IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 18, Issue 4 Ser. II (Jul. – Aug. 2021), PP 26-33
www.iosrjournals.org

Regular Versus Vertical Irregular R.C Buildings Using Base Isolation

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Abstract:
Over years, considerable attention has been paid to seismic behavior of structures with vibration control systems. Passive, active, semi-active and hybrid control systems have been used in buildings that might be subjected to high seismic activity. Among those devices, Base Isolation (BI) is a passive vibration control system that partially absorbs input seismic energy before it is transmitted to the superstructure. Seismic behavior of structures is influenced by many factors. Among these factors, ground motion characteristics and structural irregularity have dominant effects on the seismic performance. In addition, vertical irregularity of R.C. building may pose high challenge on its behavior and may increase its seismic vulnerability. In present research, four models will be investigated; these models represent regular and vertical irregular R.C buildings with fixed base or base isolation devices. Time history analyses are performed for regular and vertical irregular buildings under the effects of seven different earthquake records. A comparative study is made among time periods, base shears, interstorey drifts and displacements of the different models. The study shows that using of base isolation would lead to increasing the time period of investigated models. Moreover, it would lead to reduce base shear and interstory drift. On the other hand, using base isolation increases the lateral displacement at the lowest floor (floor above the location of BI device), while it is decreased drastically as moving to the top floors. As a result, base isolation may be considered as effective seismic response control device for vertical irregular buildings as well as regular buildings.

Key Word*:* *Base isolation, Fixed base, Vertical irregular building.*

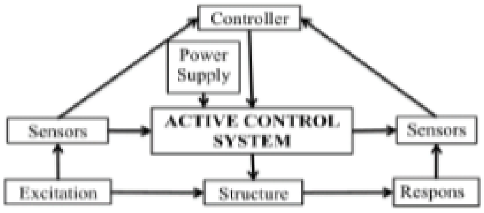
Date of Submission: 11-07-2021 Date of Acceptance: 27-07-2021

I. Introduction

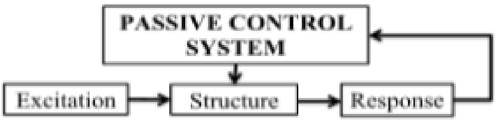
Seismic isolation is a design strategy that is based on changing the natural period of the structure by decoupling a structure from the ground motion to reduce the resulting inertial force. There are two basic seismic isolation systems; active and passive control systems, as shown in Fig. 1. Other seismic control systems, such as hybrid and semi-active are not addressed herein. Active control systems require a power supply to activate the dampers during seismic events, where the power supply could be disrupted during seismic events. For this reason, dampers with active control systems have been employed on tall buildings subjected to wind induced loading rather than the more unpredictable cyclic loading caused by earthquakes. On the other hand, passive energy dissipation systems have emerged as special devices that are incorporated within the structure to absorb the energy. The idea of utilizing separate passive energy dissipating devices within a structure to absorb a large portion of the seismic energy began with conceptual and experimental work of Kelly et al. Fig. 2 illustrates the simple concept of base isolation. The devices of passive control systems can be located either at the foundation of structure (called Seismic Isolation) or throughout the height of the structure (called Supplemental Damping Systems). An overview of passive control systems is introduced in Fig. 3. Any seismic isolation systems have three basic elements as follows:

1. A Flexible mounting (support) to elongate the period of vibration of the total system in order to shift the structural period zone away from the highest response spectrum ordinate of the incoming seismic waves; hence; to reduce the force response.
2. Some kind of energy dissipation such that the relative deflections between the building and its foundation can be controlled to practical design level.
3. A means of providing rigidity under horizontal loads such as wind or earthquake.

