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Effect of earthquake characteristics on the peak seismic response of a typical base isolated steel building with mass eccentricities

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Abstract

This research work investigates the seismic behavior of a typical 2-story steel base-isolated building (BIB) under different seismic ground motions, using the SAP2000 software, while the effect of near-fault ground motions is studied by imposing 4 pairs of near-fault (NF) and 4 pairs of far-fault (FF) seismic excitations to the building. Furthermore, the influence of the direction of the imposed earthquake excitations and potential accidental mass eccentricities are also studied by rotating the imposed pairs of seismic records from 0◦ to 360◦ and by considering 5% and 10% accidental mass eccentricities, respectively, in the conducted parametric analyses.

The results indicate that the NF seismic components are more likely to increase the peak seismic response of the building than the corresponding FF components. The computed response, while rotating the imposed pairs of seismic records from 0◦ to 360◦, with respect to the major construction axes, shows that the peak seismic response, in general, occurs along incidence angles other than the horizontal construction axes of the building. Moreover, it is observed that, under each seismic event a different incidence angle is the critical one. The determination of the critical incidence angle is hence complicated, and different dynamic simulations should be performed for each building, especially if it is a high-importance building, in order to obtain a more reliable assessment of the peak seismic response under the worst-case scenario regarding the incidence angle.

Furthermore, considering the influence of 5% and 10% accidental mass eccentricities indicates that when accidental mass eccentricities are taken into account

the peak relative displacements of the base isolated structure are, in general, increased, which is very critical for the proper estimation of the required seismic gap that should be provided around a BIB to avoid potential structural pounding with adjacent structures or the perimetric moat wall. Nevertheless, the peak floor accelerations at the superstructure have minor differences between the symmetric building and the two buildings with accidental mass eccentricities, which leads to the conclusion that the superstructure of a base-isolated building may not be significantly affected by the accidental mass eccentricities.

Keywords: base isolation, seismic isolation, peak seismic response, near vs. far fault, incidence angle, torsional effects.

1 Introduction

In the framework of this research work, parametric analyses are conducted in order to investigate the seismic behavior of a typical base-isolated (with elastomeric bearings) steel building under different seismic ground motions, using the SAP2000 software. Specifically, the effect of near-fault ground motions, as well as the influence of the direction of the imposed earthquake excitations, are also studied by imposing 4 pairs of near-fault (NF) and 4 pairs of far-fault (FF) seismic excitations to the building and by rotating the imposed pairs of seismic records from 0◦ to 360◦, with respect to the major construction axes, respectively. Furthermore, the influence of accidental mass eccentricities is also studied by considering 0%, 5% and 10% accidental mass eccentricities in the conducted parametric analyses.

Specifically, a typical 2-story steel base isolated building (BIB) is considered, with plan dimensions 24m x 20m and floor heights of 3.30m. The frame in the X direction has three equal spans of 8m each, while the frame in the Y direction has 4 equal spans of 5m each (Figure 1). Each floor is simulated as a rigid diaphragm and the masses are lumped at the floor levels.

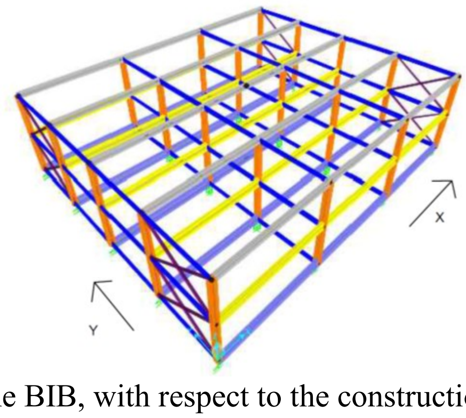

Figure 1: A 3D view of the BIB, with respect to the construction horizontal axes.

The design of the base isolation system was conducted by [1], after selecting a target fundamental eigenperiod T_{dtar}=1.2sec. Both Natural Rubber Bearings (NRBs) and Lead Rubber Bearings (LRBs) are modeled as "Rubber Isolator" type link elements using the SAP2000 structural analysis software. The NRBs have been modeled assuming equivalent linear properties, while nonlinear inelastic properties have been used for the LRBs.

Earthquake resistant design and building codes require the relocation of the mass center in each floor along the X and Y construction axes, in both positive and negative directions [2-3], while previous research works have shown that the accidental mass eccentricities may cause higher torsional amplification [4] and that base isolation can reduce the structural torques significantly [5]. Eccentricities, es, can be obtained by shifting the centers of mass of the superstructure (CMs) from the center of stiffness (CRs), which are located in the geometric center of the plan, or vice versa, i.e. by shifting the CRs from the CMs of the superstructure.

