ANJANA S, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 8, August 2022, pp. 45-49

RESEARCH ARTICLE OPEN ACCESS

Seismic Performance Comparison of a Fixed-Base and a Base-Isolated Office Building

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ABSTRACT
The topic of this thesis is base isolation. The purpose of this thesis is to offer a relative understanding of the seismic performance enhancements that a typical 12-story steel office building can achieve through the implementation of base isolation technology. To reach this understanding, the structures of a fixed-base office building and a base-isolated office building of similar size and layout are designed, their seismic performance is compared, and a cost-benefit analysis is completed. The base isolation system that is utilized is composed of Triple Friction Pendulum (TFP) bearings. The work of this thesis is divided into four phases. First, in the building selection phase, the structural systems (SMF and SCBF), layout, location , and design parameters of the buildings are selected. Then, in the design phase, each structure is designed using modal response spectrum analysis in ETABS. In the analysis phase, nonlinear time history analyses at DBE and MCE levels are conducted to obtain the related floor accelerations and inter-Storey drifts. Finally, in the performance assessment phase, probable damage costs are computed using fragility curves and FEMA P-58 methodology in PACT. Damage costs are computed for each building and seismic demand level and the results are compared.

Keywords – base isolation, Triple Friction Pendulum (TFP), seismic performance, non linear time history analysis, ETABS, PACT, fragility curve, FEMA P-58

Date of Submission: 04-08-2022 Date of Acceptance: 17-08-2022

I. INTRODUCTION

The topic of this thesis is base isolation. Base isolation is a proven technology for the seismic design of structures. The system reduces the likelihood of structural and nonstructural damage to a building subjected to seismic forces. As a result of the use of base isolation, lives and property have been saved. Base isolation technology is used primarily in critical facilities such as hospitals, museums, and emergency response centers, where the benefits of protecting the structure and its property from seismic damage far exceed the cost of implementing the system. However, despite base isolation's proven benefits, the technology is underutilized.

II. OBJECTIVE AND SCOPE OF THE PROJECT

This study analyzes a fixed-base and a base-isolated 12-story steel office building. The superstructure of each building has a lateral system composed of special moment frames (SMF) in the longitudinal direction and special concentrically braced frames (SCBF) in the transverse direction. Also, Triple Friction Pendulum (TFP) bearings are used for the isolation system in the base-isolated structure. The seismic performance of each structure is analyzed and compared for both design basis earthquake (DBE) and maximum considered earthquake (MCE) seismic demand levels. 7 ground motions are scaled to each seismic demand level to perform nonlinear time history analyses on both structures. The resulting floor accelerations and inter story drifts are used to determine the levels of structural and non-structural damage inflicted on each building. A cost-benefit analysis is then performed, which takes into account the cost of the isolation system and the damage costs of the structures and their components.

2.1 Importance of the Study

Base isolation technology works by separating or greatly reducing the lateral movement of a building's superstructure from the movement of the ground/foundation during a seismic event. To allow for this difference in lateral movement while still supporting the weight of the superstructure, base isolation bearings are designed to be very flexible laterally while being stiff vertically. This base condition is in contrast to a typical fixed-base structure, in which the connections between the superstructure and its base/foundation are rigid and translation of the superstructure is resisted in all directions.

III. METHODOLOGY

1. Design selection phase
- ➢ Building layout selected
- ➢ Structural and isolation systems chosen
- ➢ Project site selected

2. Design Phase
- ➢ Lateral systems of fixed-base and base-isolated structures designed
- ➢ Isolation system designed
- ➢ Code used: ASCE 7-10 and IS
- ➢ Method: modal response spectrum analysis run in ETABS

3. Analysis Phase
- ➢ Maximum floor accelerations and inter story drifts analysed
- ➢ Structural performance analyzed via plastic hinge deformation
- ➢ Method: nonlinear time history analysis run
- ➢ Ground motions: 7 records scaled to DBE and MCE levels

4. Performance Assessment Phase
- ➢ Damage costs computed in PACT
- ➢ Method: fragility curves and FEMA P-58 procedures and data used
- ➢ Cost-benefit analysis

IV. ASCE DESIGN CRITERIA

- Idealize diaphragms as rigid diaphragms
- No horizontal or vertical irregularities, $\rho = 1.0$
- Soil Classification: Site Class D “Stiff Soil”
- Seismic Design Category: D
- Site Risk Category: Risk Category III – “Substantial Hazard”
- Seismic Importance Factor: Ie = 1.25
- Design story drift limit: $\Delta = (0.015)$(story height)
- Recommended procedure: modal response spectrum analysis.

