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A Comparative Study on Different Types of Passive Energy Dissipating Devices

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Abstract

Earthquake induced structural vibrations causes fatigue and reduction of performance of the tall steel framed structures. One of the effective ways for improving the seismic performance of a structure is the use of bracings, dampers and isolators. These devices change the stiffness and damping of the structures thereby reducing the seismic vibrations to a great extent. The main objective of this study is to compare the different types of passive energy dissipating devices in a 3 bay 10 storey steel frame building for better seismic response. The frame was modelled in SAP2000® and some of their responses to earthquake such as base shear, maximum joint displacement, inter storey drift were determined and compare during non-linear dynamic time history analysis in SAP2000®.The passive energy dissipating devices used in this study are diagonal bracing, v bracing, cross bracing, rubber base isolator and friction damper. At first a single storied shear frame model was tested in shake table and results obtained from SAP 2000® were compared. The close proximity validated the procedure. It is observed that addition of dampers to the system increases the stiffness to the frame. When compared, displacement for steel frame with dampers is reduced by 80% and that with different bracing systems are reduced up to 78% as compared to bare steel frame. For base isolators, base shear decreases up to 63.33% but an increase in the maximum joint displacement was observed. The comparison of performances of all types of dissipating mechanisms has been presented in the study.

Keywords: Seismic performance, base isolator, dampers, bracings, inter-storey drift

1. Introduction

Now-a-days construction of tall steel frame buildings is increasing in major cities around the world. Taller buildings in a high seismic risk area undergo a higher level of dynamic response. Theyare subjected to a wide range of external forces such as earthquakes and strong winds. In order to minimize the internal stresses and vibrations within safe limits certain energy dissipating devices must be used in these structures. These dissipating devices provide damping to the structures and increases/decreases the stiffness accordingly, thus providing safety to the structures against earthquake. One such energy dissipating devices is dampers. Dampers absorb the vibrations produced due to earthquake by providing a higher damping to the structure and reduce the amplitude of seismic vibration gradually and the structure returns to its resting position from the displaced position. The different types of dampers used in the structures such as metallic dampers, friction dampers, viscous dampers, mass dampers, lead injection dampers etc. Dampers are easy to install and replace in structures but are costly. Another such passive energy dissipating device is base isolators. Base isolators in buildings decouple low to medium rise buildings from ground by absorbing the earthquake ground vibrations thus preventing the superstructure safely. Elastomeric Rubber pads, roller and ball bearings, springs and lead rubber bearings are commonly used as base isolators to reduce the seismic vibration. In case of fixed base structures, the relative displacement between the ground and the structure is almost zero. When base isolators are used, the relative displacement of the ground and the structure will be nearly equal. For fixed base structures, displacements occur at the CG of the structure whereas in case of base isolators displacements occurs at the isolation plane with minimal or no displacement in the structure above. Thus displacement and acceleration are controlled by the isolator and maintain structural integrity. Base isolation increases the fundamental period of vibrations of the structure and is generally kept as 2 seconds.

In this study the different types of passive energy dissipating devices such as diagonal bracing, v bracing, cross bracing, rubber base isolator, friction isolator, pendulum isolator and friction damper was compared. A three bay 10 storey tall steel building model was created in SAP2000® and comparison of seismic parameters in terms of base shear, displacement are extracted for each system (with different bracing types) using time history analysis.

2. Structural Details of the Modeled building

The following are the parameters of the building

- No of bays in X-direction: 3nos
- No of bays in Y-direction: 6nos
- Width of bay in X- direction: 6m
- Width of bay in Y-direction: 6m
- No of Stories: 10storey

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- Height of each storey: 3m
- Young's Modulus: $2x10^5 N/mm^2$
- Density of Steel section:$7850 kg/m^3$
- Earthquake force: El CentroE-W
- Size of bracing: 130mm x10mm(plate section);

Member section (I-section) for every storey(mm)
Columns for 1-3 storey: ISMB400
Columns for 4-7 storey: ISMB350
Columns for 8-10 storey: ISMB300
Beams for 1-10 storey: ISMB200

