.01	24.81	26.87	31.18	36.36	40.54	43.13	44.02
5	16.7	30.76	28.58	25.29	22.94	21.94	21.17	21.22	23.31	27.90	32.05	34.72	35.62
4	13.4	23.95	22.30	19.88	18.33	17.76	17.03	16.39	16.76	19.48	23.17	25.81	26.69
3	10.1	16.20	15.12	13.57	12.69	12.46	11.95	11.29	11.09	12.21	14.43	16.71	17.54
2	6.8	8.42	7.87	7.11	6.72	6.66	6.42	6.01	5.78	6.15	7.01	8.25	8.89
1	3.5	2.45	2.30	2.08	1.99	1.98	1.92	1.79	1.70	1.77	1.97	2.29	2.53
Base	0	0	0	0	0	0	0	0	0	0	0	0	0

4.3 Storey drift

Table - 6: Storey drift of main models

Storey No	Elevation	Fixed Base	Base Isolation	Roof Isolation	Base + Roof
Cabin	46	0.00080	0.00063	0.00059	0.00072
13	43.1	0.00113	0.00081	0.00118	0.00147
12	39.8	0.00147	0.00103	0.00131	0.00176
11	36.5	0.00178	0.00127	0.00103	0.00169
10	33.2	0.00204	0.00150	0.00059	0.00145
9	29.9	0.00224	0.00171	0.00039	0.00110
8	26.6	0.00240	0.00190	0.00084	0.00070
7	23.3	0.00254	0.00206	0.00137	0.00033
6	20.0	0.00267	0.00221	0.00185	0.00035
5	16.7	0.00278	0.00235	0.00221	0.00072
4	13.4	0.00281	0.00247	0.00243	0.00111
3	10.1	0.00263	0.00259	0.00240	0.00146
2	6.8	0.00194	0.00274	0.00182	0.00179
1	3.5	0.00073	0.00374	0.00069	0.00260

Table - 7: Storey drift of Storey Isolated models

Storey No	Elevation	12th Storey Isolated	11th Storey Isolated	10th Storey Isolated	9th Storey Isolated	8th Storey Isolated	7th Storey Isolated	6th Storey Isolated	5th Storey Isolated	4th Storey Isolated	3th Storey Isolated	2th Storey Isolated	1th Storey Isolated
Cabin	46	0.00032	0.00052	0.00076	0.00085	0.00085	0.00086	0.00086	0.00085	0.00081	0.00078	0.00077	0.00079
13	43.1	0.00046	0.00076	0.00118	0.00131	0.00131	0.00130	0.00129	0.00125	0.00118	0.00113	0.00111	0.00112
12	39.8	0.00087	0.00082	0.00155	0.00179	0.00179	0.00176	0.00172	0.00165	0.00155	0.00148	0.00145	0.00146
11	36.5	0.00104	0.00059	0.00166	0.00219	0.00224	0.00218	0.00210	0.00201	0.00188	0.00180	0.00177	0.00177
10	33.2	0.00072	0.00060	0.00124	0.00226	0.00252	0.00248	0.00238	0.00227	0.00214	0.00206	0.00203	0.00203
9	29.9	0.00032	0.00050	0.00100	0.00179	0.00249	0.00262	0.00255	0.00245	0.00234	0.00226	0.00223	0.00223
8	26.6	0.00060	0.00066	0.00095	0.00139	0.00196	0.00249	0.00260	0.00257	0.00249	0.00242	0.00239	0.00240
7	23.3	0.00116	0.00109	0.00108	0.00120	0.00147	0.00194	0.00248	0.00264	0.00261	0.00256	0.00253	0.00254
6	20.0	0.00168	0.00155	0.00137	0.00125	0.00127	0.00148	0.00199	0.00255	0.00269	0.00269	0.00266	0.00267
5	16.7	0.00210	0.00194	0.00169	0.00148	0.00139	0.00142	0.00163	0.00211	0.00263	0.00275	0.00277	0.00277
4	13.4	0.00237	0.00220	0.00194	0.00174	0.00164	0.00158	0.00160	0.00178	0.00225	0.00268	0.00278	0.00280
3	10.1	0.00236	0.00220	0.00196	0.00182	0.00176	0.00169	0.00161	0.00162	0.00185	0.00226	0.00257	0.00263
2	6.8	0.00181	0.00169	0.00152	0.00144	0.00142	0.00137	0.00128	0.00124	0.00133	0.00153	0.00181	0.00193
1	3.5	0.00069	0.00064	0.00058	0.00056	0.00056	0.00054	0.00050	0.00048	0.00050	0.00056	0.00065	0.00071