2 Methods

In order to consider the effect of the earthquake characteristics on the peak seismic response, 4 pairs of NF and 4 pairs of FF seismic excitations, which had been recorded during the same seismic events at different stations, obtained from the PEER Center Database [6], are selected and used. As already stated in previous studies [7], in order to achieve more accuracy, two acceleration records are considered simultaneously in the two horizontal directions, the Fault-Normal (FN) and Fault-Parallel (FP) for each ground motion.

The selection of the NF ground motions has been based on specific criteria [8], specifically: (i) an earthquake magnitude of $M_w \geq 6.0$ and (ii) a distance to the fault rupture of $R_{rup} < 15\ km$. The FF accelerograms are selected from the same seismic event, but at a further distance from the fault $R_{rup} > 40\ km$ (Tables 1 and 2). The NF and FF ground motion records are normalized to have their peak ground accelerations (PGA) equal to $0.3g$.

EQ No.	NGA seq. no.	Event	Year	Station	M_w	FN	FP	R_{jb} (km)	R_{rup} (km)	V_{s30} (m/s)
						PGA (g)	PGA (g)			
1	292	Irpinia-Italy-01	1980	Sturno	6.9	0.23	0.31	6.8	10.8	1000
2	802	Loma Prieta	1989	Saratoga - Aloha Ave	6.9	0.36	0.38	7.6	8.5	371
3	1045	Northridge -01	1994	Newhall - W Pico Canyon Rd.	6.7	0.43	0.28	2.1	5.5	286
4	1176	Kocaeli-Turkey	1999	Yarimca	7.5	0.28	0.31	1.4	4.8	297

Table 1: Characteristics of selected horizontal NF records.

EQ No.	NGA seq. no.	Event	Year	Station	M_w	FN PGA (g)	FP PGA (g)	R_{jb} (km)	R_{rup} (km)	V_{s30} (m/s)
1	283	Irpinia Italy-01	1980	Arienzo	6.9	0.03	0.05	52.93	52.94	612.78
2	799	Loma Prieta	1989	SF Intern. Airport	6.93	0.24	0.33	58.52	58.65	190.14
3	946	Northridge-01	1994	Antelope Buttes	6.69	0.05	0.07	46.65	46.91	572.57
4	1154	Kocaeli Turkey	1999	Cekmece	7.51	0.05	0.05	64.95	66.69	346.0

Table 2: Characteristics of selected horizontal FF records.

M_w magnitude, R_{jb}: Restrict range of Joyner-Boore distance, R_{rup}: Restrict range of closest distance to rupture plane, V_{s30}: Average shear wave velocity of top 30 meters of the site

Although it is common practice to apply a pair of seismic ground motions along the two principal horizontal directions of the simulated building, the earthquake excitations, which are recorded as FN and FP, can occur at any orthogonal horizontal axes, rotated randomly around the vertical axis. The excitation angle θ can be defined as the angle between the principal directions of the excitation's orthogonal components, with respect to the global axes of the system X and Y, as it is mentioned by [8]. In order to study the effects of the ground motion incidence angle, the seismic record pairs are rotated from 0° to 360°, with a 15° interval with respect to the major construction axes, and the major peak seismic response quantities are computed and presented next.

3 Results

In order to examine the effect of accidental mass eccentricities at the superstructure on the peak seismic response of the BIB, the envelopes of the peak relative displacements at the base isolation level, the maximum interstory drifts and peak floor accelerations, extracted from the four corner columns, are presented next, for the symmetric BIB versus the two buildings with bidirectional accidental mass eccentricities of 5% and 10%.

Specifically, Figures 2 and 3 provide the peak relative displacements at the base isolation level (which are very crucial for the proper estimation of the required width of the seismic gap) for the BIB without any eccentricities, with 5% eccentricities and with 10% eccentricities, in X and Y directions under NF and FF ground motions, respectively, among all excitation angles. The results indicate that the peak relative displacements in both directions are significantly increased due to the accidental mass eccentricities and the maximum relative displacements due to the NF ground motions are considerably larger than the corresponding values due to the FF ground motions.

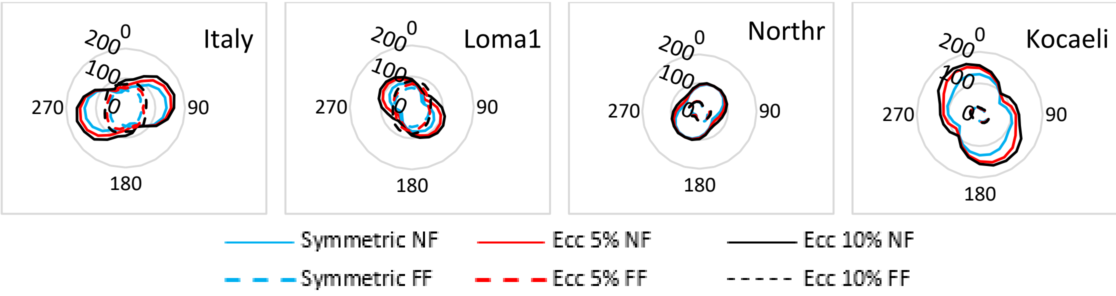

Figure 2. Peak relative displacements (mm) in X direction under NF and FF ground motions, in terms of the excitation angle for symmetric and non-symmetric (5% and 10%) BIB.

