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Pounding of a base-isolated building against adjacent fixed-supported buildings during near-fault seismic excitations

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Abstract

The peak seismic response of a 3-story base isolated building (BIB) is investigated while varying important parameters, such as the incidence angle of the imposed seismic excitations, the available seismic clearance and potential mass eccentricities, under the action of bidirectional horizontal seismic excitations, taking into account potential poundings with adjacent structures or the perimetric moat wall. A set of 5 strong near-fault (NF), fault-normal (FN) and fault-parallel (FP) pairs of seismic recordings is used, while the angle of incidence may vary in an automated parametric procedure.

The BIB is considered adjacent to a 2, 3, or 4-story fixed-supported building, which is located on its one side, while pounding may occur, not only at its base with the moat wall, but also at the upper floors of the adjacent buildings. The floor-slabs of the neighboring buildings are assumed to be located at the same levels, leading to potential slab-to-slap impacts. The parametric studies are performed using a custom-developed software application, which enables the spatial simulation of base-isolated buildings modeled as 3D MDOF systems with shear-type behavior with impact capabilities. The slabs are modeled as rigid diaphragms and the masses are lumped at the floor levels with 3 DOF at each floor. The impact modeling is based on an overlapping region and a contact plane according to which normal and tangential impact forces can be assessed, while the Coulomb law of friction restricts the magnitude of the tangential impact forces. The equations of motion of the simulated buildings are formulated at each time step taking into account the impact forces, whenever there is contact, and numerically integrated.

The conducted parametric analyses indicate that the necessary width of the provided seismic gap depends on the characteristics of both the earthquake excitation and the structural characteristics, as well as the incidence angle of the imposed earthquake excitations. Furthermore, the extent at which the incidence angle influences the peak response depends on the structural systems and the separation distance. Since the computed results cannot be generalized, numerical simulations and parametric analyses should be performed for each particular case in order to identify the most critical seismic response and obtain a more reliable assessment of the expected peak seismic response and the required clearance to avoid structural pounding in case of a very strong seismic excitation.

Keywords: base isolation, seismic isolation, near-fault excitations, seismic gap, incidence angle

1 Introduction

Since it is essential to ensure a wide seismic gap around a base isolated building (BIB) to accommodate the expected large relative displacements at the isolation level, the proper estimation of the required width is very crucial in order to avoid structural pounding with the adjacent moat wall or a neighboring building during a very strong earthquake excitation. A number of recent research works have investigated this research problem [1-4], considering factors that might influence the spatial dynamic responses of base isolated buildings during impact with the surrounding moat walls or/and adjacent structures.

In the presented research work, the peak seismic response of a base isolated building is investigated while varying important parameters, such as the incidence angle of the imposed seismic excitations, the available seismic clearance and potential mass eccentricities, under the action of bidirectional horizontal seismic excitations. Parametric studies are performed, using a specially developed software that implements an efficient approach [3] to model spatial impacts with arbitrary locations of the potential impact points.

Specifically, a typical symmetric 3-story, 3x3 bays of 5.5m and height 3.2m, BIB (Figure 1) is considered adjacent to a 2, 3, or 4-story fixed-supported building, which is located on its one side. Pounding may occur, not only at its base with the moat wall, but also at the upper floors of the adjacent buildings due to the deformation of their superstructures. The floor-slabs of the neighboring buildings are assumed to be located at the same levels, leading to potential slab-to-slap impacts.

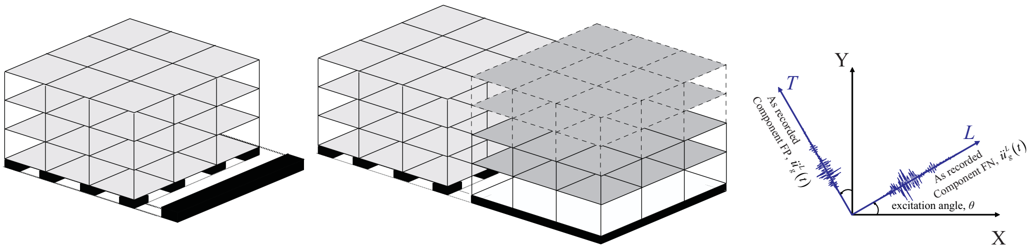


Figure 1: Typical symmetric 3-story BIB.

