Seismic response of a base-isolated building under pulse-like near-fault ground motions

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ABSTRACT

Pulse-Like Near-fault ground motions are known to challenge base-isolated buildings with their capacity to create large isolation system displacements. Such earthquake records typically contain velocity pulses with long periods and thus threaten base-isolated buildings which also have long fundamental periods that may coincide with the pulse periods of the near-fault earthquakes.

The previous studies on the influence of pulse-like near fault ground motions on the response of seismically isolated buildings concluded that the velocity pulse period influences the seismic isolator displacement and the floor acceleration. Most of the previous studies were conducted using ground motions simulated with certain parametric conditions of near-fault ground motions and/or a limited number of real earthquake ground motions.

This study intended to examine the conclusions of previous studies through response history analysis of a seismically isolated prototype building using a large number of real near-fault earthquake ground accelerations.

It was found that no consistent resonance phenomenon can be observed when the velocity pulse period is close to the natural period of the isolated building when the building is located in soft soil regions in terms of floor acceleration and isolator displacement.

1 INTRODUCTION

Seismic base isolation has been used in the past decades to protect structures from the destructive effects of earthquakes. Many seismically isolated buildings subjected to real earthquakes have displayed the expected structural performance so far. The base isolation system essentially separates the upper stories from the foundation or basement by relatively weak and elastoplastic isolation devices like lead rubber or spherical sliding bearings. The base isolators increase the fundamental vibration period and damping capacity of the structures, which reduces the structural response to the earthquake ground shaking (Kelly 1999; Aydin et al. 2012).

The characteristics and wave content of the earthquake ground motions are influential on the performance of the seismic base isolation system (Moustafa et al. 2010). The near-fault (NF) earthquake ground motions containing large amplitude velocity pulses have induced larger lateral displacement demand than the far-fault (FF) ones do.

In particular, base-isolated buildings may be protected from ground motions including high frequencies and sharp accelerations effectively. On the contrary, when the base-isolated buildings are subjected to the near-fault ground motions, the isolation system may not be as effective and increases in the structural response parameters may be observed (Makris, 1997). Long-period pulses with high peak ground velocities characterize the near-fault ground motions (Agrawal and He, 2002) and these pulses may have the potential for causing detrimental effects on flexible structures (Hall et al. 1995) such as base-isolated buildings.

The effects of the NF earthquake ground motions to the behaviour of seismically isolated buildings have been extensively studied by numerous researchers. Some of the significant studies are summarized in the following.

Lu et al. (2003) expressed that a resonance phenomenon was observed around the fundamental period of the isolated structure when it was close to the velocity pulse period of artificial NF ground motion. The pulse has more influence on the isolator displacement than the acceleration of the superstructure.

Jangid (2007) indicated that for low yield strength of lead–rubber bearing (LRB) isolators, there is significant displacement in the bearing under NF motions. The optimum yield strength of the LRB was found to be 10%–15% of the total weight of the building under NF motions.

Lu et al. (2013) concluded that, although a pulse excitation is not harmonic, it is still able to exert a resonance-like behaviour for the isolator displacement of an isolation system when the pulse period is close to the isolation period.

Özuygur (2021) studied the story acceleration of base-isolated buildings with various seismic load-resisting systems under NF and FF earthquakes. It was concluded that the floor acceleration can be reduced effectively by providing more rigidity to the superstructure and that excessive damping is detrimental.

The common conclusions drawn from the previous studies are that the NF ground motions mostly impose larger displacement on the seismic isolators and in some cases, larger floor acceleration. Furthermore, the velocity pulse period influences the seismic isolator displacement and the floor acceleration. However, most of the previous studies were conducted using ground motions simulated with certain parametric conditions of NF ground motions and/or a limited number of real earthquake ground motions.

In this study, the conclusions of the past studies were examined through response history analysis of a seismically isolated building using a large number of real NF earthquake ground motions whose velocity pulse periods vary from the shortest to the longest.

2 CASE STUDY

2.1 Properties of the structure & base isolators

The case study is an eight-story 2D steel framed office building with an Importance Level of 3 located in Wellington, NZ with a soil type D. The model configuration is shown in Figure 1. Total seismic weight of 10000kN is considered. The properties of the example building and base isolator are shown in Table 1 and Table 2. Mixed of lead rubber bearings and sliders have been used in this study and the isolation system force displacement behaviour are shown in Figure 2. The effective period of the isolation system with lower bond and upper bond properties obtained from the dynamic analysis was 2.15s and 1.85s respectively which has been used in scaling the NF ground motions to the target spectrum. The effective displacement of the base isolation system with lower bond and upper bond properties is 750mm and 600mm respectively which is shown in Figure 2.