4.1 DESIGN CRITERIA

- IS 1893 (Part 1)
- IS 4326
- IS 13827
- ASCE 7-10

V. DESIGN OF THE BASE-ISOLATED OFFICE BUILDING

The first step of designing the base-isolated office building was to design the base isolation system. The isolation system was designed to meet a target base-isolated effective period and effective viscous damping ratio for a given design displacement.

Then, the maximum displacement of the isolation bearings was calculated to determine the moat size (the gap size between the building and concrete retaining wall at the base of the building). Lastly, the superstructure was designed to meet the required seismic performance criteria.

VI. DESIGN OF THE ISOLATION SYSTEM – MOAT

The moat size of the isolation system was determined by the maximum bearing displacement expected for an MCE event, using the lower-bound properties of the isolation bearings. Conservatively, the maximum of the hand-calculated value and the average value of 7-time histories was used, while taking into account the effects of torsion.

VII. ANALYSIS PHASE

In the analysis phase, the inter-story drifts and floor accelerations of both the fixed-base and base-isolated office buildings were found at design basis earthquake (DBE) and maximum considered earthquake (MCE) levels via nonlinear time history analyses. Also, the structural performance levels were analyzed by tracking plastic hinge rotations occurring in the structural members, according to ASCE 41-06 standards.

VIII. NON LINEAR TIME HISTORY ANALYSIS

In order to account for the variation of the office building’s response throughout the duration of each earthquake ground motion, a time history analysis was required. A time history analysis involves simulating earthquake ground motion accelerations that vary over time, and tracking the structure’s response to these ground motions. The seismic response parameters that were considered for this study were

- floor accelerations
- inter story drifts
- plastic hinge rotations
- isolation bearing displacements and forces

IX. MODELLING IN ETABS

ETABS is a highly effective and reliable software developed by Computers and Structures Incorporation, USA, which is used for professional use in analyzing and developing the models and components. It is easy, simple to use and compare and time saving software tool.

Verification of Models

This section illustrates the checks that were performed in order to verify consistency between the ETABS models for each structure.

Verification of Models – Equivalent Damping Check

The fixed-base model was assigned a modal damping value equal to the effective damping of the isolation system (22%) in order to verify that the resulting floor accelerations and inter story drift values were within a close range to the base-isolated model. The results of each ground motion's inter story drifts and floor accelerations in the special moment frame direction.

X. RESULTS AND ANALYSIS

The figures in this section illustrate the results obtained from the analysis phase.

As can be seen by the results in Figures, implementing base isolation reduced the response of the fixed-base structure by roughly half for nearly all response parameters, directions, and ground motion records. The fixed-base response is shown in blue and the base-isolated response is shown in red in each figure.

The implementation of base isolation was slightly more effective for reducing floor accelerations than for reducing inter Storey drifts. The inter Storey drifts in the direction of the braced frames were the most consistent parameters for all ground motions and buildings, due to the greater lateral stiffness of the braces compared to the moment frames.

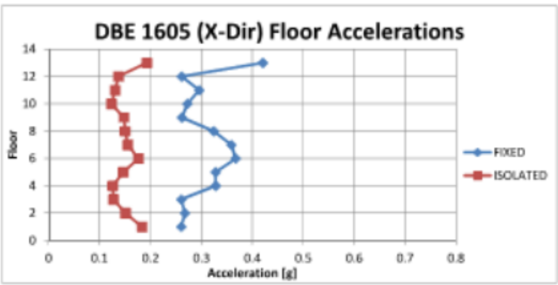

Figure 1 SMF-Direction Maximum Floor Accelerations

A maximum acceleration of 0.55 g was reached at the roof of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.29g.

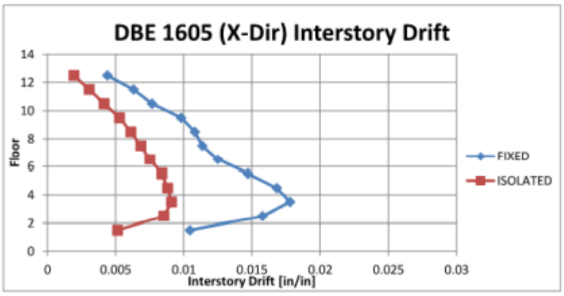

Figure 2 SMF-Direction Maximum Inter-Storey Drifts

A maximum inter-Storey drift of 0.025 was reached at the lower half of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.010.

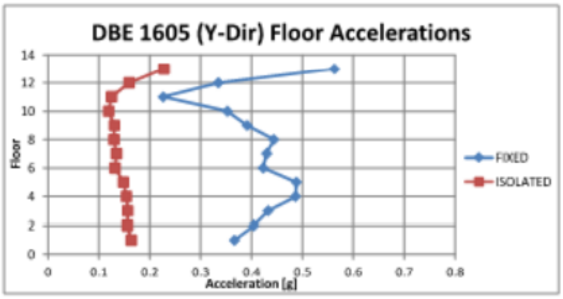

Figure 3 SCBF-Direction Maximum Floor Accelerations

A maximum floor acceleration value of 0.67 g was reached at the roof of the fixed-base structure, while the base-isolated structure had a maximum value of 0.24 g.