4.4 Base shear

Table - 8: Base shear (in kN) of main models

Fixed Base	Base Isolation	Roof Isolation	Base + Roof
3420.67	2509.69	3177.63	2180.74

Table - 9: Base shear (in kN) of Storey Isolated models

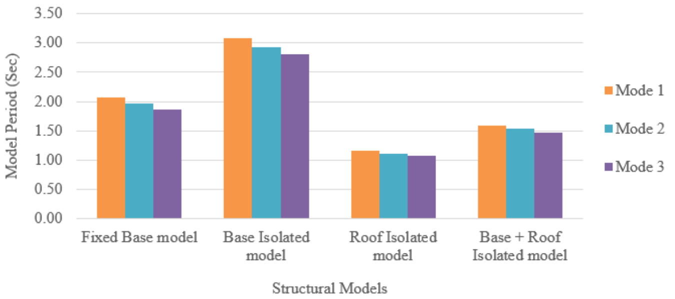
12th Storey Isolated	11th Storey Isolated	10th Storey Isolated	9th Storey Isolated	8th Storey Isolated	7th Storey Isolated	6th Storey Isolated	5th Storey Isolated	4th Storey Isolated	3th Storey Isolated	2th Storey Isolated	1th Storey Isolated
3307.42	3220.41	3165.07	3091.26	3025.22	2996.81	2916.98	2880.27	2833.55	2799.61	2750.42	2619.05

5. Discussion

According to IS-1893:2016, the number of modes to be used in the analysis should be such that the total sum of modal masses of all modes considered is at least 90% of the total seismic mass. Here, for Fixed Base and Roof Isolated building model the modal mass of the sum of total 12 modes are 93% and for Base Isolated and Base + Roof Isolated model total mass of all modes are 99%.

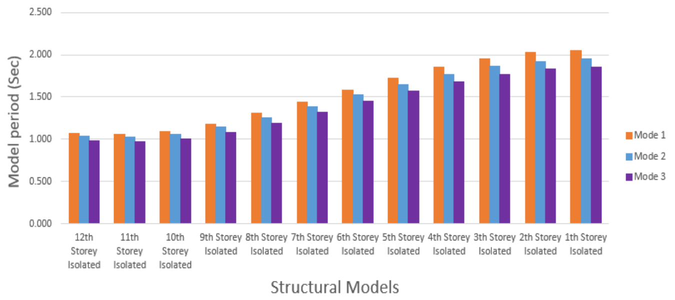
Fundamental period of Base Isolated model is maximum that is 3.08 sec whereas Roof Isolated model having minimum period that is 1.15 sec. Which means Roof Isolated model is behaving stiffer compared to Fixed Base model but the reason in reduction of fundamental period is the increasing resistance towered the vibration in model that is Isolated upper storey.