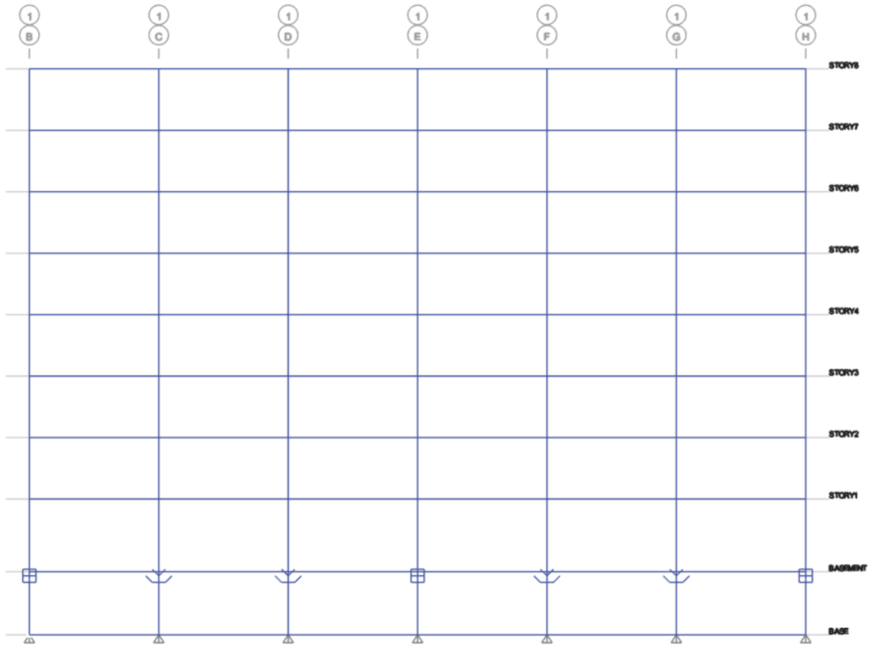

Figure 1: Case Study Model

Table 1: Properties of Example Building

Items	**Properties**
Inter-storey height [m]	3.8m
Bay length [m]	8m
Seismic Weight [kN]	10000 kN
Column dimensions [mm]	950CHS20_ConcFilled
Beam dimension [mm]	800HCB466

Table 2: Properties of Base Isolators

Items	**Symbol**	**Value**	**Units**
Nominal effective yield stress of lead	σ_{YL}	10	MPa
Nominal shear modulus of rubber	G	0.45	MPa
Nominal friction coefficient (fast)	μ	0.075	
Lead core diameter	D_L	324	mm
Bonded rubber diameter	D_B	1300	mm
Total thickness of rubber	T_r	280	mm
Yield displacement	Y	15	mm
LRB Characteristic Strength (nominal)	Q_d	825	kN
LRB Post-elastic Stiffness (nominal)	k_d	2	kN/mm

Properties based on values provided by Earthquake Protection Systems (EPS)

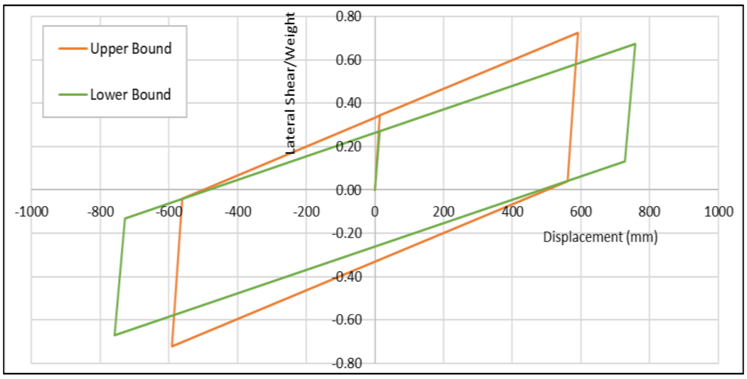

Figure 2: Isolation System Force-Displacement Behaviour, CALS

3 SEISMIC HAZARD AND GROUND MOTIONS SELECTION

A Probabilistic Seismic Hazard Analysis (PSHA) is conducted to obtain the acceleration and displacement spectra. The PSHA is calculated using the latest version of the national seismic hazard model (NSHM) from GNS, most significantly updated in Stirling et al. (2012) from the initial model constructed in Stirling et al. (2002). The ground motion prediction equations (GMPEs) employed are those for NGA-West2 GMPEs as recommended in Van Houtte (2017a). Site-specific Uniform Hazard Spectra (UHS) results have been provided at the 1000-year, and 2500-year return periods, corresponding to 50-year probabilities of exceedance of 5%, and 2%.