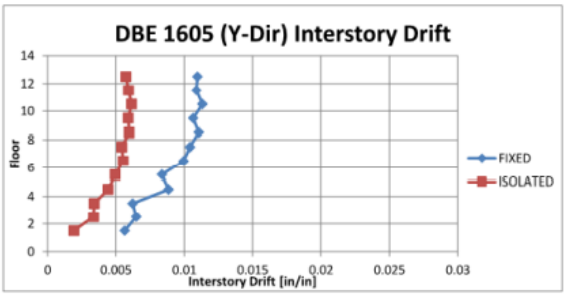

Figure 4 SCBF-Direction Maximum Inter Storey Drifts

A maximum inter Storey drift of 0.012 was reached at the upper half of the fixed base structure, while the base-isolated structure had a maximum value of only 0.006.

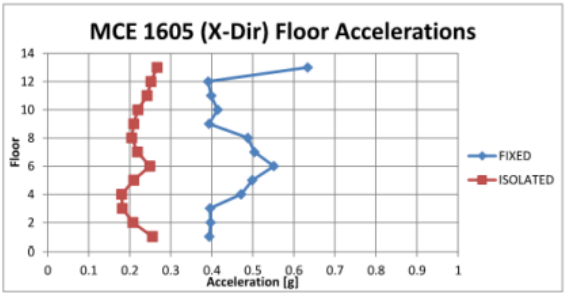

Figure 5 SMF-Direction Maximum Floor Accelerations

A maximum acceleration of 0.80 g was reached at the roof of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.40g.

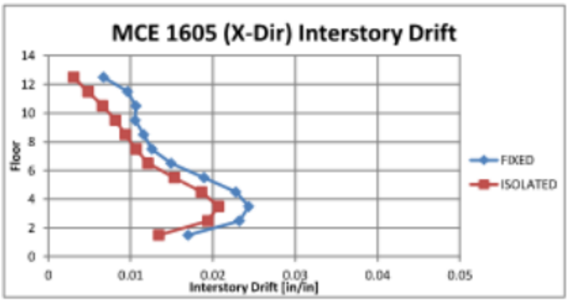

Figure 6 SMF-Direction Maximum Floor Accelerations

A maximum inter Storey drift of 0.036 was reached at the lower half of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.020.

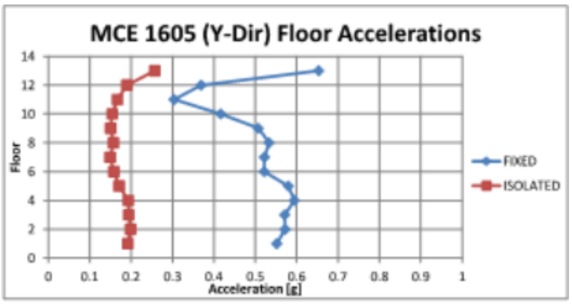

Figure 7 SCBF-Direction Maximum Floor Accelerations

A maximum floor acceleration value of 0.90 g was reached at the lower half of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.28 g.

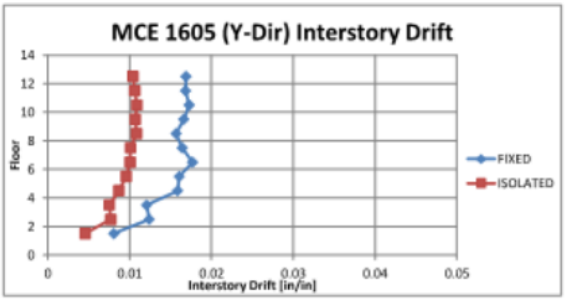

Figure 8 SCBF-Direction Maximum Inter Storey Drifts

A maximum inter Storey drift of 0.018 was reached at the upper half of the fixed-base structure, while the base-isolated structure had a maximum value of only 0.011.

XI. CONCLUSION

This section summarizes the conclusions that were reached as a result of this study.

Benefits of Base Isolation

The benefits of implementing base isolation in the 12-story steel office building were clearly shown by the results of this study, including

- Reduction of floor accelerations and inter story drifts by more than half
- Improvement of structural seismic performance levels
  - o Change from Life Safety (LS) to no or very small plastic deformations (Immediate Occupancy, IO) at design basis earthquake (DBE) seismicity
  - o Change from Collapse Prevention (CP) to small or moderate plastic deformations (IO/LS) at maximum considered earthquake (MCE) seismicity
- Savings in damage costs
- Total savings after taking into account the 10% isolation system cost.

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