A set of 5 strong near-fault (NF), fault-normal (FN) and fault-parallel (FP) pairs of seismic recordings has been selected and used, with the major characteristics of the imposed earthquake excitations summarized in Table 1, while the angle of incidence may vary in an automated parametric procedure through the developed software that performs the parametric studies.

Earthquake	M_w	Station	Comp	PGA (g)	PGV (cm/s)	PGD (cm)
Loma Prieta, USA 1998	6.9	LGPC	FN	0.94	97	62.5
			FP	0.54	72.1	30.5
Erzican, Turkey 1992	6.7	Erzincan	FN	0.49	95.4	32.1
			FP	0.42	45.3	16.5
Northridge-01, USA 1994	6.7	Newhall -W Pico Canyon Rd.	FN	0.43	87.7	55.1
			FP	0.28	74.7	21.8
Northridge-01, USA 1994	6.7	Sylmar – Converter Sta	FN	0.59	130.3	54
			FP	0.8	93.3	53.3
Denali, Alaska 1999	6.2	TAPS Pump Station #10	FN	0.33	95.5	92.4
			FP	0.27	121.3	116.2

Table 1. Major characteristics of the imposed earthquake excitations.

2 Methods

The parametric studies are performed using a custom-developed software application [4], which enables the spatial simulation of base-isolated buildings modeled as 3D MDOF systems with shear-type behavior. The slabs are modeled as rigid diaphragms and the masses are lumped at the floor levels with 3 DOF at each floor. The nonlinear inelastic bidirectional coupled Bouc–Wen model is employed for the simulation of the base isolation system, with a coupled plasticity model to take into account the bidirectional lateral response of the seismic isolators [5-7]. The adjacent moat wall, which is assumed to be 100 cm thick and 100 cm high, is modeled as a single-mass system, with three dynamic DOF.

The impact modeling is based on an overlapping region and a contact plane according to which normal and tangential impact forces can be assessed, while the Coulomb law of friction restricts the magnitude of the tangential impact forces. The equations of motion of the simulated buildings are formulated at each time step taking into account the impact forces, whenever there is contact, and numerically integrated using the Newmark method.

The utilized methodology is quite simple and efficient, taking into account the geometry at the vicinity of impact. The location of impact is not pre-determined and multiple impacts can be simultaneously considered. With this approach, the investigation of effects of certain factors that cannot be examined using planar (2D) simulations, such as the effect of the incidence angle, which might play an important effect on the peak seismic response [8-9], torsional effects due to eccentricities and the spatial effect of adjacent conventionally fixed-supported structures.

The following section provides the maximum of the peak interstory drifts of the 4 corner columns of the BIB, under each of the five earthquake excitations (unscaled), as computed from spatial parametric studies, considering potential pounding with the moat wall or/and with adjacent conventionally fixed-supported buildings. The possibility of mass eccentricities of 10% is also investigated in order to assess its effect on the peak seismic response, as well as the estimated width of the required seismic gap around the BIB in order to avoid structural pounding under the specific earthquake excitations.

3 Results

Figures 2, 3 and 4 provide the peak interstory drift ratios (resultant) at each floor of the 3-story BIB during poundings with either the moat wall or/and the 2-, 3- and 4-story respectively, adjacent fixed-supported buildings (FSBs), with the same characteristics as those of the superstructure of the base isolated building (BIB), in terms of the angle of incidence. A seismic gap of 20 cm is set, while two cases are investigated: (a) without any eccentricities, and (b) with bidirectional eccentricities of the superstructure of the BIB equal to 10% of the floor plan dimensions of the floors.

The critical angle of incidence, along which the seismic excitations cause the maximum interstory drifts is not along the major construction axes of the BIB and it differs for each of the five earthquakes that are imposed. Therefore, the usual practice of imposing the seismic excitations along the major construction axes may lead to substantial underestimation of the actually expected peak seismic response and the required width of the provided seismic gap.