Elastomeric bearing systems represent common means for introducing the flexibility to isolated structures by consisting of thin layers of rubber that are bonded to steel plates as shown in Fig. 4. Lead Rubber Bearing, LRB is one of elastomeric bearing system that will be investigated in the present research. LRB consists of low damping natural rubber with central hole. A lead core is pressed and fitted into the hole as shown in Fig. 5. This lead core deforms in almost pure shear and yields at low levels of shear stress that produces stable hysteretic behavior over number of cycles. When used as an isolation system, LRB exhibit characteristic strength that assures rigidity under earthquake and wind loads. In the present research, finite element program, ETABS, with time history analysis is employed to investigate the behavior of base isolated structures. Seven-time history records are used as recommended in ECL 201-2011.



a. Active Control System



Passive Control System

Fig. 1 Flow Charts of Active and Passive Control

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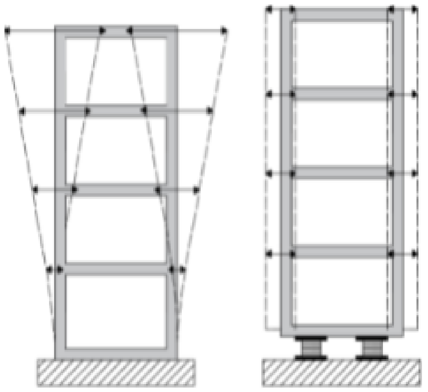


a. Fixed base b. Base isolated

Fig. 2 The Concept of Base Isolation

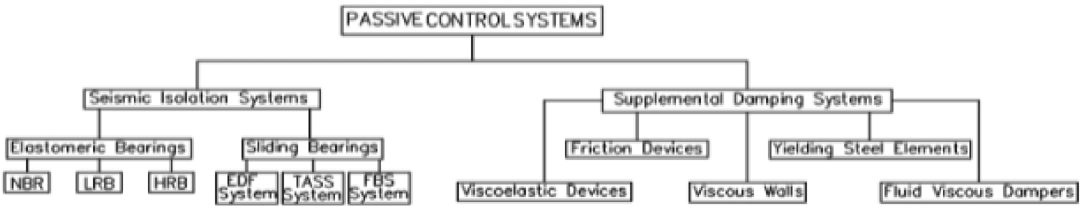


Fig. 3 An Overview of Passive Control System

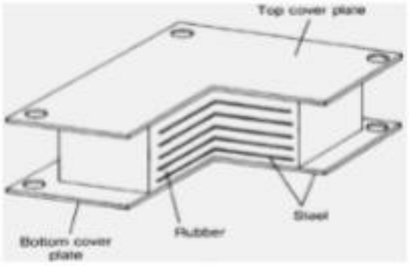


Fig. 4 Construction of Elastomeric Bearing

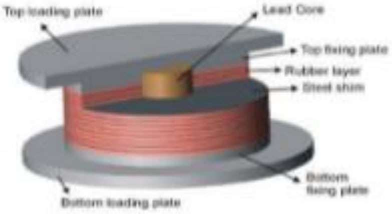


Fig. 5 Lead-Rubber Bearing

Vertical Irregular Buildings

Irregularities in structures result in non-uniform response of a structure due to non-uniform distribution of structural properties. Vertical irregularity typically refers to the uneven distribution of mass along the height of a multi-story structure, sudden change of mass or stiffness or strength of structure. Sudden geometrical change (set-backs) of floor plan between subsequent floors would lead to also to vertical irregularity. Fig. 5 shows types of vertical irregularity, as defined in ECL201-2011. During a seismic event, vertical irregularity in buildings may lead to soft story mechanism. Plan irregularity typically refers to the uneven distribution of stiffness, mass or strength in the plan of a structure resulting in unaccounted distribution of torsional response of the structure when subjected to a seismic excitation.

II. Methodology

Computer software ETABS is used to conduct dynamic time history analysis for different models. The program incorporates features for nonlinear modelling of structural components, as well as base isolators. The beams and columns are represented by frame elements with material properties for concrete and reinforcement. The isolation system, Lead Rubber Bearing system, is simulated by the rubber isolator links, with appropriate design properties. The employed buildings are modelled as regular or vertical irregular supported on a fixed base configuration or base-isolated configuration. Seven input ground motions with different characteristics are applied in X direction of the structure. Gravity (dead and live) loads and seismic loads are determined based on the ECL201-2011.