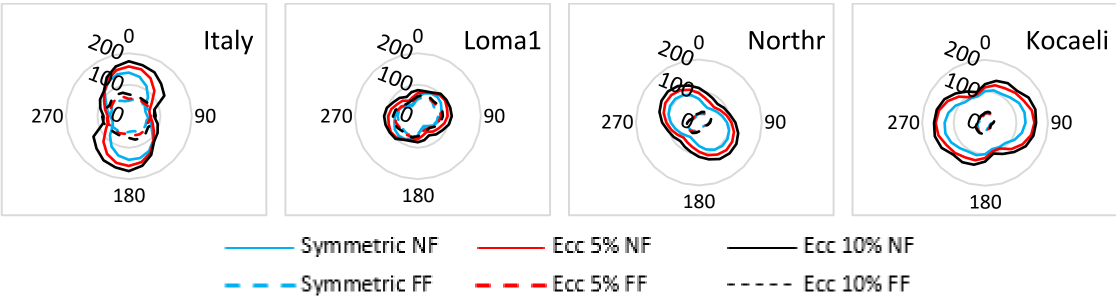

Figure 3. Peak relative displacements (mm) in Y direction under NF and FF ground motions, in terms of the excitation angle for symmetric and non-symmetric (5% and 10%) BIBs.

Figures 4 and 5 provide the peak interstory drifts computed at the symmetric BIB and the BIB with 5% and 10% accidental mass eccentricities, for the X and Y directions, respectively. In general, the peak interstory drifts are greater under NF excitations, in both X and Y directions, although this increase strongly depends on the angle of incidence angle, while the accidental mass eccentricities do not significantly influence the peak interstory drifts of the BIB.

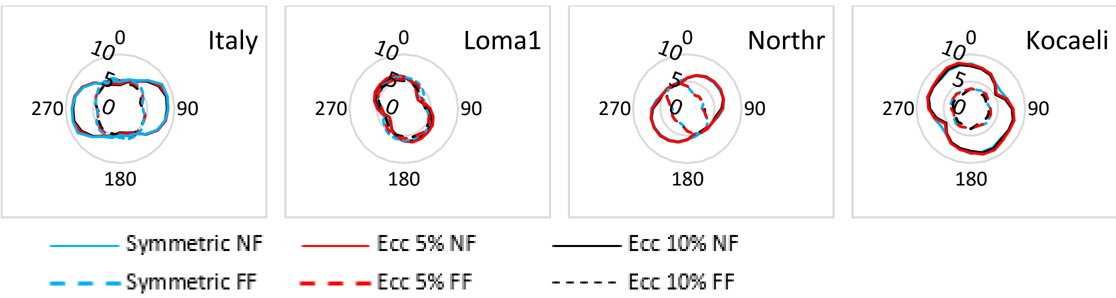

Figure 4. Maximum interstory drifts (mm) in the X direction under NF and FF ground motions, in terms of the excitation angle, for symmetric and non-symmetric (5% and 10%) base isolated buildings.

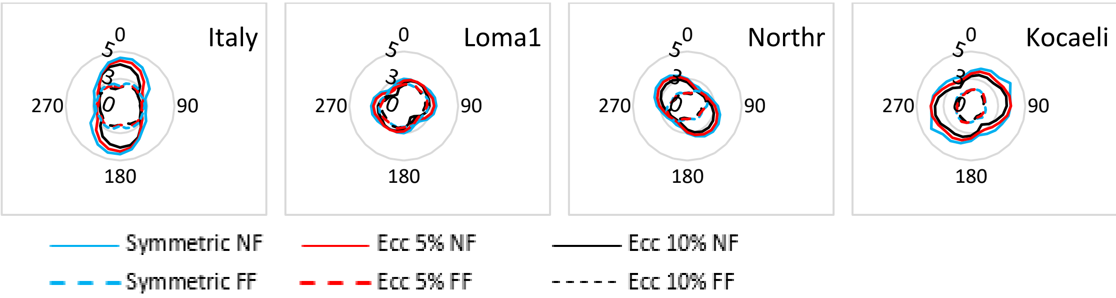

Figure 5. Maximum interstory drifts (mm) in the Y direction under NF and FF ground motions, in terms of the excitation angle, for symmetric and non-symmetric (5% and 10%) BIBs.

