COMPDYN 2013
4th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Kos Island, Greece, 12–14 June 2013

EFFECT OF NEAR-FAULT GROUND MOTIONS ON SEISMIC RESPONSE OF DEEP BASEMENT WALLS

E. Amirzehni[1], M. Taiebat[1], W.D.L. Finn[1], and Ronald H. Devall[2]

[1]Department of Civil Engineering, University of British Columbia, Vancouver, BC, Canada
e-mail: {elnazam,mtaiebat,finn}@civil.ubc.ca

[2] Read Jones Christoffersen Ltd., Vancouver, BC, Canada
e-mail: rdevall@rjc.ca

Keywords: Basement Wall, Seismic Response, Near-Fault Motions, Dynamic Analysis

Abstract. *The current state of practice for seismic design of basement walls in British Columbia is using the Mononobe-Okabe (M-O) method, which is based on the Peak Ground Acceleration (PGA). Preliminary results from a recent study of the authors show that the designed walls based on the M-O method with the code mandated PGA for Vancouver are too conservative. This conclusion was achieved by designing the basement wall for the earth pressures derived from the M-O method with different fraction of the code PGA, then subjecting the designed walls to ground motions matched to the UHS of Vancouver in a series of dynamic analyses, and monitoring the performance of the walls from results of the analyses. It was found that walls designed for the M-O pressures based on 50-60% PGA in Vancouver result in satisfactory performance in terms of moment, shear capacity, and drift ratio along the height of the wall, when subjected to ground motions with a 2% exceedance rate in 50 years. This conclusion was based on the use of far-fault motions for analysis. The objective of the present study is to check whether such walls would be safe when subjected to near-fault motions of approximately similar intensity.*

1 INTRODUCTION

Ground motions close to a ruptured fault can be significantly different than those observed further away from the seismic source. The near-fault zone is typically assumed to be restricted to within a distance of about 10 km from the ruptured fault. In the near-fault zone, ground motions contain large velocity pulses, typically with periods of $T = 2^+$ seconds, which impart concentrated energy input at the longer periods [1]. Pulse-type motions have been identified as critical in the design of buildings in the near-fault zone and their effect is to increase the long-period portion of the acceleration response spectrum which leads to larger displacements [2].

The current state of practice for seismic design of basement walls in British Columbia is using the Mononobe-Okabe (M-O) method [3, 4], which is based on the Peak Ground Acceleration (PGA). In 2005 the National Building Code of Canada (NBCC) changed the seismic hazard level from 10% in 50 years in NBCC 1995 to 2% in 50 years in NBCC 2005, which leads to doubling the PGA in Vancouver from 0.24g to 0.46g [5, 6]. This new hazard level remained the same in NBCC 2010 [7]. The new PGA leads to very large seismic forces that make the resulting structures much more expensive. Since there is a little evidence of any significant damage to basement walls during major earthquakes, the Structural Engineers Association of British Columbia (SEABC) considered that current design procedures must be overly conservative and initiated a task force to review the current design procedures for seismic design of basement walls. The authors have the task to evaluate the current design procedure.

A series of nonlinear two-dimensional dynamic analyses have been conducted to model the seismic behavior of the basement walls designed for various fractions of the NBCC 2010 PGA for Vancouver. Preliminary results in recent studies of the authors indicate that walls designed for M-O pressures based on 50-60% PGA in Vancouver are safe for the ground motions with a 2% exceedance rate in 50 years [8, 9]. These conclusions are based on the use of far-fault motions for analysis. This paper describes an extension of the previous study to evaluate the performance of basement walls subjected to near-fault motions with approximately similar intensities. These motions differ from near-fault motions in having large velocity pulses.