III. Modelling and Analysis of Structures

- **Description of Buildings**

Four models A, B, C and D are studied in the present research. Each model represents R.C. moment resisting frame with 13 floors; the building is intended to be of high importance as a healthy facility (hospital). Each model has ground story height 3.5 m and typical story height of 3m. The frame consists of columns with dimensions 0.6mx0.6m, beams with dimensions 0.3mx0.6m and slabs with thickness 0.15m. For analysis requirements, the characteristic strength of concrete is assumed to be 30 MPa and yield strength of steel is assumed to be 360 MPa. For Loading data, live loads, floor finish and wall loads are assumed to be 0.3 t/m2, 0.2 t/m2 and 0.7 t /m, respectively. Model A represents a regular building with fixed base as shown in Figs.6 and 8. Model B has the same superstructure as that of model A; whereas; the base isolation devices are introduced as shown in Fig. 10. Model C

represents vertical irregular building with fixed base as shown in Figs. 6, 7 and 9. Model D has the same superstructure as that of model C; whereas; the base isolation devices are introduced as shown in Fig. 10. Table 1 presents the seismic data required for analysis.

- **Time History Analysis**

Step-by-Step nonlinear dynamic time history analysis has been employed to evaluate seismic performance. In present analysis, seven-time history records are used, as recommended by ECL201-2011. Table 2 presents the characteristics of ground motion used: earthquake component, date, soil type, magnitude M, PGA, PGV and a/v ratio; a/v ratio is the ratio of peak ground acceleration to peak ground velocity. The used ground motions are classified as L (Low), M (Medium) and H (High) according to their frequency content. These records are downloaded from pacific earthquake engineering center website (PEER2000).

- **Lead Rubber Bearings**

The laminated rubber bearing (LRB) is the most commonly used base isolation system. The basic components of LRB system are alternate layers of built in steel and rubber plates. The dominant features of LRB system are dual actions of linear spring and damping. Generally, the LRB system exhibits high-damping capacity, horizontal flexibility and high vertical stiffness. The equivalent viscous of LRB is a design variable that depends on the diameter of the lead core. It is typically varying from 15% to 35% of diameter of LRB. The system operates by decoupling the structure from the horizontal components of earthquake ground motion by interposing a layer of low horizontal stiffness between structure and foundation. Table 3 present the characteristic of LRB used in that research.

Table no1 Seismic data required for analysis

No	Parameter	Values as per ECP201-2011
1	Seismic zone	3
2	Reduction Factor (R)	5
3	Importance Factor(I)	1.4
4	Soil Type	C
5	Damping Ratio	5%

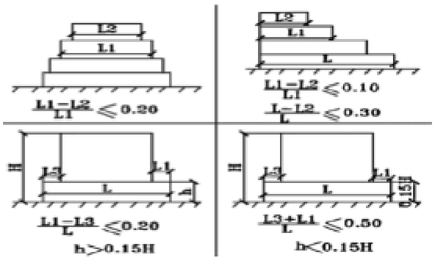


Fig. 5 Types of Vertical Irregularity (set-backs)

Table no2 Characteristic of the selected ground motions

NO	Record ID	Earthquake/ Component	Date	M	Soil type	PGA (g)	PGV (m/s)	a/v ratio	Frequency Content
1	P0030	Parkfield / PARKF/C02065	28/06/1966	6.1	Deep braod	0.477	75.1	0.63	L
2	P0993	Northridge / NORTHR/STC180	17/01/1994	6.7	Deep braod	0.477	61.5	0.78	L
3	P0449	Morgan Hill / MORGAN/CYC285	24/04/1984	6.2	Rock	1.298	80.8	1.61	H
4	P0082	San Femando / SFERN/PCD164	09/02/1971	6.6	Shallow stiff	1.226	112.5	1.09	M
5	P0934	Northridge / NORTHR/SYL360	17/01/1994	6.7	Deep braod	0.843	129.6	0.65	L
6	P1056	Kobe / KOBE/TAZ000	16/01/1995	6.9	Soft deep	0.693	68.3	1.01	M
7	P0890	Northridge / NORTHR/MUL279	17/01/1994	6.7	Deep narrow	0.516	62.8	0.82	M

