TIME HISTORY ANALYSIS OF IRREGULAR RC BASE ISOLATED STRUCTURE WITH AND WITHOUT MASONRY INFILL

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Abstract: This article presents an outline of the base isolation techniques with special emphasis for reducing earthquake forces on the structures. The effects of base isolation on structures are briefly discussed. Base isolation is an anti-seismic design strategy that can reduce the effect of earthquake ground motion by isolating the superstructure from the foundation. The important feature of the base isolation technique is that it introduces flexibility to the structure. In this present study, a G+9 storey RC irregular structure is considered and dynamic analysis has been carried out by Time History analysis using ETABS V15.1 software as per IS-1893:2002(Part-I). The lead rubber bearing is used as the seismic isolation device which is provided at the base of the structure and the masonry infills are modelled as compression diagonal struts which are assumed to be pin-jointed at both ends. Equivalent diagonal strut method was considered to design the masonry struts as per IS-1893:2016(Part-I). For the Time History analysis BHUJ earthquake ground motion records was considered. This present study tends to demonstrates how the structure efficiency can be influenced by providing seismic isolation system and how the masonry infills behave as a constituent part of the structural system in seismic events. The performance of building will be evaluated on the basis of seismic parameters like storey displacement, time period, inter-storey drifts and base shear.

IndexTerms **-** Base isolation (BI), Lead rubber bearing (LRB), Masonry Infills (MI), ETABS, Isolated base (IB), Fixed base (FB), Fixed base with masonry infill (FBMI), Isolated base with masonry infill (IBMI)

I. INTRODUCTION

The conventional method of design of earthquake resistant structures is built on the idea that increasing the capacity of seismic resistance of a structure by using, for example, braced frames, shear walls or moment-resistant frames. Yet, these old design methods often give rise to high floor accelerations in rigid buildings and high interstory drifts in case of flexible buildings. Even though structure is intact, because of this the structural & non-structural components in the building get damaged during earthquake. This is not tolerable for the buildings where components are costlier than the structure itself. High-precision production facilities are one of the example of buildings that comprise very sensitive and costly equipment. Also, police and fire stations, hospitals and telecommunication centres are the type of facilities that may hold valuable tools & must remain operational straightaway after earthquake.

In order to reduce inter-story drift, furthermore to reduce floor accelerations, the notion of base isolation is being implemented. Base isolation technique is also referred as passive control system, where the structural movements are not controlled by any external agency, but somewhat through a specifically designed interface within the structure or at the base of the structure, which be able to reduce the seismic forces transmitting to the structure from the ground. Whereas the active control techniques, which are still under research and development for the seismic resistance of structures and they need of installing of several logically controlled external agencies like actuators, to lessen the structural movements. One downside of these systems is the relatively high maintenance cost of control systems and the actuators, which are to be working at all-time in order to respond to any seismic events. There is also a third type of techniques, known as hybrid control techniques, which utilize the best of both active and passive control systems.

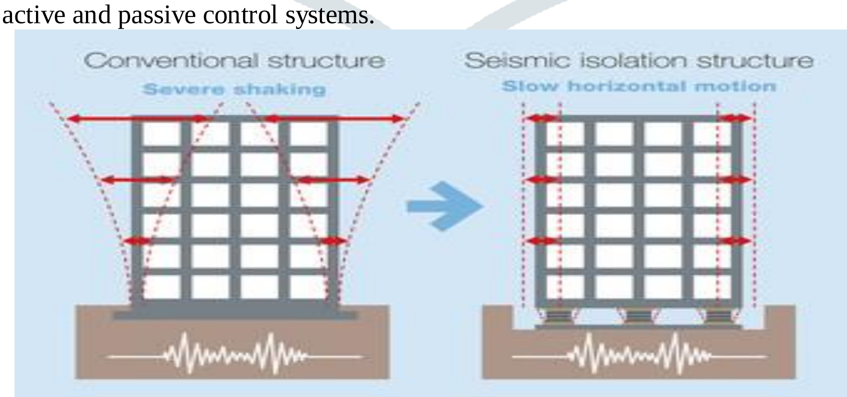


Fig.1: Effects of Seismic Isolation

The effect of base isolation can be achieved by installing certain devices between the foundation and the structure, to reduce the movement of building from that of the ground by making them separated. In general there are two basic approaches to base isolation, which have some common features.

One of the approaches is to set up the bearings of high vertical stiffness but with relatively low horizontal stiffness, between foundation and the structure. Such devices, increases the natural time period of the structure and swings away from the predominant high frequency range of the earthquake forces. The other approach is to provide a friction or sliding surface between the structure & its foundation to increase the flexibility of the structure. The transmission of shear force to the superstructure across the isolation boundary is restricted by the static friction force.

II. OBJECTIVE OF THE STUDY

The main objective of the present study is to assess the seismic response of 3D irregular RC residential building of 10 storey for both fixed base and base isolated (using Lead Rubber Bearing isolator) condition also with & without the presence of masonry infill's for earthquake zones III, IV&V.

The overall objectives of the present study are as follows:

- ❖ To carry out modeling and finite element analysis of fixed base and base isolated irregular building with & without the presence of masonry infills by using ETABS Version -15.1 software and study the effect of seismic forces on these models.
- ❖ To design and study the effectiveness of lead rubber bearing isolator used as seismic isolation system for the structures.
- ❖ To know the influence of masonry infill wall panels in RC framed structures in terms of deformation.
- ❖ To study the behavior of frame with masonry infill panels by modeling the infill panel as a diagonal strut.IS: 1893-2016(part-I) method is used for modeling the strut.
- ❖ To determine the various dynamic response properties like storey shear, storey displacement, inter-story drift, storey acceleration for all the models.
- ❖ To carry out the comparison between fixed base and base isolated structure with & without the presence of masonry infills by Time History method on the basis of response properties like storey shear, storey displacement, inter-story drift, storey acceleration.