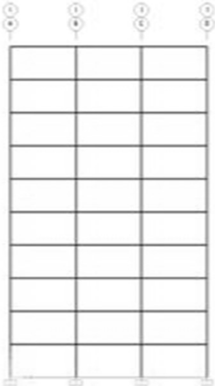
Fig 1: No bracing

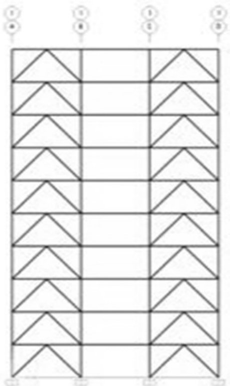
Fig 2: Inverted V bracings

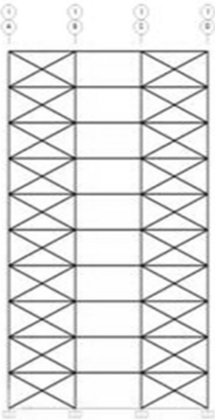
Fig 3: Cross bracings

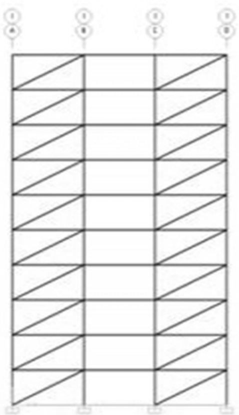
Fig 4: Diagonal bracings

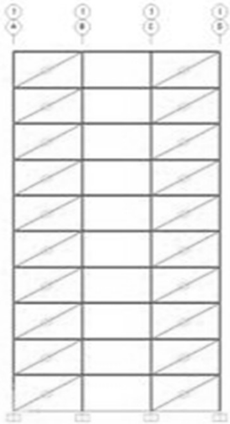
Fig 5: Friction Dampers

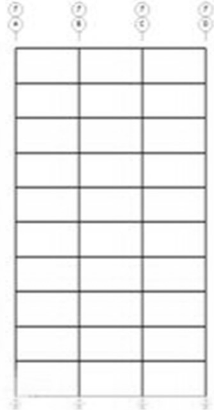
Fig 6: Base Isolators

Table 1: Optimum Slip Load

Storey	Optimum Load
10th floor	36.00KN
9th floor	38.00KN
8th floor	43.00KN
7th floor	45.00KN
6th floor	48.00KN
5th floor	55.00KN
4th floor	58.00KN
3rd floor	60.00KN
2nd floor	67.08KN
1st floor	71.42KN
Ground floor	83.33KN

3. Methodology

3.1 Friction Damper Modeling in SAP2000®

Friction damper dissipates energy through Columb friction when solid surfaces sliding relative to one another. During the times of severe earthquake device slips at the predetermined load know to be slip load. When the device attains its slip point it shift the structural fundamental load away from the earthquake resonant frequency. Various forms of friction damper are chevron braced, X braced, diagonal braced damper. For earthquake slip load will be considered 30% of the building weight [1]. Damper should be designed for optimum slip load; in case of its higher or lower slip load condition structure response will be vigorous. Slip load structure is designed based on Time history analysis (THA) results before and after earthquake displacement condition. Shear force undertaken by the frame will be equal to the energy dissipation capacity of the frame which means the slip load will optimum under the referred condition. The Optimum Slip load has been calculated for the 10 storey steel frame structure and the values are in the table 1.

3.3Base Isolation Modeling in SAP2000®

The base isolation system is becoming a popular means of earthquake mitigation. The main objective of this study is to compare the performance of different types of base isolators with that of fixed base building. This study presents a performance analysis of different type of base isolator such as are rubber isolation, triple pendulum isolation, friction isolator in 10 storey steel building by using SAP2000®. The selected ground motion is El Centro E-W component. The rubber base isolator used elastomeric isolation system with steel and rubber plates placed in alternate layers through vulcanization process. The rubber plates provide the horizontal low shear stiffness whereas the steel plates provide the high vertical stiffness to control the bouncing effect. For modeling a rubber base isolator in SAP2000® the parameters are as follows [2]:
Non linear link type: rubber bearing,
Linear stiffness forU1: 1500000KN/m,
Linear stiffness forU2 and U3: 800KN/m,
Non linear stiffness for U3 and U2: 2500KN/m,
Yield strength ofU2 and U3: 80KN,
Post yield stiffness ratio U2 and U3: 0.1.
The remaining nodes are left free.

In addition to rubber bearing the building is analyzed for friction pendulum isolator in the system. These isolators reduce the superstructure acceleration upto a great extent. The advantage of friction pendulum isolator over rubber isolator is that the frictional force developed at the base of the structure is proportional to the mass of the structure and the centre of resistance and the centre of mass coincides with one another. The constraints selected to define the isolator in the program are as follows [2]: Non linear link type – friction isolator,
Linear stiffness forU1: 15×10^6KN/m,
Linear stiffness forU3 and U2: 750KN/m,
Non linear stiffness U3 and U2: 15×10^3KN/m,
Friction coefficient forU3 and U2: slow: 0.03, fast: 0.05, Rate parameter forU3 and U2: 40,
Radius of sliding surface U3 and U2: 2.3.