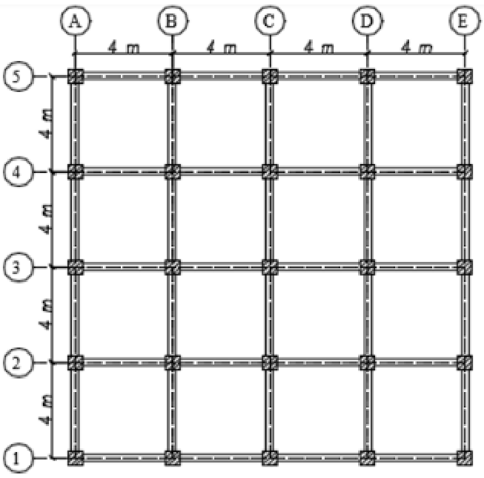


Fig. 6 Plans of Models A, B, C (for floors from 1 to 7) and D (for floors from 1 to 7)

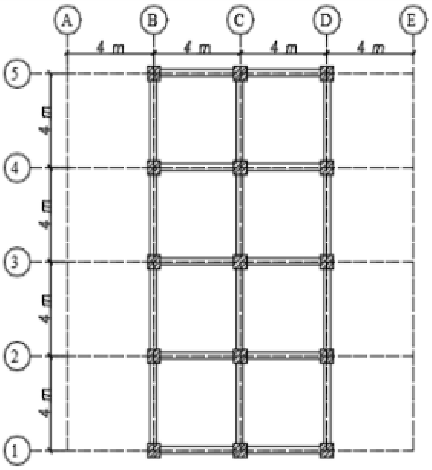


Fig. 7 Plans of Models C and D (for floors from 8 to 13)

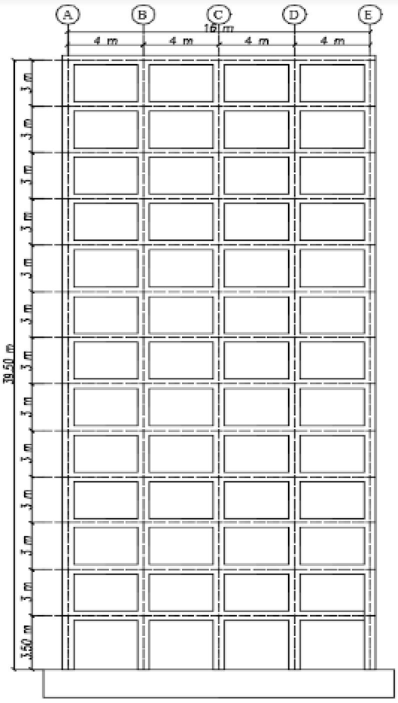


Fig.8 Elevation of Models A, B

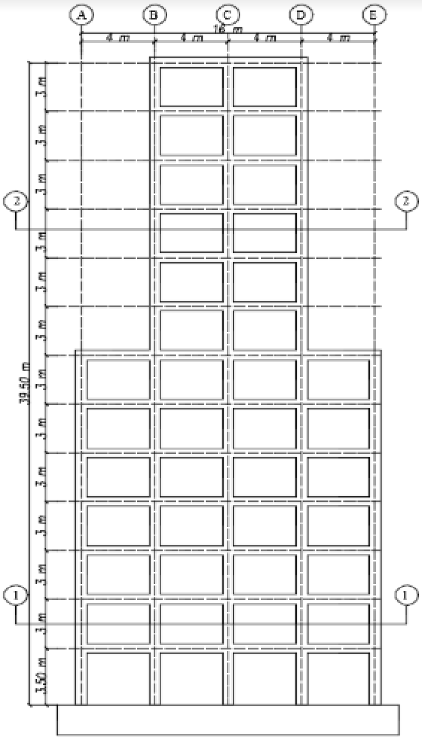
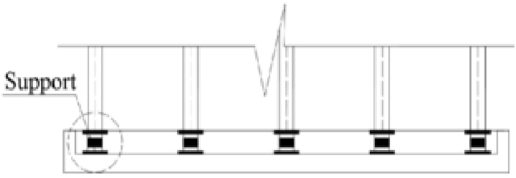