III. METHODOLOGY

The methodology followed to assess the seismic response of the structure is as follows:

- ❖ Conducting detailed discussion on previous research studies related to seismic analysis of structures with lead rubber bearing base isolation system and also on seismic analysis of structures with masonry infill modelled as a diagonal strut.
- ❖ To import the Architectural grid data of the structure into the ETABS software and modeling it.

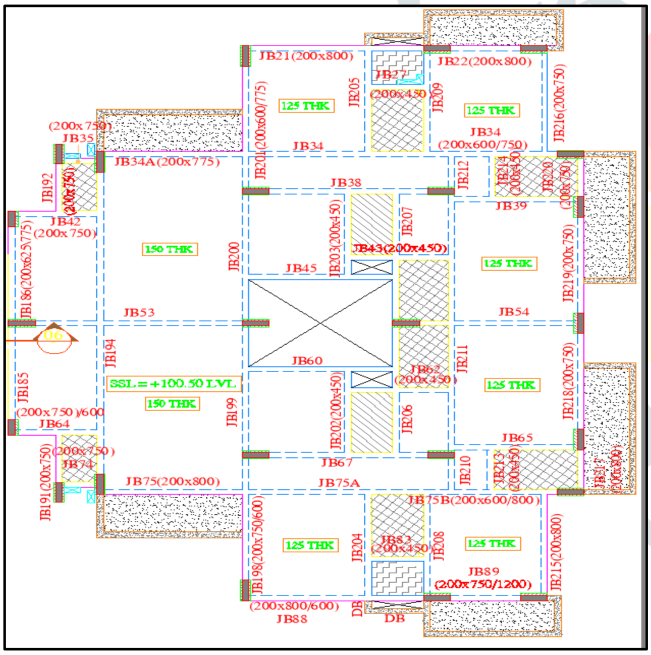


Fig.2: GA of Ground Floor Level

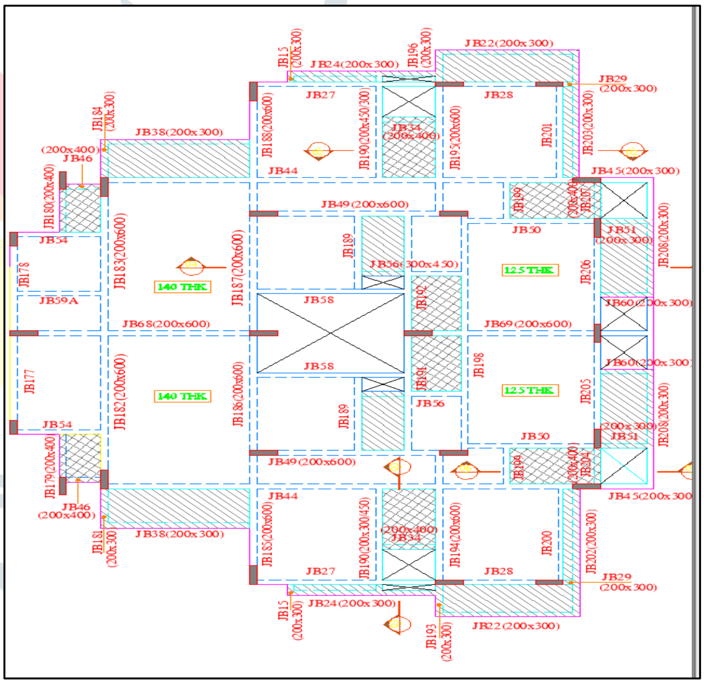


Fig. 3: GA of Remaining 9 Floors

- ❖ The masonry infill wall panels are modeled as a diagonal compression strut as per the specifications given in IS: 1893-2016(Part-I).

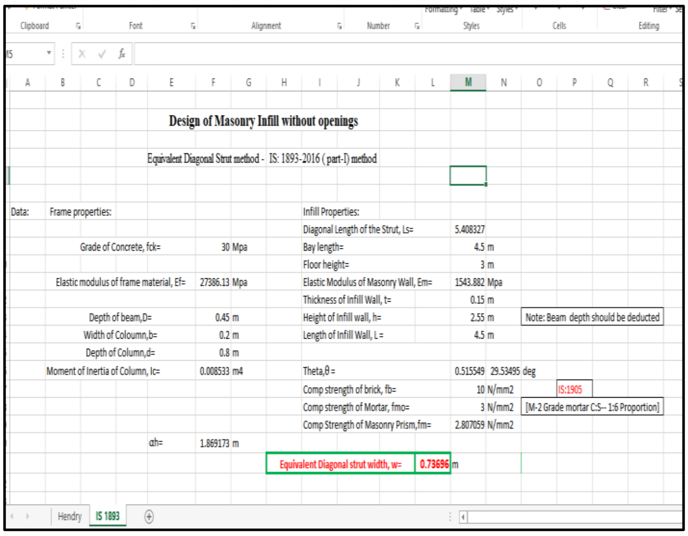


Fig.4: Excel Spread sheet for Determination of Strut width

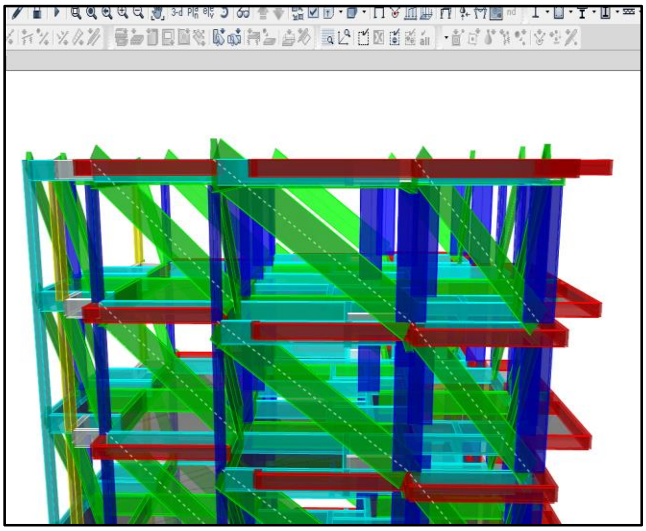


Fig.5: Modelling of Equivalent diagonal strut in ETABS

- ❖ After modeling, static analysis is carried out to determine the maximum vertical load (DL+LL) acting on the columns in a fixed base structure.
- ❖ The lead rubber bearing isolator is designed for the structure considering the maximum vertical load acting on the columns.