2 DESCRIPTION OF COMPUTATIONAL MODEL

A basement wall was designed by Structural Engineering Association of British Columbia (SEABC) specifically for this study based on the current state of practice but using the earth pressure derived from the M-O method with 50% of the code mandated PGA for Vancouver. The design PGA for Vancouver in the current code NBCC 2010 is 0.46g which corresponds to the probability of exceedence of 2% in 50 years. Taiebat et al. [8, 9] analyzed the nonlinear seismic response of this basement wall by using the two–dimensional finite difference computer program FLAC 7.00 [10]. In their simulations the response of the soil was modeled by a Mohr-Coulomb elastic-perfectly

(d)

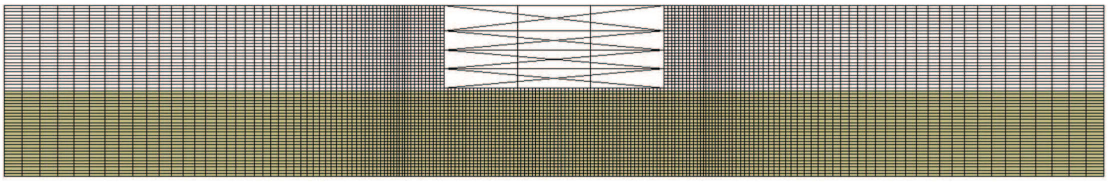


Figure 1: Basement wall model in FLAC [8, 9]

plastic constitutive model with degraded elastic moduli. The required model parameters were elastic shear modulus, Poisson's ratio, cohesion, friction, and dilation angles of soil. Similar numerical model has been employed in the present study to explore the effect of near fault ground motions on the seismic response of the designed basement wall. The properties used in conjunction with the Mohr-Coulomb model for the two layers of soil shown in Figure 1 are the same as used by Taiebat et al. [8, 9] in their analyses of the same wall under far-fault motions. Predominant period of the system under the damped free vibration conditions was calculated to be $T = 0.4$ seconds.

3 SELECTING GROUND MOTIONS

The ground motion database compiled for studying the effects of near-fault ground motions constitutes a representative number of far-fault and near-fault ground motions. Eigth far-fault ground motions, listed in Table 1, were selected from the Pacific Earthquake Engineering Research Center (PEER) strong ground motion database [11]. The candidate input motions are in the magnitude range of 6.5 to 7.5, within 30 km of the causative fault plane from earthquake sites with average shear wave velocities, Vs30, in the range of 360 and 760 m/s which is consistent with the reference site class in NBCC 2010. Each of the selected motions has two components, fault normal and fault parallel; the component of the motion which has a higher PGA was selected for the analysis and reported in Table 1.

A total of nine near-fault records with forward directivity were also chosen from the PEER database and are shown in Table 3. They cover a range of PGA, PGV, pulse periods, and distances from the fault. Only the effect of forward directivity is considered; the fling step effect is not studied. The records are from earthquakes having moment magnitudes range of 6.5 to 7.5, and were recorded at closest fault distances of 0 to 20 km. The records are again taken from site class C soils. In the case of near-fault motions, for each record, the component of the motion which leads to the higher drift ratio, after conducting the dynamics analyses (next section), is reported in Table 3 as the selected component.