Fig. 9 Elevation of Models C, D



a. Foundation in case of model B and D

Fig. 10 Foundation in Case of Base isolation

Table no3 Design of lead rubber bearing

No.	LRB Parameter	Horizontal stiffness (Kh) tonf/m	Vertical Stiffness (Kv) tonf/m
1.	Regular Building(model B)	62.34	30514.5
2.	Vertical Irregular Building (Model D)	109.15	66075

IV. Result

4.1 Time Period

The basic idea of base isolation is to shift the fundamental time period of the structure away from the highest response spectrum ordinate of the incoming seismic waves. Fig. 11 shows the mode shapes for fundamental time period in the four models. Periods of first 13 vibration mode shapes for the investigated models are presented in Table 4. For these models, time periods increase with ratio from 1.24 to 2.2 times of that of regular models as presented in Table 4a. Time periods also increase from 1.24 to 2.3 times of that of vertical irregular models as presented in Table 4b. Hence it could be concluded that, base isolation elongates the fundamental time period of the structure by almost 1.25 to 2.25 times for original value. On the other hand, by comparing the fundamental time periods of models A and C; it can be deduced that the fundamental period of irregular structure (model C) is less than that of regular structure (Model A) by almost 20%.

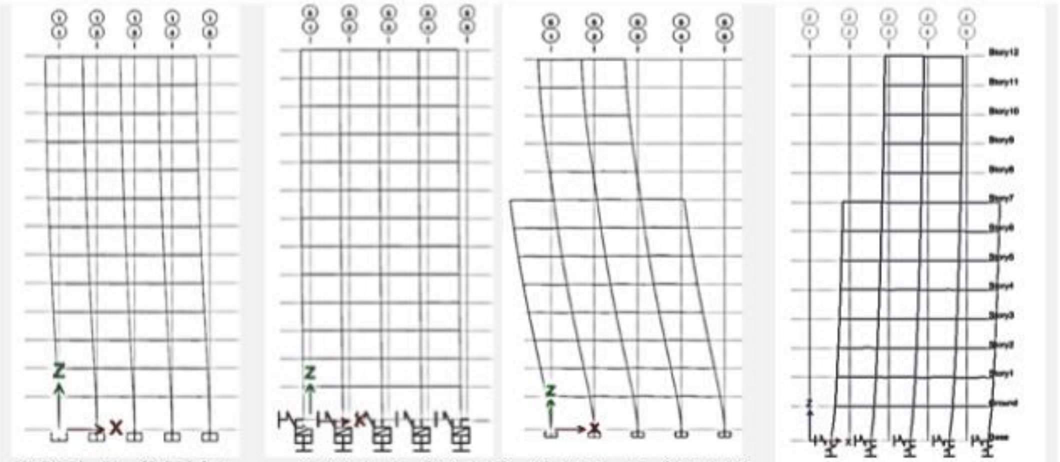
Table no4 Comparison between Time Periods of the first 13 Mode of shapes

a. Regular models

Mode No.	Model A, TA, s	Model B, TB, s	Ratio of Increment (TB/TA)
1	1.861	4.083	2.2
2	1.861	4.083	2.2
3	1.432	3.586	2.09
4	0.604	0.956	1.56
5	0.604	0.956	1.56
6	0.343	0.451	1.29
7	0.343	0.451	1.29
8	0.233	0.292	1.24
9	0.233	0.292	1.24
10	0.163	0.205	1.25
11	0.163	0.205	1.25
12	0.096	0.135	1.4
13	0.096	0.135	1.4

