Fixed and Base Isolated Framed Structures: A Comparative Study

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Abstract. Necessity of constructing multi-storied buildings is increasing these days. But they are more prone to severe damage due to earthquakes. Base isolation is one of the most powerful tools pertaining to the passive structural vibration control technologies. The structure above the ground, is separated from the effects of earthquake forces by introducing a mechanism that helps the structure to hover. This project deals with analysis of 10 storey RCC, Steel and Composite structures of different shapes with and without base isolation in various seismic zones by Response Spectrum Method using ETABS software. Lead rubber bearings designed as per UBC97 was used for base isolation. Plus shape was found to be most suitable for base isolation for RC structure, whereas for steel and composite structures rectangular and hollow shapes were found suitable. It was also observed that concrete structure performs best when base isolated, compared to other structures.

Keywords: Response Spectrum Analysis; ETABS; Base Isolation; Lead Rubber Bearing

1. Introduction

An earthquake is one of the most dangerous natural disasters that causes maximum fatalities and economic losses. Also, multi-storey buildings are the ones which are most prone to severe damage by earthquakes. Seismic zones in India are classified into Zone 2, Zone 3, Zone 4 and zone 5 based on the intensity of earthquake. Base isolation system is a technique introduced in a structure in which the superstructure is separated from the seismic forces of the ground. Base isolators reduce the resonance of the building by increasing the time period which results in reducing the base shear, storey drift etc. and increasing the storey displacement. Base isolation using Lead Rubber Bearing is found to be most efficient and economical. Tanwer et al., 2019 [1], have compared different types of base isolation system with fixed based and found that. that the base isolation system substantially increases the time period of the structure, it reduces correspondingly the base shear up to 75% as compared to fixed one, in base isolated structure frequency and storey drift has reduced as compared to fixed base. Moniri, 2016 [2], has evaluated the seismic performance of reinforced concrete (RC) buildings under near-field earthquake and reported that for two earthquakes with nearly identical conditions, more displacement values are obtained in the near-fault record. Overall and relative displacement increases with the building height. Islam et al., 2012 [3], have studied Seismic Base Isolation for Buildings in Regions of Low to Moderate Seismicity and found that savings may be in the order of 5–10% of the
total structural cost for base isolated building. Patel et al., 2012 [4], have analysed CFT, RCC and steel building subjected to lateral loading and found that CFT building is good in load carrying capacity with small cross section of column. They found that beyond 30 storey RCC will not be useful with this geometric frame structure. They also concluded that use of concrete filled steel tube columns provide considerable economy in comparison with conventional steel building. Moretti et al., 2014 [5], analysed base-isolation systems to increase earthquake resiliency of healthcare and school buildings. From the study it has been found that the base-isolated system provide significant median damage savings and repair time reduction compared to fixed-base system. From the well-established methods reviewed by many researchers, base isolation system proves to be the most effective solution for a broad range of earthquake engineering problems and the effectiveness of this system for various shapes of buildings is studied in this paper.

2. Objectives

The main objectives of the study are:
- To analyse a 10 storey RCC, Steel and Composite framed structure of Rectangular, L, T, Plus and Hollow shapes based on IS 1893:2016 [6] in various seismic zones by response spectrum method.
- To design Lead Rubber Bearing Base Isolator for all structures in different zones.
- To compare the effect of earthquake on various parameters like storey stiffness, maximum displacement, maximum storey shear, storey drift & overturning moment for fixed and base isolated structure.
- To study the effectiveness of base isolation and determine the most suitable shape of structure each for RCC, steel and composite materials.
- To find the most suitable structure among concrete, steel and composite for base isolation.

3. Modelling of the Structures

Buildings were modelled in five different shapes for concrete, steel & composite structure. The different shapes were Rectangular, L, T, Plus and Hollow. Hence a total of 15 models were analyzed in each seismic zone. Table 1 gives an idea about the building under consideration. The shapes of buildings are shown in Fig.1, 2, 3, 4 and 5.

| Sl No. | Parameters               | Description                             |
|--------|--------------------------|-----------------------------------------|
| 1      | No. of stories           | 10                                      |
| 2      | Type of frame            | Special Moment Resisting                |
| 3      | Total height of building | 30.5                                    |
| 4      | Area of building         | 990 m²                                  |
| 5      | Soil Type                | Medium                                  |
| 6      | Method of analysis       | Response Spectrum Method                |

Table 1. Building Data
3.1 Load details

Dead Load and Live Load are considered as per IS 875:1987 part 1 and 2 [7] for residential building. Seismic loads are considered according to IS 1893:2016 for different zones. Dead load and Live load are taken as 2kN/m and 5kN/m respectively for all floors except on roof, where they are considered as 1kN/m and 3kN/m respectively. Cladding load is taken as 0.5kN/m.

3.2 Section Properties

Section properties for concrete, steel and composite structures are presented in Tables 2, 3 and 4.

Table 2. Concrete Structure

| Description        | Parameters     |
|--------------------|----------------|
| Beam               | 350 x 450 mm   |
| Column             | 450x450 mm     |
| Slab               | 250mm          |
| Grade of Concrete  | M30            |
| Grade of Rebar     | Fe415          |

Table 3. Steel Structure

| Description        | Parameters     |
|--------------------|----------------|
| Beam               | ISWB 300       |
| Column             | ISHB 350       |
| Secondary Beam     | ISLB 250       |
| Slab               | 110mm          |
| Grade of Rebar     | Fe415          |
| Grade of steel     | Ee345          |
4. Design of Lead Rubber Bearing

The design of Lead Rubber Bearings is done according to Uniform Building Code (UBC 97 Vol. 2).