Table 1: Isolator Link Properties

Particulars	1) LRB_1	2) LRB_2	2) LRB_3	2) LRB_4
Axial Load (DL+LL), W =	2316.6 KN	2913.49 KN	4155.15 KN	5621.58 KN
Effective Horizontal Stiffness, K_{eff} =	1492.01 KN/m	1876.44 KN/m	2676.14 KN/m	3620.61 KN/m
Yield force, Q_d =	48.52 KN	61.02 KN	87.03 KN	117.75 KN
Post yield Horizontal Stiffness, K_d =	1257.62 KN/m	1581.65 KN/m	2255.72 KN/m	3051.81 KN/m
Effective Vertical Stiffness, K_V =	492886.8 KN/m	619882.9 KN/m	884062.2 KN/m	1196064 KN/m

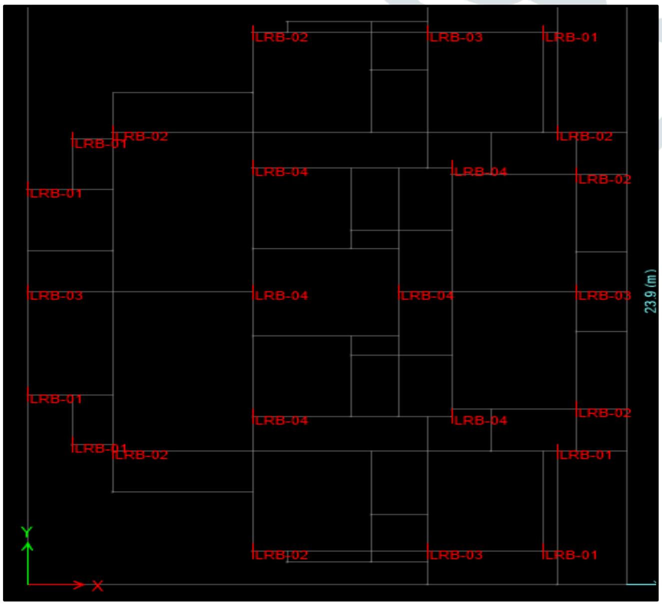


Fig.6: Top View of modeled isolators

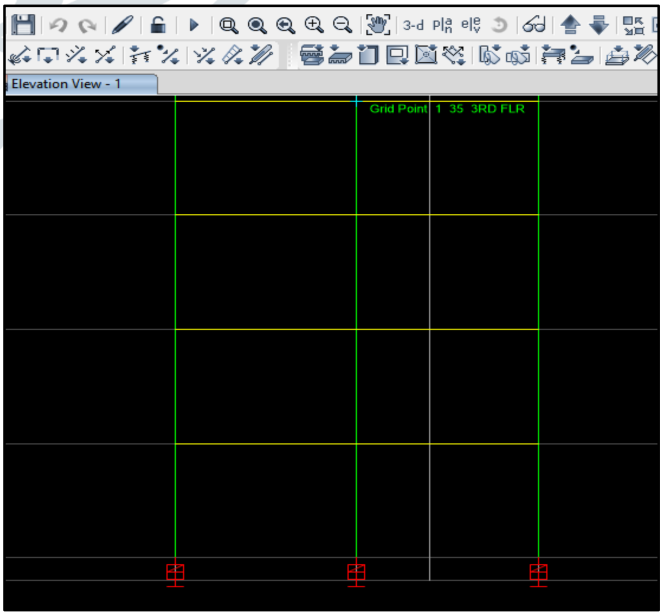


Fig.7: Isolator Elevation View

- ❖ Time history analysis is carried out for the models considering BHUJ (Gujarat, India) earthquake data and above mentioned response properties are determined as per IS: 1893-2002(Part-I).
- ❖ All the obtained results are tabulated, discussed and conclusions are drawn.

IV. Defining Time History Function

The effects of LRB isolator and masonry infill on the buildings in this present study are analyzed for a single ground motion data. The ground motion data selected for the purpose of analysis is of BHUJ earthquake with peak acceleration 0.106g which occurred on 26/01/2006.Details of the earthquake are given in table below.

Table 2: BHUJ Earthquake Details

Bhuj Earthquake	26-Jan-2006
TIME	08:46:42.9 I.S.T.
Station	Ahmedabad
Lat & Long	23 02 N, 72 38 E
Accelerogram Band pass filtered between	7/100 Hz and 27.0 Hz
Initial Velocity	-0.001411 m/s
Initial Displacement	3.970 mm
Peak Acceleration	-1.0382 m/s^2 at 46.940 sec