b. Vertical Irregular models

Mode No.	Model C, TC, s	Model D, TD, s	Ratio of Increment (TD/TC)
1	1.536	3	2.3
2	1.526	2.999	2.28
3	0.65	2.474	2.09
4	0.614	0.904	1.56
5	0.337	0.873	1.56
6	0.326	0.476	1.29
7	0.235	0.45	1.29
8	0.227	0.285	1.24
9	0.169	0.277	1.24
10	0.161	0.211	1.25
11	0.12	0.206	1.25
12	0.093	0.136	1.4
13	0.076	0.134	1.4



(1) Mode #1 of Model A T=1.861 s

(2) Mode #1 of Model B T=4.083 s

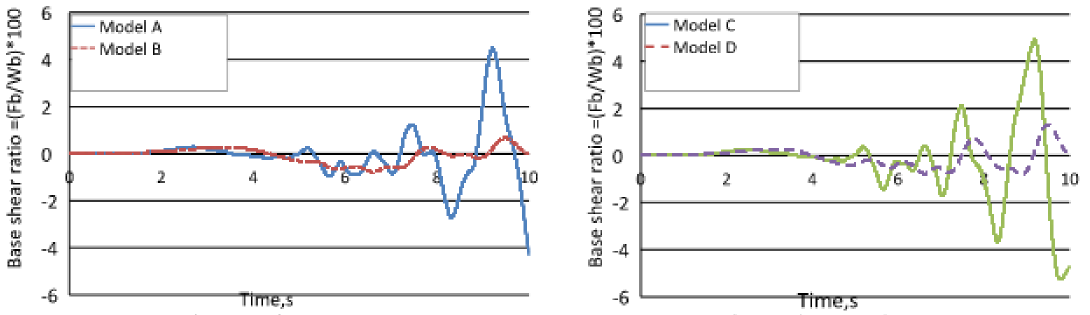
(3) Mode #1 of Model C T=1.536 s

(4) Mode #1 of Model D T=3 s

Fig. 11 Mode Shapes of Fundamental Time Periods

4.2 Base Shear

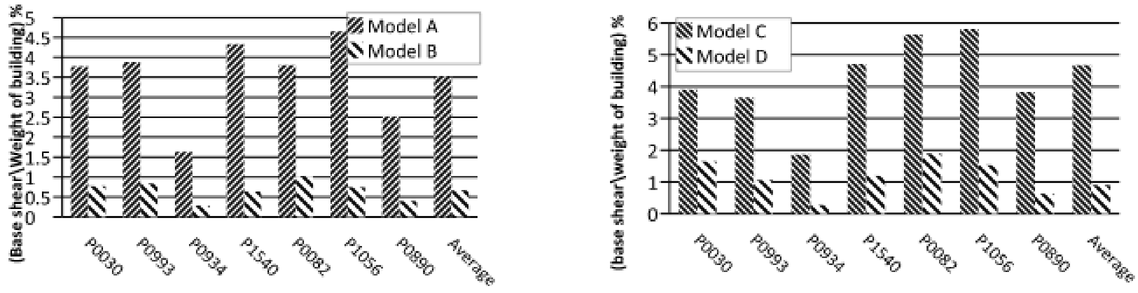
Base shear is an estimation of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure. The study investigated the effect of base shear of seven-time history records on the investigated models. Fig. 12 shows that, time history of base isolated of different models when subjected to ground motion P1056; base shear is represented as ratio of weight of building. It is observed that ratio of maximum base shear is greatly reduced by almost 75% when using base isolation techniques for all investigated models. The investigated models when subjected to the selected ground motions (not shown) show similar behavior of reduction of maximum base shear to that presented in Fig. 12. For convince, the peak base shear of all investigated models subjected to the seven ground motions are presented in Fig. 13 as bar chart. In addition, Fig. 13 includes an average estimation of peak base shear for all investigated ground motions. From Fig. 13, it is observed that maximum base shear is decreased by almost 80% in regular and vertical irregular buildings when using base isolation devices. Fig. 14 shows accumulated average peak shear along height for different models when subjected to different earthquake ground motions. Hence, it could conclude that base isolation configuration is very effective in reducing the base shear as compared to conventional structure. On the other hand, by comparing the peak of average base shear of model A and C; it can be deduced that the peak of average base shear of model C is less than that of regular structure (model A) by almost 10%.