Graph - 1: Periods of modes for main four models



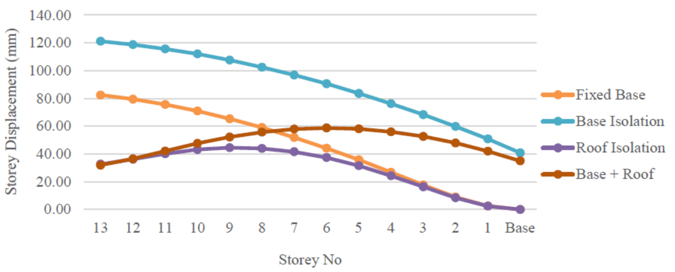
The above graph of period of first three modes shows Base Isolated model is more flexible than other models. Also, the Roof Isolated model surprisingly showing less fundamental period than the Fixed Base model. The reason is the initial force of that isolated roof storey. When earthquake strikes the building the Fixed Base one tries to oscillate while the Roof Isolated one is imparting the inertial force in to the oscillation of building through the reverse oscillation of isolated roof storey. Here, period of Base + Roof Isolated building is moderate in between Base Isolated and Fixed Base model. The reason behind this is the period is limiting due to reverse oscillation of Isolated upper storey.

Graph - 2: Periods of modes for Storey Isolated models



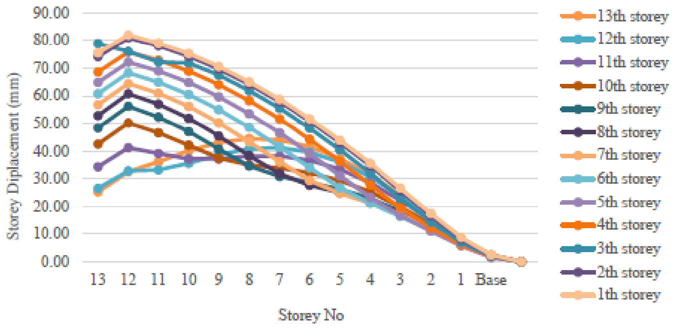
As shown model period of storey isolated models in the graph, it observed that with decreasing the level of storey isolation the fundamental period is increasing. In other words, increasing the level of storey isolation decrease the flexibility of buildings and building is behaving as stiffer one. In this Storey Isolation system, the isolated mass of storeys contributes to the fundamental mode of vibration, which is properly isolated by a long period.

Graph - 3: Displacements of main four models



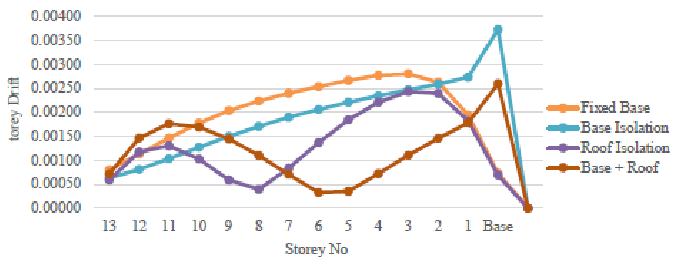
In the graph of storey displacement of main four models, the value of displacement is increased uniformly for Fixed Base and Base Isolated models, but for Roof Isolated and Base + Roof Isolated model displacement is varying non-uniformly. Because, in Fixed Base model there is only structural damping which provides resistance to the earthquake force. In Base Isolated model the base isolator decouples the earthquake force at base and also structural damping have some resistance. Whereas Roof Isolated and Base + Roof Isolated model have additional mechanism, that is the inertial force of additional upper isolated storey which provide effective resistance to earthquake force.

Graph - 4: Displacements of Storey Isolated models



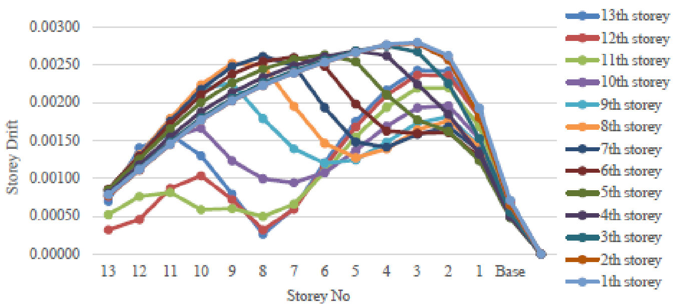
For all Storey Isolated models, displacement is reduced compared to Fixed Base model but increasing compared to Roof Isolated model.