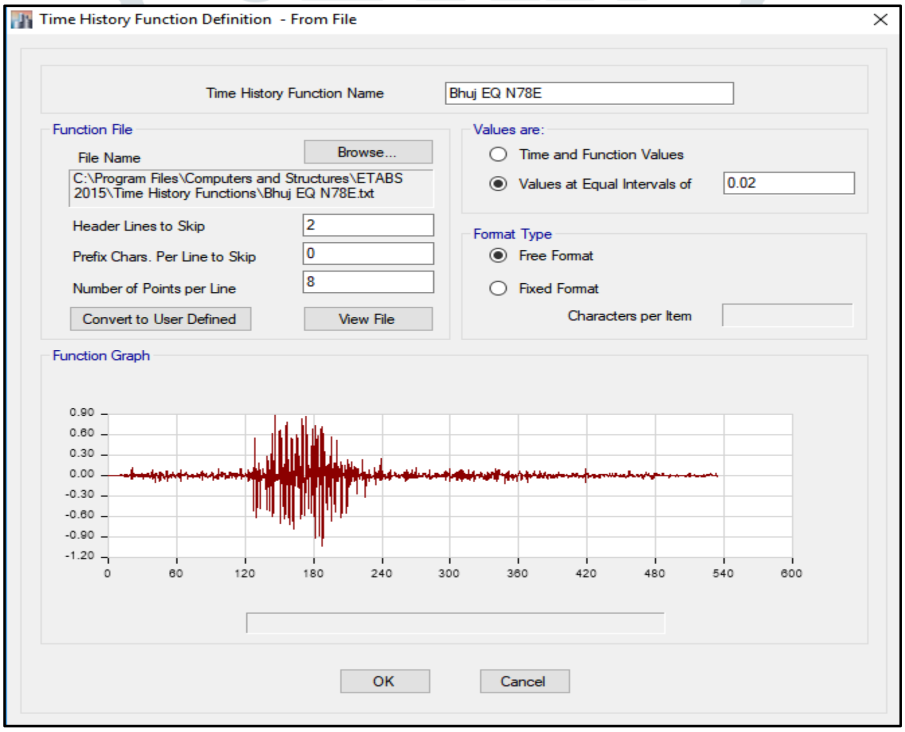


Fig.8: Time History Acceleration of BHUJ Earthquake

The types of models considered for this present study are as follows-

- **Model - 1:** RC Bare frame with fixed base and without masonry infill **(FB)**
- **Model - 2:** RC Bare frame with isolated base and without masonry infill **(IB)**
- **Model - 3:** RC Bare frame with fixed base and with masonry infill **(FBMI)**
- **Model - 4:** RC Bare frame with isolated base and with masonry infill **(IBMI)**

V. RESULTS AND DISCUSSION

❖ MODAL ANALYSIS

NATURAL FREQUENCY

It is a function of mass and the stiffness of the structure, where it can change with respect to building configurations which includes irregularity, due to adaptation of seismic isolation system and several other factors. The natural frequency of all the four building models are determined by conducting modal analysis using the software and are tabulated below.

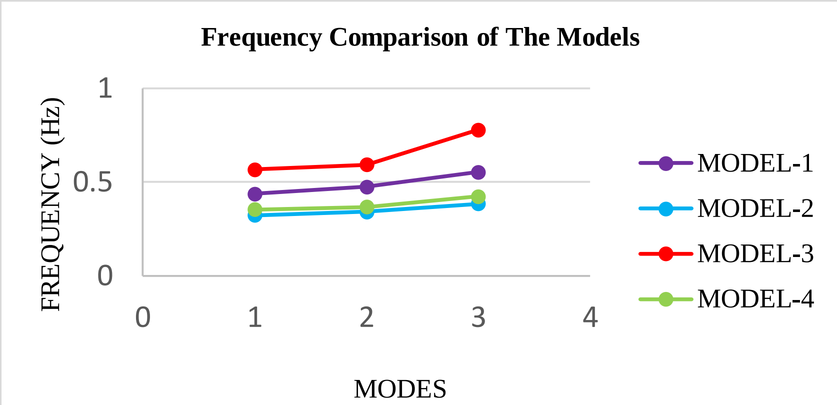


Fig.9: Comparison of Frequency Values of Different Models

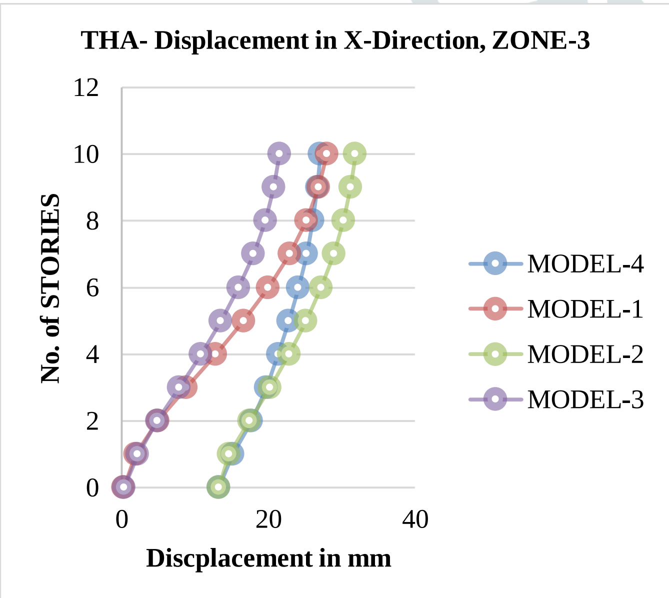
The natural frequency of a building is a function of both mass of the structure and the stiffness, it can be noted that as the stiffness of the structure tends to increase the frequency values also increase. By studying the variation of natural frequency values of all the models with respect to models it can be concluded that the for a structure provided with lead rubber bearing isolator as seismic isolation system the frequency tends to decrease.

For an LRB isolated building the frequency values was found to be decreased by 26.1% than that of fixed base building. The masonry infill which is modelled in fixed base structure tends to add stiffness to the structure and the frequency is increased by 29.8% compared to fixed base structure without masonry infill's. The frequency was found to be increased by 19.2% for the structure with LRB isolator and with masonry infill compared to fixed base structure without any infills but the time period in LRB isolated building with masonry infill was increased by 9.3% due to added stiffness to the frame structure compared to structure without infill's.

❖ TIME HISTORY ANALYSIS

DISPLACEMENT

a) ZONE-3



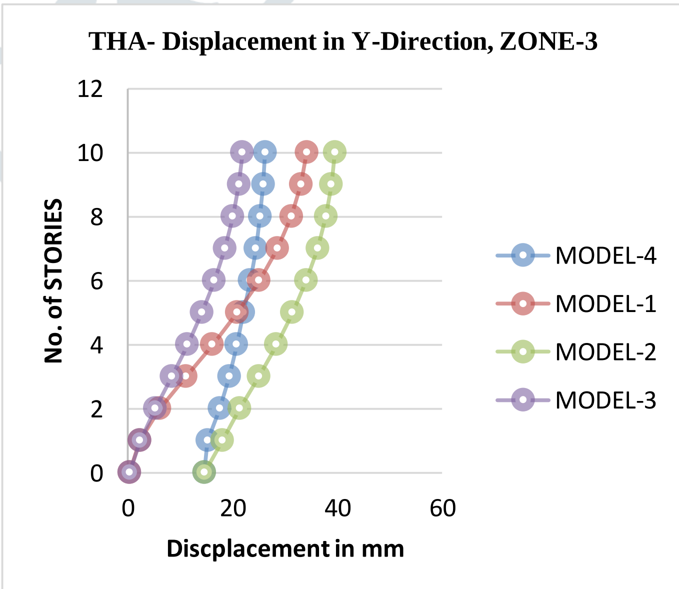


Fig.10: Comparison of Storey Displacement of different models in X & Y Direction, Zone-3