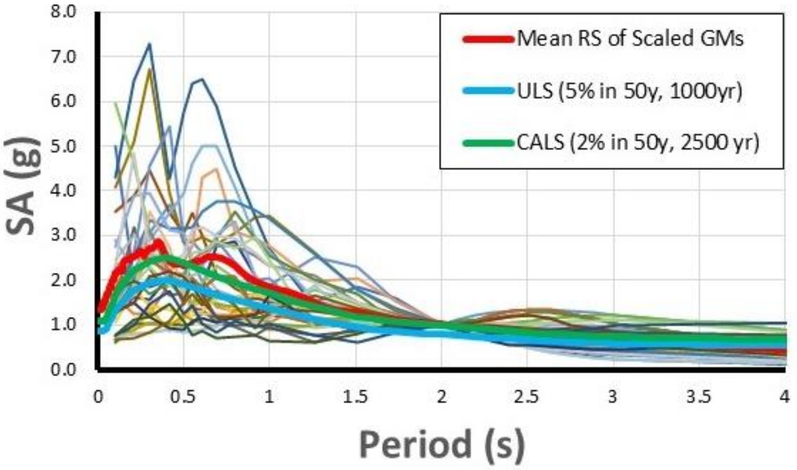

Figure 3: Mean 5% damped uniform hazard spectra

The ground motion selection follows the requirements of NZS1170.5 Section 5.5. First, 91 unidirectional near fault pulse like earthquake ground acceleration time histories (Baker, 2007) whose velocity pulse periods vary from 0.4 to 12.9s were obtained from PEER (2019). However, the records with the scaling factor of more than 4 were rejected and only 36 records are selected for the time history analysis in this study as shown in Table 3. The characteristics, including pulse amplitudes of the selected ground motions and the scaling factors are given in Table 3. To keep the pulse characteristics of the ground motions, amplitude scaling has been used not spectrum matching. All the ground motions have been scaled to the target spectrum (CALS) of a single conditional period (Baker 2011; Carlton and Abrahamson 2014; Kwong and Chopra 2017), the natural period of the isolated building, which is 2.15s. The reason for scaling the NF ground motions to the single-period spectral acceleration is to keep all the selected ground motions at the same amplitude of acceleration around the natural period of the isolated building as much as possible to catch the influence of velocity pulse period amplitude more precisely.

4 NONLINEAR TIME HISTORY ANALYSES AND RESULTS

Response history analyses were performed on the prototype building using the NF earthquake ground motions given in the previous section. The maximum isolator displacement obtained from the analysis of the NF ground motions is presented in Table 3 & Figure 4 showing the corresponding pulse period to demonstrate the influence of the pulse period on the isolator displacement. Neither a consistent relation between peak isolator displacement and the pulse period nor the resonance phenomenon around the conditional period 2.15s was observed unlike the previous conclusions based on simulated ground motions.

The ground motions with record number of 11, 12, 28, 38, 40, 50, 58, 74, 75, and 84 generated peak isolator displacement demand larger than 750 mm, whereas the rest generated peak isolator displacement demand smaller than 750mm. The mean value of the peak isolator displacements was calculated as 680 mm, which was interestingly close to the isolator displacement obtained from the equivalent lateral force procedure as 750mm.

Table 3: Pulse-like near fault ground motions properties.

No	Event	Year	Station	Tp	Pulse Amplitude	M_w	R_{jb}	Scale	Max Isolator Dis. (mm)
3	Imperial Valley-06	1979	Aeropuerto Mexicali	2.4	44.3	6.5	0.3	4	599
4	Imperial Valley-06	1979	Agrarias	2.3	54.4	6.5	0.7	3.1	572
7	Imperial Valley-06	1979	EC Meloland Overpass FF	3.3	115	6.5	0.1	1.7	553
11	Imperial Valley-06	1979	El Centro Array #4	4.6	77.9	6.5	7.1	3	988
12	Imperial Valley-06	1979	El Centro Array #5	4	91.5	6.5	4	2.9	1069
13	Imperial Valley-06	1979	El Centro Array #6	3.8	112	6.5	1.4	2.4	823
14	Imperial Valley-06	1979	El Centro Array #7	4.2	109	6.5	0.6	2.2	718
16	Imperial Valley-06	1979	El Centro Differential Array	5.9	59.6	6.5	5.1	4	713
19	Irpinia, Italy-01	1980	Sturno	3.1	41.5	6.9	10.8	3.8	284
28	N. Palm Springs	1986	North Palm Springs	1.4	73.6	6.1	4	4.1	829
29	San Salvador	1986	Geotech Investig Center	0.9	62.3	5.8	6.3	3.5	601
32	Superstition Hills-02	1987	Parachute Test Site	2.3	107	6.5	1	1.25	516
34	Loma Prieta	1989	Gilroy Array #2	1.7	45.7	6.9	11.1	4	773
35	Loma Prieta	1989	Oakland - Outer Harbor Wharf	1.8	49.2	6.9	74.3	4.16	674
36	Loma Prieta	1989	Saratoga - Aloha Ave	4.5	55.6	6.9	8.5	3.33	616
37	Erzican, Turkey	1992	Erzincan	2.7	95.4	6.7	4.4	1.67	679
38	Cape Mendocino	1992	Petrolia	3	82.1	7	8.2	2.85	879
40	Landers	1992	Lucerne	5.1	140	7.3	2.2	3.33	1565
42	Northridge-01	1994	Jensen Filter Plant	3.5	67.4	6.7	5.4	2.5	654
43	Northridge-01	1994	Jensen Filter Plant Generator	3.5	67.4	6.7	5.4	2.5	656