Graph - 5: Drift of main four models



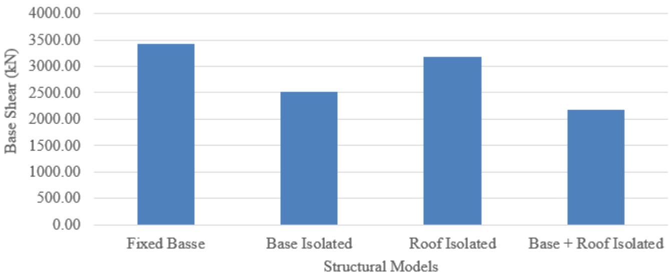
Result of drift, for Base + Roof Isolated model has similar results as Base Isolated model has but, change is the drift for storey 1 is less than Base Isolated model and less till the 10th storey. In case of Roof Isolated also drift is less compared to Fixed Base and Base Isolated models. It can be easily shown in the graph below. For Roof Isolated model drift of storey 1 decreases up to 81% in comparison to Base Isolated model.

Graph - 6: Drift of Structural Isolated models



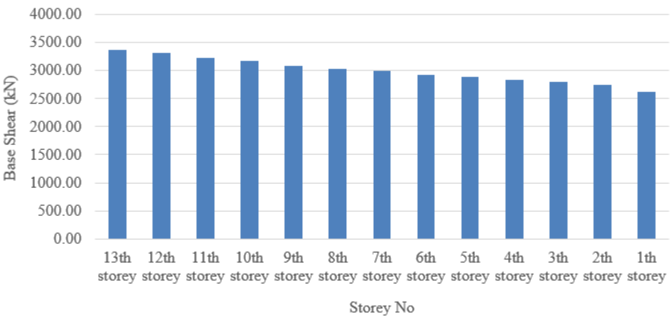
In this graph value of storey drift for all models are under 0.003 and drift is maximum for the model which has isolation level at storey 1. With increasing level of storey isolation value of storey drift is getting decreased. In all Storey Isolated models 11th Storey Isolated model is showing comparatively less storey drift.

Graph - 7: Base shear of main four models



As the graph tells, base shear is high in Fixed Base model and Roof Isolated model. Base shear of Base + Roof Isolated model is very much less compared to Fixed Base model. Base shear of Base Isolated model is around 26%, Roof Isolated model is 7% and Base + Roof Isolated model 36% less compared to Fixed base model.

Graph - 8: Base shear of Structural Isolated models



According to this graph, value of base shear is reducing with reducing the level of Storey Isolation. There is also an observation for increasing the effective stiffness LRB leads to reduce base shear for all Storey Isolated models.

6. CONCLUSIONS

1. Isolating storeys of building is attempted to control the fundamental mode of vibration of building by the isolating mass mechanism. In Storey Isolation system, the isolated mass of storeys contributes to the deceasing in fundamental mode of vibration.
2. Story isolation systems at any level are quite effective in mitigating force. The effectiveness (i.e. seismic behavior) of a Storey Isolation system decreases as the isolation level decreases vertically.
3. For this case study of G+13 storey building, optimum level to isolated the building is 11th Storey. Which gives better seismic behavior in comparison of Roof Isolated model and far better than Fixed Base model.
4. Roof Isolation and Storey Isolation system may effectively reduce the response of earthquake forces in comparison of Fixed Base building are possible, if a sufficient amount of mass can be isolated.
5. In this parametric study conducted, the dynamic behavior of the all Storey Isolated buildings has proven to be substantially improved over the Fixed Base building, as regards the storey displacement, storey drift and base shear under earthquake action.
6. Multi-storey isolation system (i.e. Base + Roof Isolated building) is effective in reducing seismic response, but do not seem to offer compelling performance more advantageous over base isolation. The most sensible application that can be envisioned is to provide a second isolation level to partition a deformation demand that is too large to be accommodated at a single level.

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