b) ZONE-4

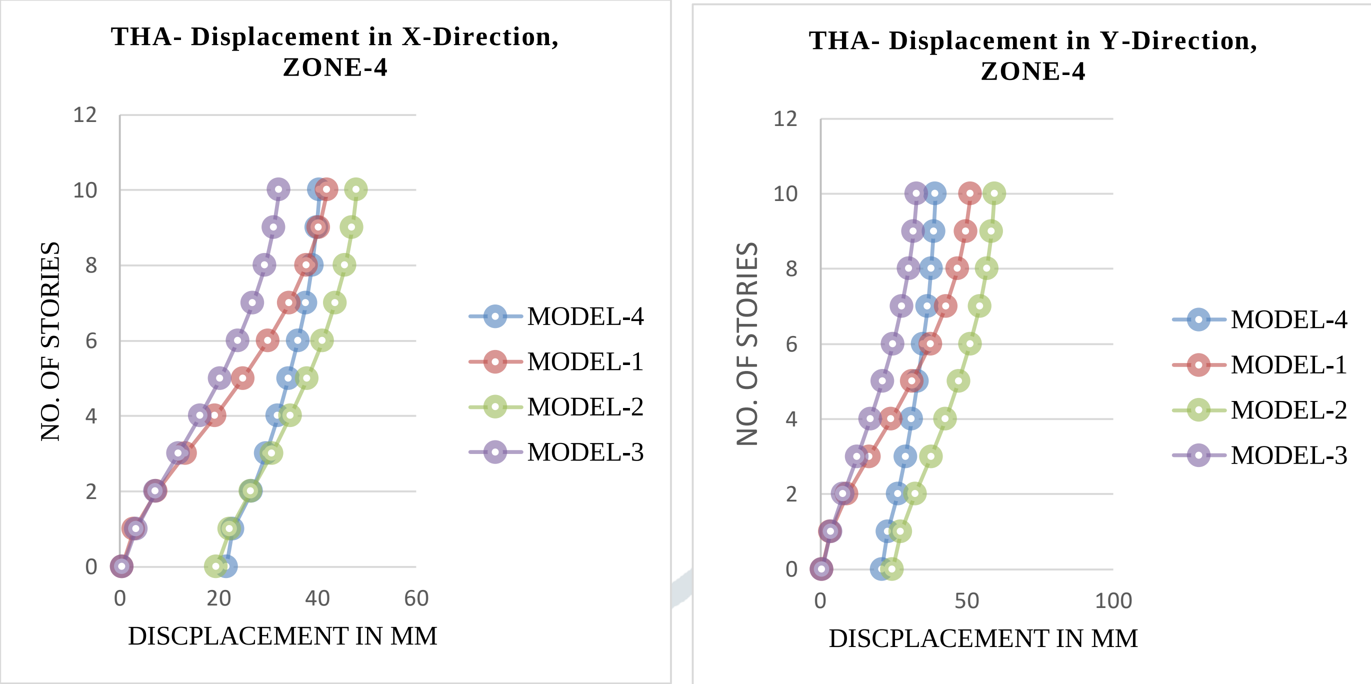


Fig.11: Comparison of Storey Displacement of different models in X & Y Direction, Zone-4

c) ZONE-5

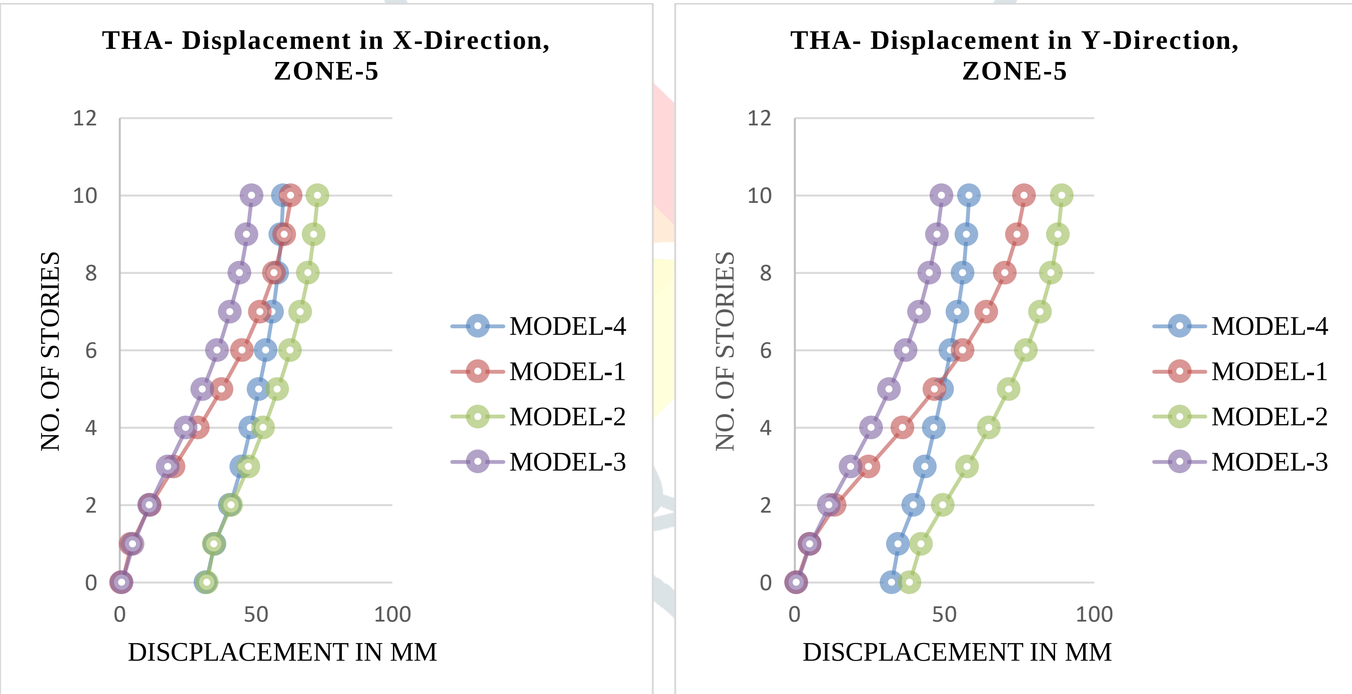


Fig.12: Comparison of Storey Displacement of different models in X & Y Direction, Zone-5