45	Northridge-01	1994	LA Dam	1.7	77.1	6.7	5.9	2.85	624
46	Northridge-01	1994	Newhall - W Pico Canyon Rd.	2.4	87.8	6.7	5.5	1.56	681
49	Northridge-01	1994	Rinaldi Receiving Sta	1.2	167	6.7	6.5	1.72	621
50	Northridge-01	1994	Sylmar - Converter Sta	3.5	130	6.7	5.4	1.85	825
51	Northridge-01	1994	Sylmar - Converter Sta East	3.5	117	6.7	5.2	2.38	627
52	Northridge-01	1994	Sylmar - Olive View Med FF	3.1	123	6.7	5.3	1.58	477
53	Kobe, Japan	1995	Takarazuka	1.4	72.6	6.9	0.3	2.5	339
54	Kobe, Japan	1995	Takatori	1.6	170	6.9	1.5	0.7	405
56	Chi-Chi, Taiwan	1999	CHY006	2.6	64.7	7.6	9.8	2.38	427
58	Chi-Chi, Taiwan	1999	CHY101	4.8	85.4	7.6	10	3.57	1003
73	Chi-Chi, Taiwan	1999	TCU065	5.7	128	7.6	0.6	1.25	306
74	Chi-Chi, Taiwan	1999	TCU068	12	191	7.6	0.3	1.58	1011
75	Chi-Chi, Taiwan	1999	TCU075	5.1	88.4	7.6	0.9	2.7	791
81	Chi-Chi, Taiwan	1999	TCU102	9.7	107	7.6	1.5	2.2	638
84	Chi-Chi, Taiwan	1999	TCU128	9	78.7	7.6	13.2	4	770
91	Chi-Chi, Taiwan-06	1999	CHY101	2.8	36.3	6.3	36	3.33	199

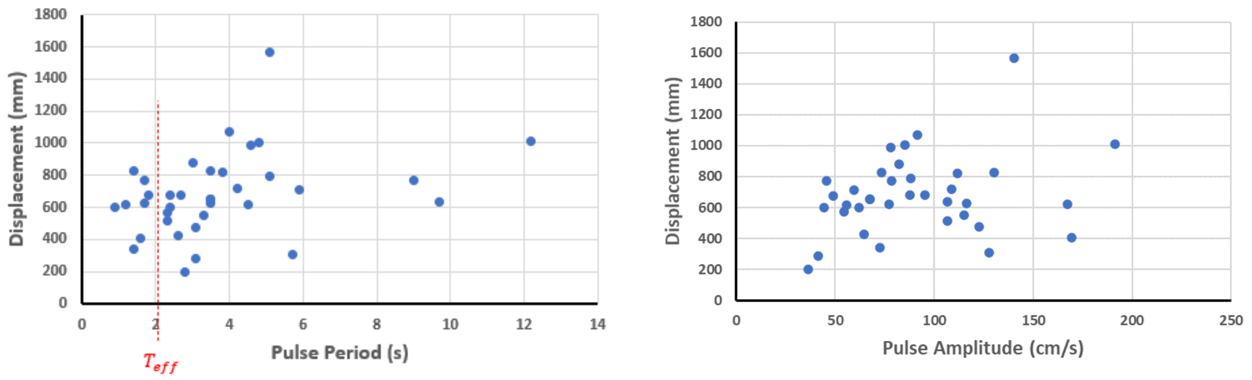

Figure 4: Influence of the pulse period & amplitude on the isolator displacement

5 CONCLUSION

Based on the response history analyses conducted on the prototype building using the real NF ground motions, the following conclusions can be made:

1. No resonance phenomenon is observed when the velocity pulse period is close to the natural period of the isolated building.
2. There is not any consistent relationship between the velocity pulse period and the peak isolator displacement.
3. There is not any consistent relationship between the velocity pulse amplitude and the peak isolator displacement.

4. The increase or decrease in the isolator displacement, is predominantly caused by the ordinate of the acceleration spectra.

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