Regular Models Vs P1056

Vertical Irregular Models Vs P1056

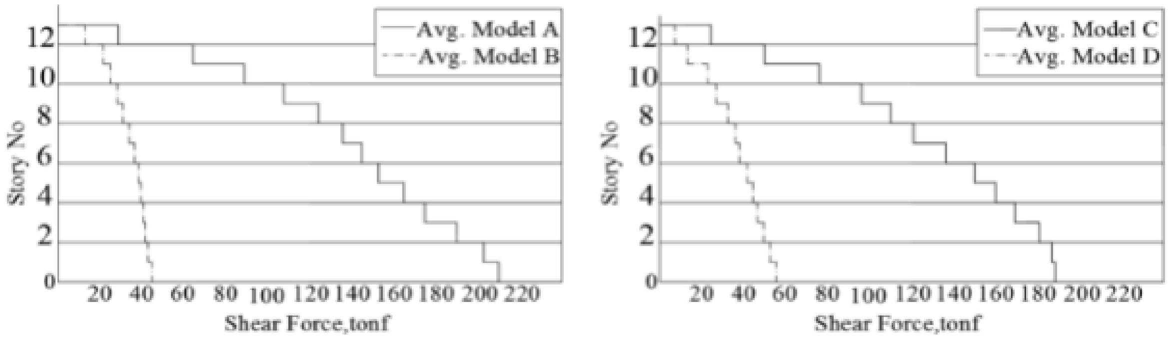
Fig. 12 Time history P1056 of base shear ratio for different models



a.Regular Models Vs Time Histories

b.Vertical Irregular Models Vs Time Histories

Fig. 13 Base shear of time histories for different models



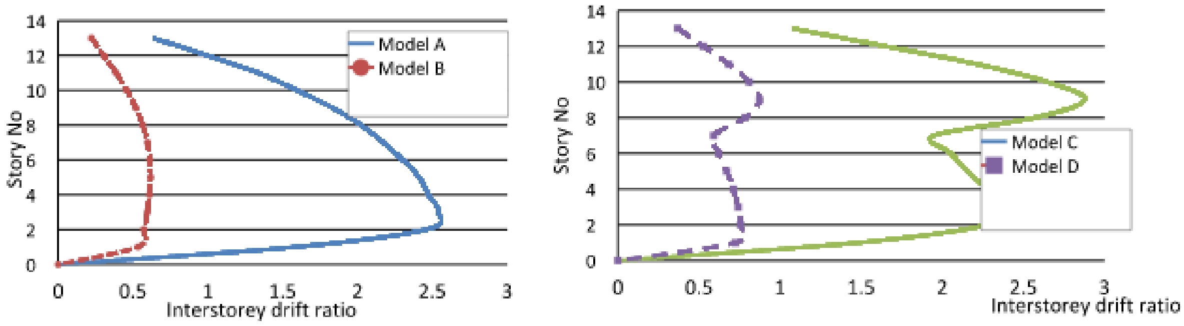
a.Regular Models Vs Accumulated Shear

b.Vertical Irregular Models Vs Accumulated Shear

Fig. 14 Accumulated average peak shear along height for different models

4.3 Interstory Drift

Maximum interstory drifts along height of fixed base and base isolated building are shown in Fig. 15. Fig. 15a shows that, by comparing the interstory drift of models A and B; it can be deduced that the peak interstory drift is reduced by almost 75%. Similarly, 70% reeducation of peak interstory drift is expected when comparing models C and D (Fig. 15b). Fig. 15 shows by using BI devices, peak interstory drift would usual occur in the lower zone of middle third of height of building in regular models; whereas; interstory drift have two peaks in lower third and highest third of height of building in vertical irregular models. Fig. 15b denote that as if the vertical irregular models behave as two buildings above each other. On the other hand, by comparing interstory drift of models A and C; it can be deduced that the peak of interstory drift of model C is less than 10% on lowest floor and more than 60% on the top floor of that regular structure (model A).