Discussions

The Time History analysis was carried out by considering Bhuj earthquake ground motion data. The earthquake forces were applied in both x & y direction, since the structure considered is having both vertical and plan irregularities the displacement of top floor will be different in both the directions.

In Zone-3 referring to Fig. -10, there was a reduction of 23.06% in x-direction and 35.83% in y-direction in top floor displacement of fixed base (FB) structure with masonry infill compared to FB structure without infill. Accordingly there was a reduction of 27.54% in x-direction and 46.25% in y-direction in structure having base isolator and masonry infill compared to structure with only the base isolator. In other zones i.e. zone-4 and zone-5 the change in the percentage of the displacement is same but the displacement value tends to increase as the seismic zones increase. The displacement values was found to be more in base isolated structures compared to non-isolated structures.

STOREY DRIFT

a) ZONE-3

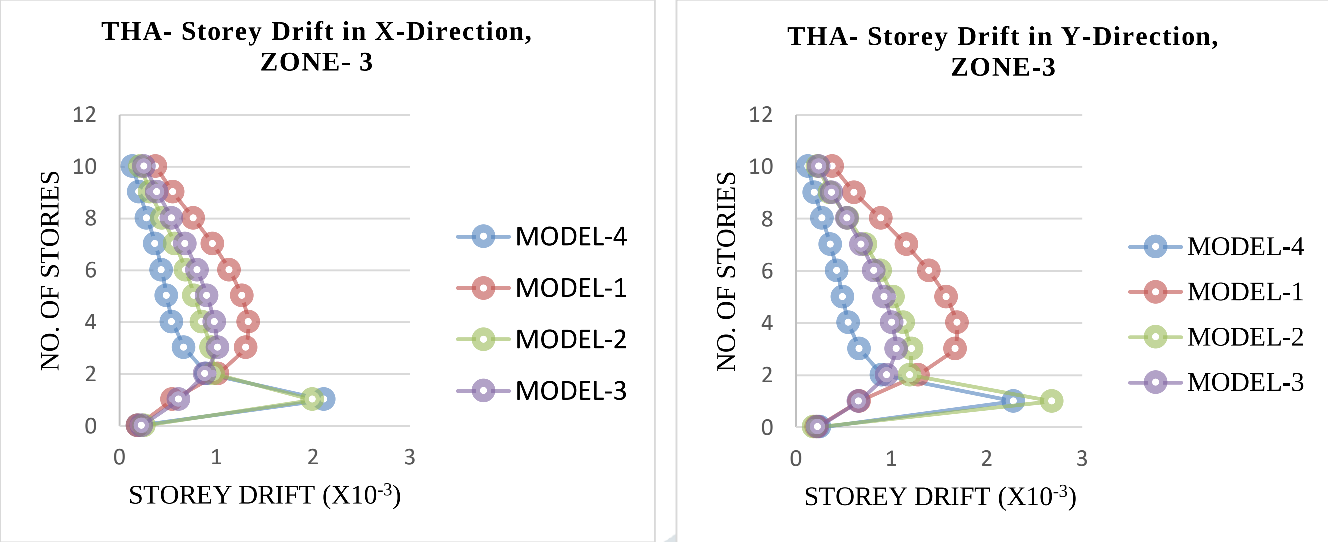


Fig.13: Comparison of Inter-Storey Drift of different models in X & Y Direction, Zone-3

b) ZONE-4

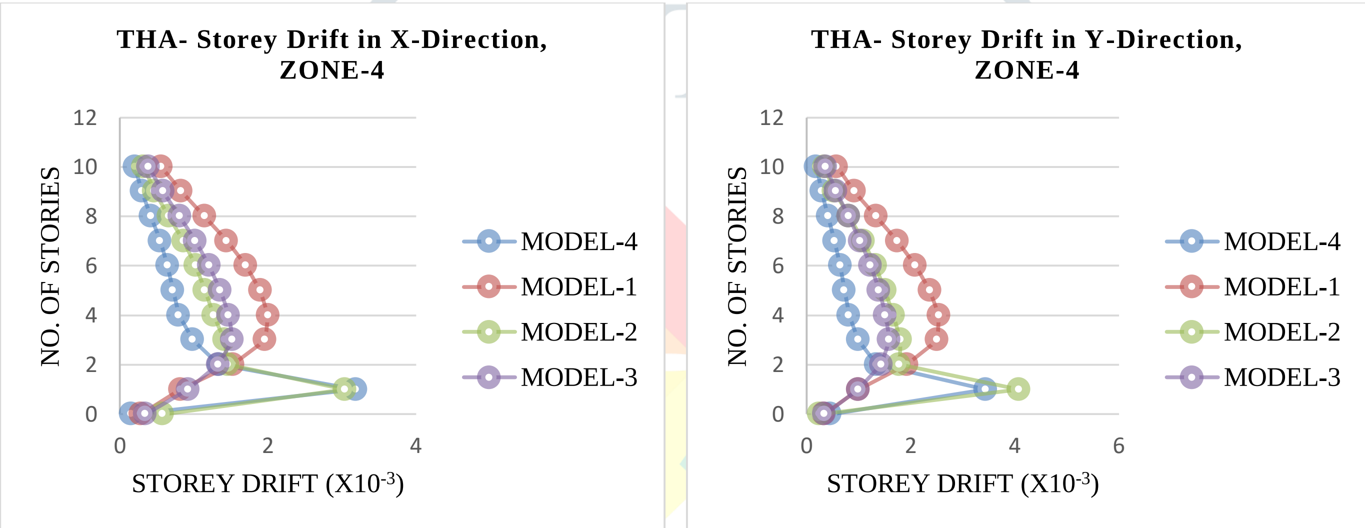


Fig.14: Comparison of Inter-Storey Drift of different models in X & Y Direction, Zone-4