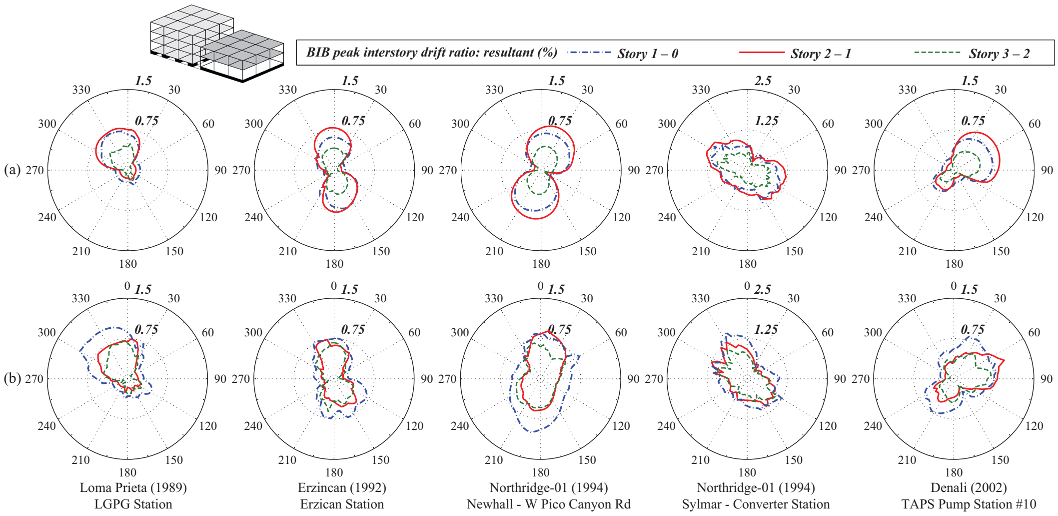


Figure 2: Peak ratio of the interstory drifts resultant at each floor of the BIB during collisions with the adjacent 2-story FSB and the moat wall, in terms of the angle of incidence considering a gap size of 20 cm: (a) no eccentricity case, (b) 10% bidirectional eccentricities.

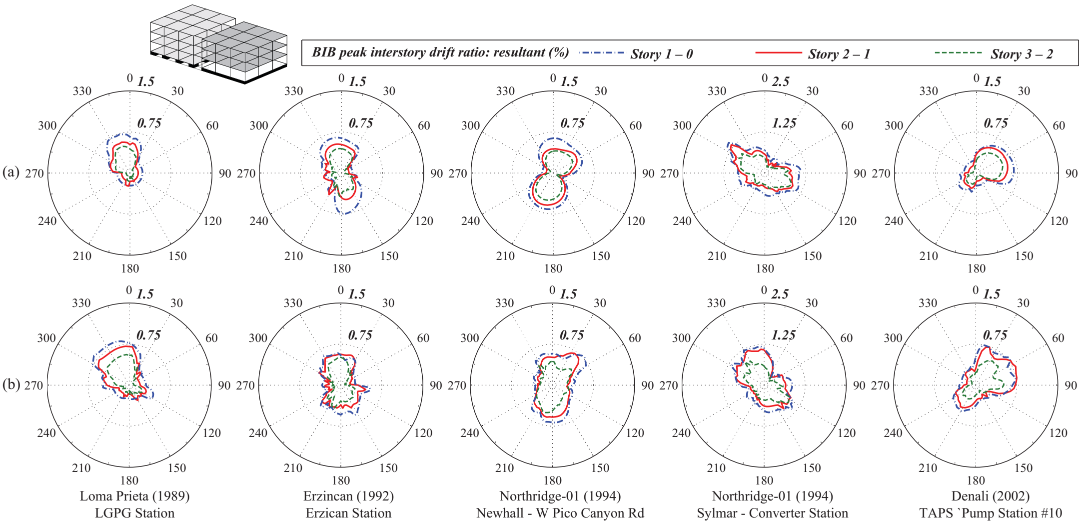
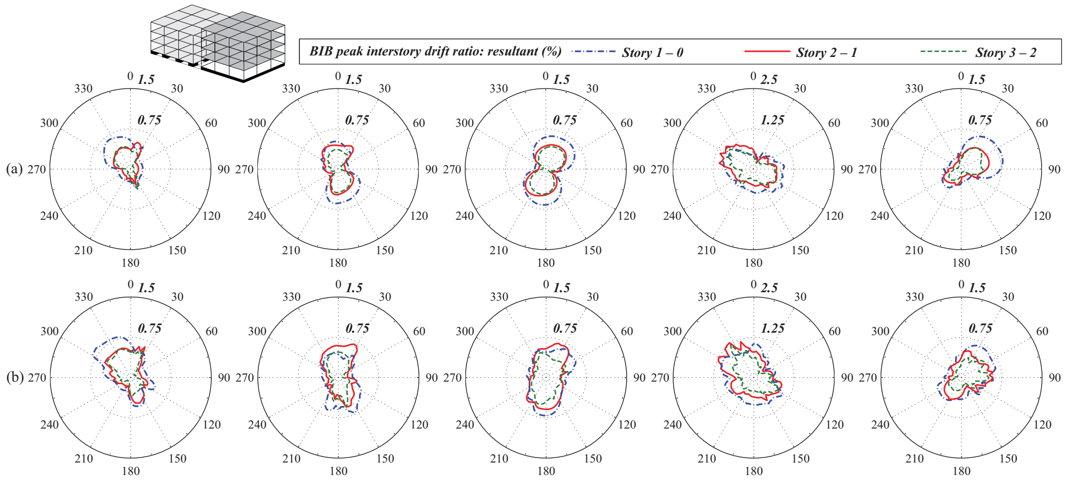