Finally, a comparison between the peak floor accelerations of the BIBs is presented, with (5% and 10% eccentricities) and without any eccentricities is presented in X and Y directions, in Figures 6 and 7, respectively, showing that the accidental mass eccentricities do not significantly affect the peak seismic response of the base-isolated building under all ground motions, both NF and FF.

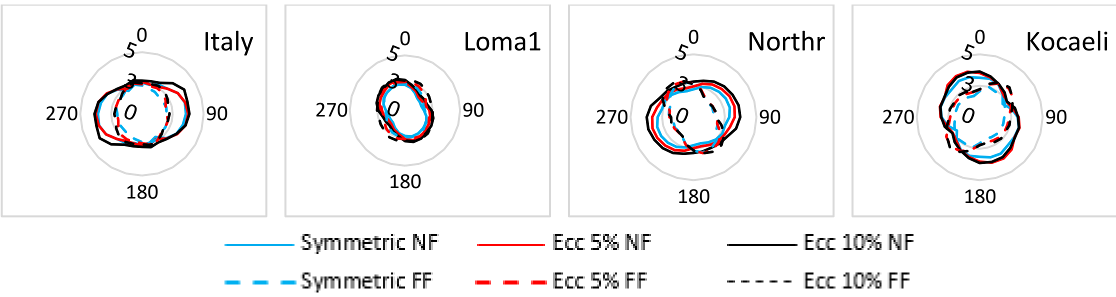

Figure 6. Maximum floor accelerations (m/s^2) in the X direction under NF and FF ground motions, in terms of the excitation angle for symmetric and non-symmetric (5% and 10%) BIBs.

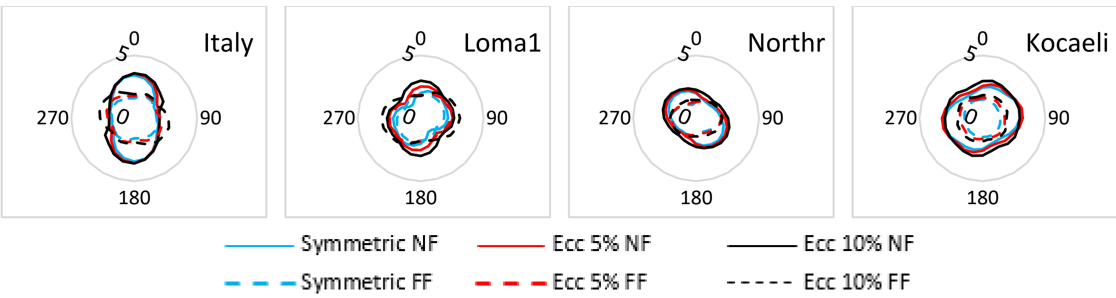

Figure 7: Maximum floor accelerations (m/s^2) in the Y direction under NF and FF ground motions, in terms of the excitation angle for symmetric and non-symmetric (5% and 10%) BIBs.

4 Conclusions and Contributions

In this research work the effect of NF and FF ground motions imposed on a typical steel BIB has been investigated, through nonlinear time-history analyses considering various angles of a set of 4 NF and FF seismic records of the same earthquake events. Parametric analyses have been performed by varying the excitation angle and the results indicate that the critical angle of excitation is, in general, not along the principal horizontal axes- 0 or 90 degrees. Furthermore, the maximum response occurs at different excitation angle for each pair of seismic records, which means that when taking into account the seismic lateral forces only at the principle horizontal directions for the seismic design of a building, may lead to a significant underestimation of its actual response. The overall conclusion is that, under each seismic event a different incidence angle is the critical one. The determination of the critical incidence angle is hence complicated or even impossible, and different simulations should be performed for each base-isolated building, in order to obtain a more reliable evaluation of the peak seismic response. Moreover, the effectiveness of seismic isolation seems to strongly depend on the proximity to active faults, as well as the angle of the seismic incidence with respect to the principal construction axes.

In additon, considering 5% and 10% bidirectional accidental mass eccentricities on the peak seismic response of the BIB under both NF and FF seismic excitations, at arbitrary directions of the seismic incidence, mass eccentricities generally increase the response of the base-isolated buildings, due to the increase of the torsional effects, which causes rotations of the diaphragms. However, the rotation of the diaphragms are due to the essentially rigid-body rotation of the base-isolated building at the isolation level rather than the deformation of the superstructure. Specifically, the maximum relative displacements at the base isolation level are significantly increased due to the existence of mass eccentricities, either of 5% or of 10%, which is critical for the proper assessment of the required width of the provided seismic gap around a BIB to avoid any impact incidences during very strong seismic excitations. On contrary, regarding the deformations of the superstructure, minor differences are observed for both peak interstory drifts and absolute floor accelerations due to the mass eccentricities, which leads to the conclusion that the superstructure of a base-isolated building is practically not affected by the accidental mass eccentricities.

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