c) ZONE-5

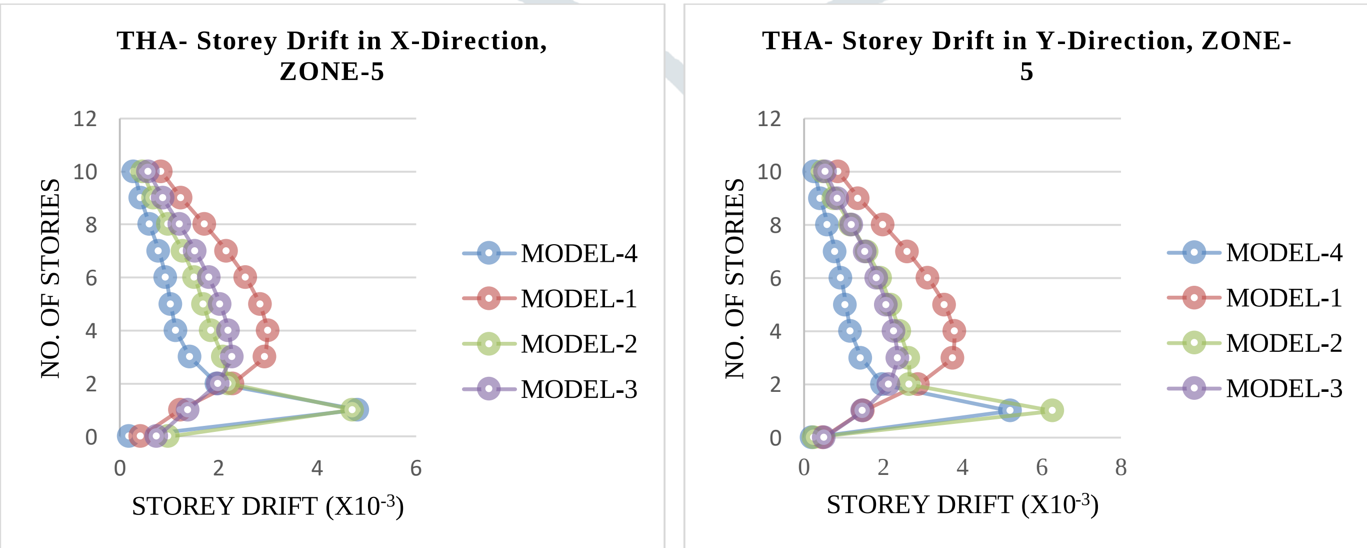


Fig.15: Comparison of Inter-Storey Drift of different models in X & Y Direction, Zone-5

Discussions

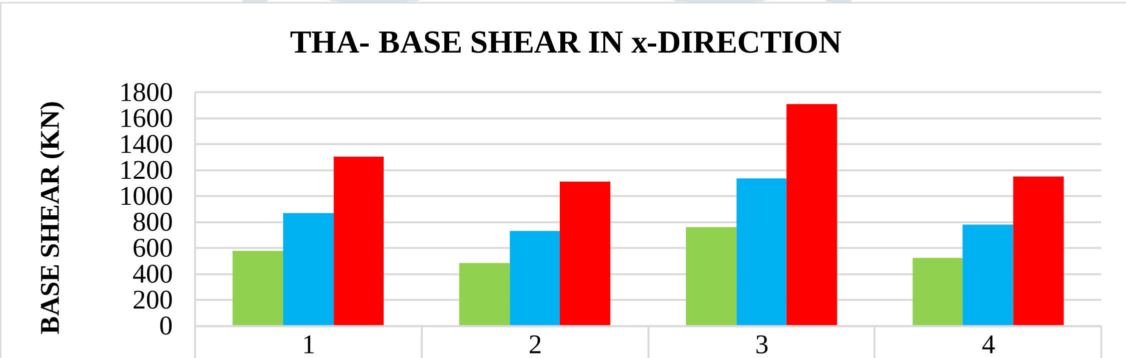
The storey drift is the difference in displacements of two consecutive stories which is divided by the height of the storey under consideration. In a moment resisting frame structure having low stiffness the storey drift will be high which may lead to numerous problems to structural and non-structural elements under seismic forces. Hence the inter-storey drift in building must be limited to possible extent and should comply with IS- 1893:2016(part-I) drift limitations (clause- 7.11.1.1) which suggests the drift values in any storey should be less than 0.004t the height of the storey under consideration.

In zone-3 (referring to Fig.-13), the inter-storey drift value was maximum of at 4th floor level in fixed base structure and was decreased by 24.1% in x-direction in fixed base structure with masonry infill at the same floor level. There was 28.23% reduction of storey drift in y-direction but was at the third storey level. In case of base isolated structure the storey drift values were more than that of non-isolated structures due to low horizontal stiffness of the LRB isolators. The presence of masonry infill gave additional stiffness for the frame structure which leads to lesser drift values than structures without masonry infill but in case of isolated structure storey drift was more in structure with masonry infill at the ground floor level. It was observed that a 5.9% increase in x-direction whereas there was 14.9% increase in drift in y-direction at ground floor level in isolated building with masonry infill compared to isolated structure without masonry infill's.

In zone-4 (Fig.-14), the storey drift was maximum at 4th storey level in fixed base structure without infill and tend to decrease by 24.1% in x-dir. & 36.7% in y-dir. compared to structure with masonry infill's. The storey drift in LRB isolated structure was maximum at ground floor level and the drift value was more than the structures without isolator. In x-dir there was 4.8% increase and 15.6% decrease in drift values in isolated structure with infill compared to isolated structure without infill.