Figure 3: Peak ratio of the interstory drifts resultant at each floor of the BIB during collisions with the adjacent 3-story FSB and the moat wall, in terms of the angle of incidence considering a gap size of 20 cm: (a) no eccentricity case, (b) 10% bidirectional eccentricities.



Loma Prieta (1989)
LGPG Station

Erzincan (1992)
Erzican Station

Northridge-01 (1994)
Newhall - W Pico Canyon Rd

Northridge-01 (1994)
Sylmar - Converter Station

Denali (2002)
TAPS Pump Station #10

Figure 4: Peak ratio of the interstory drifts resultant at each floor of the BIB during collisions with the adjacent 4-story FSB and the moat wall, in terms of the angle of incidence considering a gap size of 20 cm: (a) no eccentricity case, (b) 10% bidirectional eccentricities.

Subsequently, the peak interstory drifts of the BIB, which is adjacent to a 2-, 3- and 4-story conventionally FSB, while the width of the available seismic gap varies between 15 and 45 cm, are computed for the seismic excitations with 0° and 180° angles of seismic incidence. Figure 5 provides the envelope of peak interstory drifts of the BIB among the corner columns in terms of the available seismic gap size for different arrangement of the adjacent FSB and moat wall, for 0° and 180° incidence angles.

The computed peak seismic responses indicate that seismic characteristics, such as the direction and frequency content, of the imposed ground motion, also can significantly affect the peak interstory drift ratios. In general, the superstructure’ drift ratio increases rapidly when the separation distance between structures decreases and, then, in some cases, might slightly decrease with further reduction in the separation.

4 Conclusions and Contributions

Spatial (3D) simulations of a typical 3-story BIB standing adjacent to a 2, 3, or 4-story FSB, which is located on its one side, with the ability to consider pounding that may occur, not only at its base with the moat wall, but also at the upper floors of the adjacent buildings, have been conducted using a specially designed and developed software, which allows the efficient performance of parametric studies. Pairs of horizontal (FN and FP) components of 5 strong near-fault seismic recordings have been used, with the simulated buildings subjected to two orthogonal seismic components, of which the angle of incidence could be automatically varied.