a.Regular Buildings Vs Interstory drift

b.Vertical Irregular Buildings Vs Interstory drift

Fig. 15 Interstory drifts ratio along height for different models

4.4 Lateral Displacement

Maximum story displacement is represented by the ratio between peak story displacements to height of building. Fig. 16 shows the relationship between story displacement ratio and story number for all investigated models. Displacement ratio in model A increases steadily as the story height increased as presented in Fig. 16a. When using BI techniques, the rate of increase of displacement ratio is great in the ground story (story above the location of BI device). On the other hand, the rate of increase of displacement ratio in upper floors is greatly depressed as the story height increased. By comparing models, A and B, it can be deduced that story displacement ratio in model B is higher in the ground story than that of regular structure (model A). Whereas, story displacement ratio in model B in the upper stories are less than that regular structure (model A). Similarly, the comparing between models C and D is the same comparing between models A and C. on the other hand, by comparing models A and C it can be deduced that the peak story displacement ratio of model C is more than three times of that regular structure.

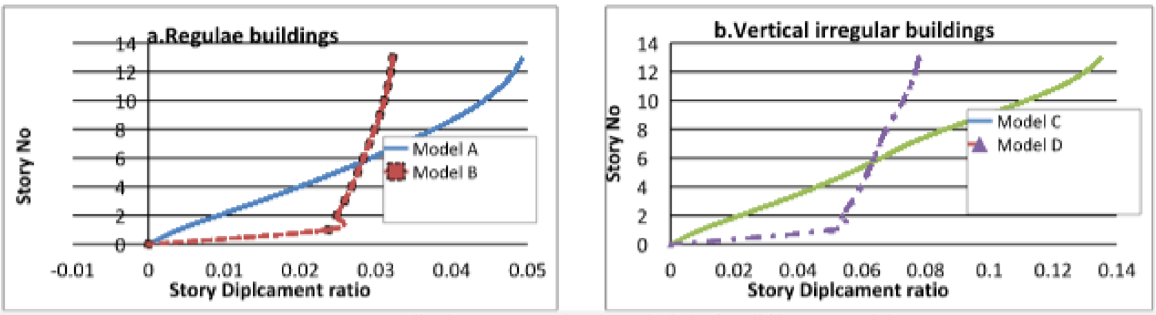


Fig. 16 Story displacement ratio along height for different models

V. Discussion &Conclusion

The Study is limited to the investigated models. According to the investigation study; the following conclusions can be drawn:

- Installing BI devices would increase the fundamental period by almost from 1.25 to 2.25 times its original values for both regular and vertical irregular buildings.
- Installing BI devices in regular buildings and vertical irregular buildings would decrease the base shear by almost 80% for both types of buildings.

- Installing BI devices in regular buildings would lead to decrease interstory drift by 75% and 70% for regular buildings and vertical irregular buildings, respectively.
- Installing BI devices would lead to great increase of lateral displacement ratio in the lowest floor (floor above the location BI device); whereas; the rate of increase of displacement ratio in upper floors is greatly depressed as the story height increased for both regular buildings and vertical irregular buildings.
- In case of using vertical irregularity configuration in models, fundamental time period would decrease by 20%, base shear would increase by 10%, peak interstory drift would increase by 10% on lowest floor and decrease in higher floors by 60% and lateral displacement ratio would increase three times of that regular structure.

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Somia Saad Galalah. et. al. " Regular Versus Vertical Irregular R.C Buildings Using Base Isolation." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 18(4), 2021, pp. 26-33.