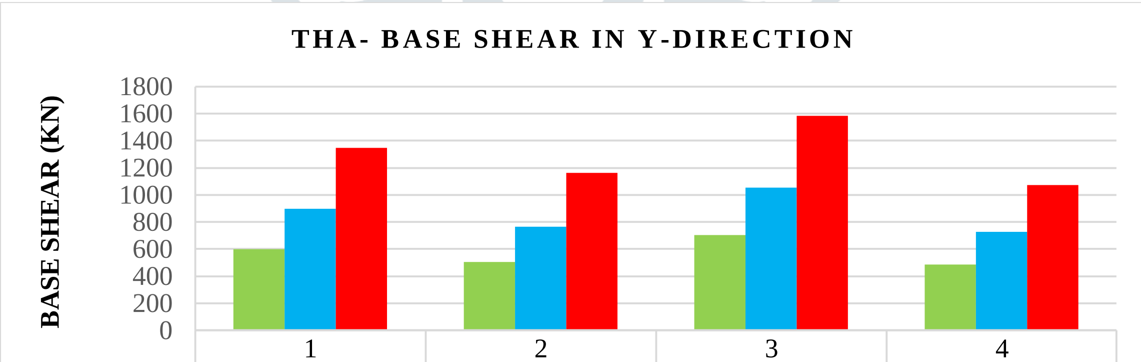
In zone-5 (Fig.-15), the storey drift was maximum at 4th storey level in fixed base structure without infill and tend to decrease by 24.1% in x-dir. & 37.5% in y-dir. compared to structure with masonry infill's. The storey drift in LRB isolated structure was maximum at ground floor level and the drift value was more than the structures without isolator. In x-dir there was 2.2% increase and 17.1% decrease in drift values in isolated structure with infill compared to isolated structure without infill.

BASE SHEAR



	1	2	3	4
ZONE- III	581.01	486.22	759.61	526.25
ZONE- IV	871.55	733.28	1139.36	782.19
ZONE- V	1307.1	1113.81	1709.2	1154.39

Fig.16: THA- Comparison of Base Shear values of all models in X-Direction



	1	2	3	4
ZONE- III	597.5	506.16	703.4	485.9
ZONE- IV	896.35	764.06	1055.1	725.05
ZONE- V	1345.02	1160.8	1582.9	1074.7

Fig. 17: THA- Comparison of Base Shear values of all models in Y-Direction

Discussions

The base shear of a structure mainly relies on the input seismic acceleration occurred due to ground movement during the earthquake. It also depends on site soil condition, proximity to geological faults and natural time period of vibration of the building. If the structural mass of building is more and having high stiffness the base shear corresponding will also be high. For the building with LRB isolator the base shear tends to be less compared to non-isolated building due to flexibility provided by the rubber isolator and also reducing the seismic forces acting in the structure.

Referring to base shear values obtained in Zone-3,it was seen that the base shear tends to increase by 30.73% for earthquake in x-direction and 17.7% in y-direction for a fixed base structure with masonry infill compared to bare frame without infill. This is due to the stiffness provided by masonry infills and the additional weight added to the structure by infills. However in case of isolated building without infill's, the base shear was found to be decreased by 16.31% in x-dir. and 15.2% in y-dir. compared to non-isolated building. Whereas in isolated structure with infill's the base shear was increased by 8.2% in x-direction and decrease of 4% in y-direction compared isolated structure without infill's.

In zone-4,the base shear tends to increase by 30.73% for earthquake in x-direction and 17.7% in y-direction for a fixed base structure with masonry infill compared to bare frame without infill. However in case of IB without infills, the base shear was found to be decreased by 15.86% in x-dir and 14.75% in y-dir compared to non-isolated building. Whereas in IB with infills the base shear was increased by 6.67% in x-direction and decrease of 5.1% in y-direction compared isolated structure without infills.

In zone-4 ,the base shear tends to increase by 30.73% for earthquake in x-direction and 17.7% in y-direction for a fixed base structure with masonry infill compared to bare frame without infill. However in case of IB, the base shear was found to be decreased by 14.78% in x-dir and 13.69% in y-dir compared to non-isolated building. Whereas in isolated structure with infills the base shear was increased by 3.64% in x-direction and decrease of 7.41% in y-direction compared isolated structure without infills.

VI. CONCLUSIONS

- From the Modal analysis results, it can be concluded that the natural frequency tends to decrease in LRB isolated structure compared to non-isolated structure.
- As natural frequency is a function of mass & stiffness of the structure, presence of masonry infill gives additional stiffness to the structure and hence natural frequency tends to increase in structure with the infills.
- The natural time period tends to be more in base isolated structure compared to non-isolated structure because of the flexibility provided to the structure due to presence of isolators.
- Structures with masonry infill have lesser time period compared to those without infills, this is because the structure will become stiffer by providing masonry infills.
- The seismic responses such as base shear, storey drift & storey displacement of the buildings was tend to be more in Time History method of analysis compared to Response Spectrum analysis.
- The seismic response values of all models tend to be more in high seismic zones.
- As the base shear depends on parameters such as mass and stiffness of the structure, the base shear of base isolated structure was less than the non-isolated structure.
- The structures with masonry infill tend to have more base shear than the structures without infills as the presence of masonry infill leads to additional mass and stiffness for the structure.
- The bare frame models have maximum top storey displacement compared to models with masonry infills.
- The LRB base isolated structures have more displacement than that of non-isolated structures, which plays a major role in reducing the effect of seismic forces acting on the structure.
- In bare frame models the maximum inter-storey drift was observed at fourth storey level and in base isolated structures maximum inter-storey drift was observed at ground floor level.
- The inter-storey drift was higher in base isolated structures compared to non-isolated structures at ground floor level, but even though they show large drift value at ground floor level the inter-storey drift was reduced by considerable amount for the remaining above stories. The storey drift values obtained were well within the IS codal limit i.e. 0.004t the storey height.

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