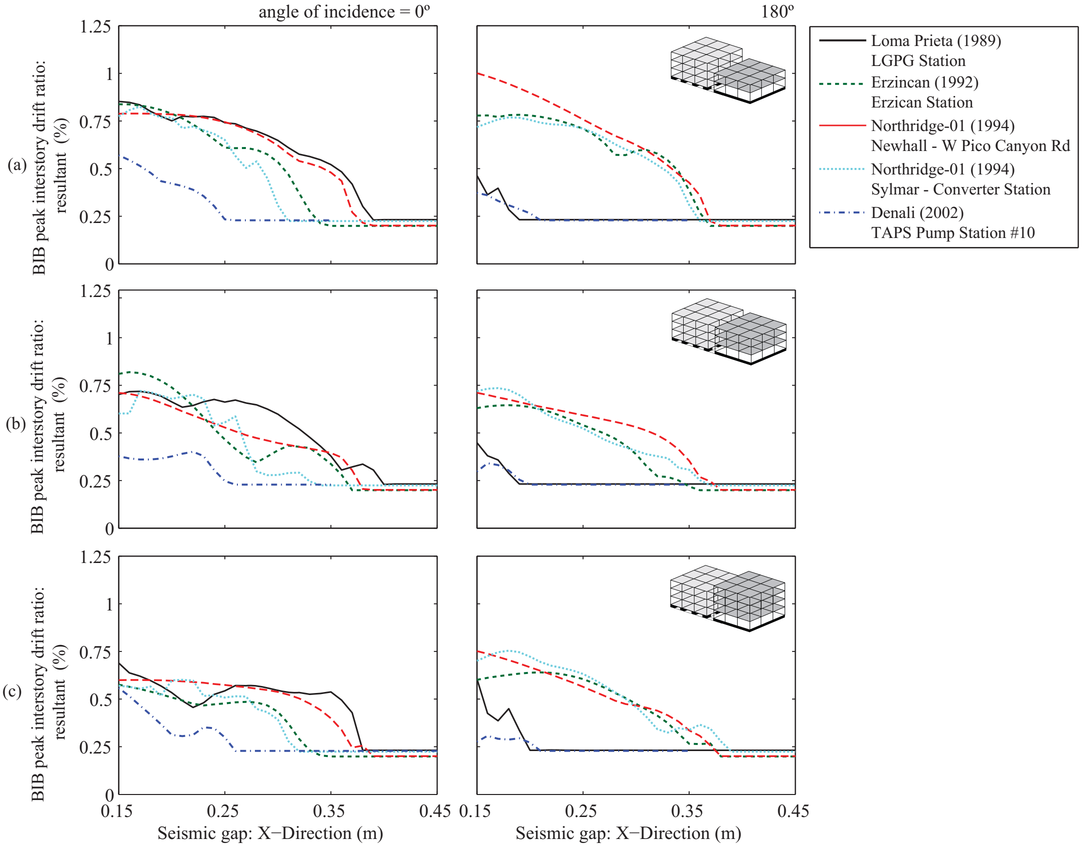


Figure 5: Envelope of peak interstory drifts of the BIB among the corner columns in terms of the available seismic gap size for different arrangement of the adjacent FSB and moat wall, for angle of incidence equal to 0° and 180°.

The parametric analyses have shown that the possibility of pounding increases and the detrimental effects of pounding become more severe for certain values of the incidence angle of the imposed excitations. Furthermore, the characteristics and potential eccentricities of the adjacent structures may significantly affect the peak seismic response of the base isolated building in case of structural pounding. Consequently, spatial simulations and parametric analyses should be performed for each particular case, in order to obtain a more reliable assessment of the required width of the provided seismic gap and the expected peak seismic response in case of potential pounding.

Torsional effects that a base isolated building might experience due to potential mass eccentricities may further increase the required width of the provided clearance to prevent structural pounding and, in case of unavoidable pounding, may significantly increase its peak seismic response. The parametric analyses indicated that the necessary width of the provided seismic gap depends on the characteristics of both the earthquake excitation and the structural characteristics, as well as the incidence angle of the imposed earthquake excitations. The extent at which the incidence angle influences the peak response depends on the structural systems (e.g.

number of stories and/or moat wall) and the separation distance. Since the process of identifying the critical incidence angle is more complex while considering pounding to adjacent multistory buildings, the results presented herein cannot be generalized. Therefore, numerical simulations and parametric analyses should be performed for each particular case in order to identify the most critical seismic response and obtain a more reliable assessment of the expected peak seismic response and the required clearance to avoid structural pounding in case of a very strong seismic excitation.

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