**General Assumptions**
- Soil Profile Type : S<sub>D</sub> (From Table 16J)
- Damping 𝛽<sub>eff</sub> - 0.05 (Assumed)
- Damping Coefficient B<sub>D</sub> – 1 (From Table A16C)
- Near Source Factor N<sub>V</sub> – 1 (From Table 16 C)
- Design Time Period T<sub>D</sub> – 2.5 s (Assumed)
- Maximum Shear Strain of Rubber 𝜎 – 100%
- Shear Modulus of Rubber – 0.7 MPa
- Horizontal Time Period – 2s (Assumed)
- Bulk Modulus of Rubber – 2000 MPa
- Seismic Coefficient C<sub>V</sub><sub>D</sub> (Zone 4) – 0.54 Table 16R

Maximum support reaction is obtained from the results of analysis of models with fixed base. Further, design steps are followed from the book ‘Design of Seismic Isolated Structures’ by Kelly and Naeim [8]. An LRB designed rectangular concrete structure is shown in Fig. 6.

![Figure 6. Example of LRB designed for rectangular concrete structure in Zone 4](image)

5. Results and Discussions

It is observed that storey drift, storey shear and overturning moment reduced for base isolated structure whereas storey displacements increased.
5.1 Comparison of base isolation for concrete structures of different shapes

Fixed and base isolated concrete structures of different shapes are analysed and percentage change in various parameters on base isolation are compared and are shown in Fig. 7-10.

![Figure 7. Percentage Increase in Max Storey Displacement](image)

Maximum percentage increase in displacement is found for T shaped structure in all zones. Next highest value is for Plus Shaped Structure. In all zones, percentage reduction in drift is found to be maximum for plus shaped structure. Also, the least value is found for L Shaped and Hollow Shaped Structures.

![Figure 8. Percentage Reduction in Storey Drift](image)

![Figure 9. Percentage Reduction in Storey Shear](image)

Maximum percentage reduction in storey shear is found for plus shaped structure in all zones. Least value is found for L shaped structure.

![Figure 10. Percentage Reduction in Overturning Moment](image)

Maximum percentage reduction in overturning moment is for plus shaped structure in all zones. The least value is found for L shaped structure.

5.2 Comparison of base isolation for steel structures of different shapes

Fixed and base isolated steel structures of different shapes are analysed and percentage change in various parameters are compared and are graphically represented in Fig. 11-14.
5.3 Comparison of base isolation for Composite structures of different shapes

Fixed and base isolated composite structures of different shapes are analysed and percentage change in various parameters on base isolation are compared and are shown in Fig. 15-18.

Maximum percentage increase in Storey displacement is found for Hollow shaped structure in all zones. In all zones, percentage reduction in drift is found to be maximum for hollow shaped structure. Also, the least value is found for T Shaped Structure.

Storey Shear Maximum percentage reduction in storey shear is found for Rectangular shaped structure in all zones. Maximum percentage reduction in overturning moment is for Rectangular shaped structure in all zones. The least value is found for T shaped structure.
Maximum percentage increase in displacement is found for Hollow shaped structure in all zones. In all zones, percentage reduction in drift is found to be maximum for hollow shaped structure. Also, the least value is found for L Shaped.

Figure 17. Percentage Reduction in Storey Shear

Figure 18. Percentage Reduction in Overturning Moment

Maximum percentage reduction in storey shear is found for Hollow shaped structure in all zones.

Maximum percentage reduction in overturning moment is for Hollow shaped structure in all zones. The least value is found for plus shaped structure.

5.4 Comparison of base isolation of RCC, Steel and Composite structures of Rectangular Structure

Fixed and base isolated rectangular concrete, steel and composite structures are analysed and results are compared and are shown in Fig. 19-22.

Figure 19. Percentage increase in Max Storey Displacement

Figure 20. Percentage Reduction in Drift

In all zones, Percentage increase in Maximum Storey Displacement is found to be maximum for Concrete structure. But displacement values were found maximum for steel compared to other structures. In all zones, percentage reduction in drift is found to be maximum for concrete structure. Also, least value is found for steel structure.
Maximum percentage reduction in storey shear is found for Concrete structure in all zones. Percentage reduction values for steel and composite structures are comparable.

Maximum percentage reduction in Overturning Moment is found for concrete structures in all zones. Least value is obtained for steel structure.

6. Conclusions

From the studies conducted on different shapes of RC, Steel and Composite structures, the main conclusions drawn are:
• For concrete structure, plus shaped structure is found most suitable for base isolation in all zones. It may be due to symmetry of the structure. L shaped structure is found to be the least suitable, it may be due to irregular shape.
• For steel structure, rectangular and hollow shaped structures are found to be most suitable for base isolation. It may be due to closed symmetry of structure which when base isolated, the stiffness decreases.
• For composite structure, hollow shaped structure is found to be most suitable for base isolation in all zones. Next suitable structure found is rectangular shaped.
• It is also observed that concrete structure performs best when base isolated compared to other structures. Steel structure is found to be least suitable for base isolation.

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