Note:
U1 means x direction
U2 means y direction
U3 means z direction

3.3 Validation

A one storey steel frame as shown in fig 7 was tested in shake table using sinusoidal excitation of amplitude 1mm and similar model has been modeled and analyzed in SAP2000® with sinusoidal excitation.
The result was obtained that the natural frequency of vibration by using shake table is 6.44 Hz and by using SAP2000® is 6.645 Hz and the storey displacement using shake table was found to be 21mm where as in SAP2000 storey displacement was obtained as 20.68mm. The results obtained from shake table and SAP2000® are almost comparable.

After validating the results the similar process was adopted for analyzing the ten storey steel framed building using time history analysis in SAP 2000®.The various responses were noted down from SAP 2000® Platform. The responses are discussed below.

Fig 7: Laboratory model prepared for validation purpose

4. Results and Discussion

The results obtained from SAP2000® are discussed below
It has been observed from the Fig 11, that addition of dampers to the system increases the stiffness to the frame. As a result the joint displacement in case of friction damper is reduced by 78.13% compared to bare steel frame.
In case of bracing systems from Fig 8, Inverted V bracing system showed the least displacement followed by X bracing system and Diagonal bracing system. The joint displacement is reduced by 76.60%, 65.69% and 65.65% in case of inverted V bracings, X bracings and diagonal bracings respectively when compared with the joint displacements in case of un-braced steel frame.
For base isolation it is observed that the inter-storey drift and top floor acceleration are very less compared to the fixed base structure as shown in Fig 9.
From Fig 10 the base shear in case of X bracing increased by 56% and that in case of inverted V bracing system the base shear increased by 54% as compared to the un-braced structure. The base shear in case of diagonal bracing showed an increase of 28%. Thus it can be concluded that Inverted V

Table 2: Percentage Difference In Displacement In Each Storey Of Building Using Different Energy Dissipater

Storey no	% Difference in bracing			%Difference in damper	% Difference in base isolator		
	Diagonal bracing	Inverted V bracing	Cross Bracing	Friction damper	Rubber isolator	Friction isolator	Triple pendulum isolator
0	-	-	-	-	100	100	100
1	65.65	76.60	65.69	78.13	91.05	96.00	94.45
2	69.21	81.06	73.90	82.39	78.45	89.42	85.38
3	72.17	82.69	76.87	84.01	67.17	82.72	76.31
4	73.41	83.19	77.98	84.34	57.98	76.85	68.15
5	74.30	83.38	78.65	84.05	50.13	71.55	61.38
6	75.06	83.65	79.37	83.98	42.5	66.07	54.72
7	75.46	83.81	79.92	83.93	35.81	61.30	48.25
8	75.17	83.32	79.61	84.35	32.55	58.63	45.28
9	74.83	82.95	79.42	83.52	29.54	56.33	42.59
10	74.06	82.25	78.84	83.10	28.08	55.55	41.60

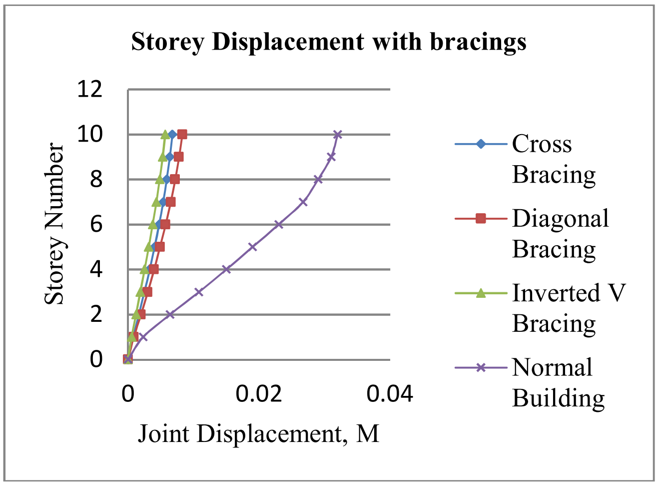

Fig 8: Comparison of Joint Displacement of different types of Bracings with earthquake force along X-direction

Bracing system is the most effective in enhancing the performance of the building as compared to X braced steel frames and diagonal braced steel frames. Similarly the use of friction damper in each floor in the same frame model showed 70% increase in base shear as compared to the steel frame building. But in case of Isolators the base shear observed is less than that of the fixed base steel frame model. The % decrease in base shear for friction isolator, triple pendulum isolator and rubber isolator are 40%, 60% and 63.33% respectively.
It is also observed that in fixed base structures the natural period of the structure being 1.457 sec at its first mode and for rubber isolator, triple pendulum isolator and friction isolator natural period increases up to 2.643 sec, 2.740sec and 2.78 sec respectively. This increase in the time period causes increase in bearing displacement but the acceleration of the superstructure decreases significantly.

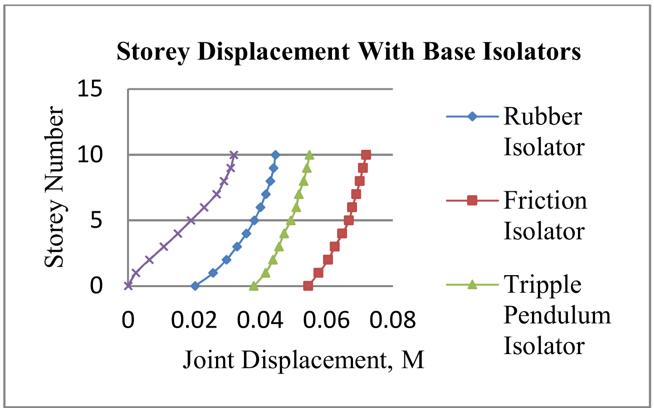

Fig 9: Comparison of Joint Displacement of different types of Base Isolators with earthquake force along X-direction

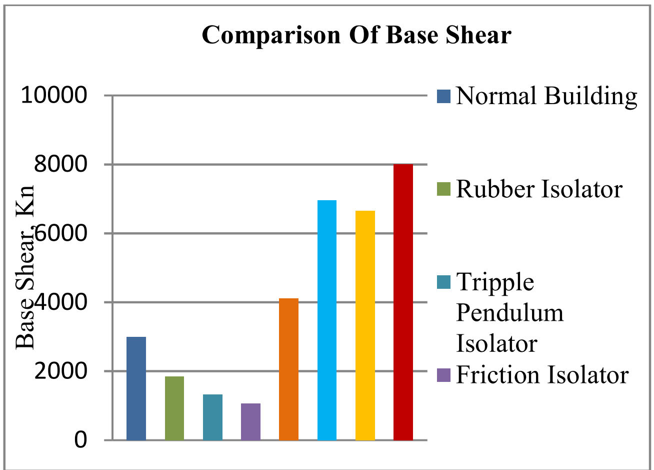

Fig10: Comparison of Base Shear of different types of Bracing systems, Friction Damper and different type of Base Isolator with earthquake force along X-direction

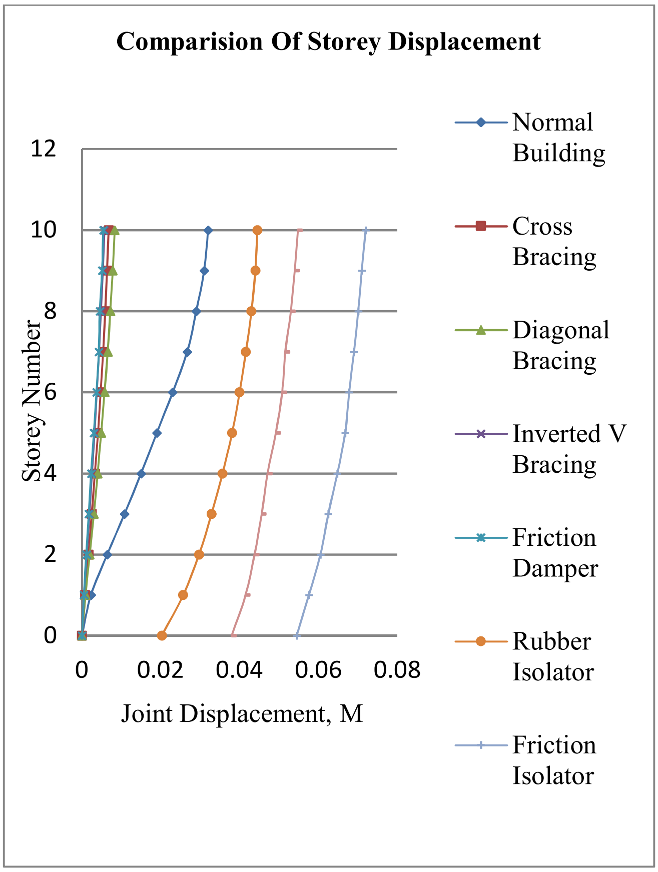

Fig11: Comparison of Joint Displacement of different types of Bracing systems, Friction Damper and different types of Base Isolators with earthquake force along X-direction

Disclosures

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