Table 1: Earthquakes included in the study of far-fault ground motions

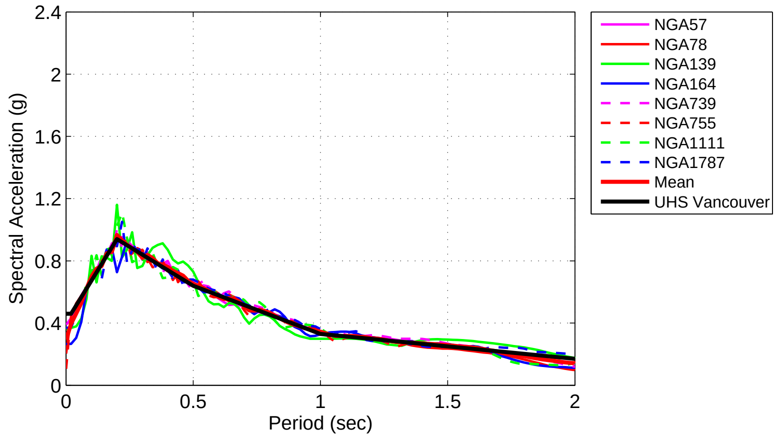
NGA	Event	Year	Station	Mag	Mechanism	R_{jb}(km)[a]	R_{rup}(k
57	San Fernando	1971	Castaic - Old Ridge Route	6.61	Reverse	19.3	22.6
78	San Fernando	1971	Palmdale Fire Station	6.61	Reverse	24.2	29
139	Tabas- Iran	1978	Dayhook	7.35	Reverse	0	13.9
164	Imperial Valley-06	1979	Cerro Prieto	6.53	Strike-Slip	15.2	15.2
739	Loma Prieta	1989	Anderson Dam (Downstream)	6.93	Reverse-Oblique	19.9	20.3
755	Loma Prieta	1989	Coyote Lake Dam (SW Abut)	6.93	Reverse-Oblique	20	20.3
1111	Kobe- Japan	1995	Nishi-Akashi	6.9	Strike-Slip	7.1	7.1
1787	Hector Mine	1999	Hector	7.13	Strike-Slip	10.3	11.7

(a) Joyner-Boore distance to rupture plane.
(b) Closest distance to rupture plane.

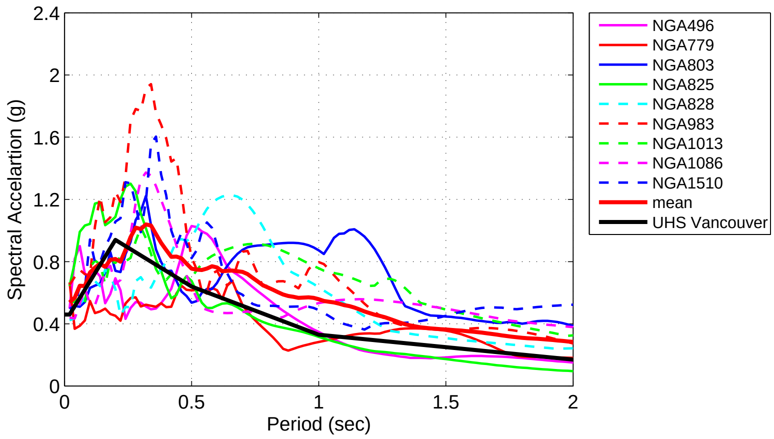
Table 2: Earthquakes included in the study of near-fault ground motions

NGA	Event	Year	Station	Mag	Mechanism	R_{jb}(km)	R_{rup}(k
496	Nahanni- Canada	1985	Site 2	6.76	Reverse	0	4.9
779	Loma Prieta	1989	LGPC	6.93	Reverse-Oblique	0	3.9
803	Loma Prieta	1989	Saratoga - W Valley Coll.	6.93	Reverse-Oblique	8.5	9.3
825	Cape Mendocino	1992	Cape Mendocino	7.01	Reverse	0	7
828	Cape Mendocino	1992	Petrolia	7.01	Reverse	0	8.2
983	Northridge-01	1994	Jensen Filter Plant Generator	6.69	Reverse	0	5.4
1013	Northridge-01	1994	LA Dam	6.69	Reverse	0	5.9
1086	Northridge-01	1994	Sylmar - Olive View Med FF	6.69	Reverse	1.7	5.3
1510	Chi-Chi- Taiwan	1999	TCU075	7.62	Reverse-Oblique	0.9	0.9

The selected far-fault ground motions were spectrally matched to the NBCC 2010 Uniform Hazard Spectra (UHS) of Vancouver, in the period range of 0.02–1.7 seconds using computer program SeismoMatch [12]. The mean acceleration spectrum of these scaled records is shown in Figure 2(a) together with the NBCC 2010 UHS for Vancouver. Thus, on average, the nine time histories reasonably represent the NBCC 2010 UHS design level for Vancouver. On the other hand, the near-fault motions were linearly matched to UHS of Vancouver in the period range of 0.02–1.7 seconds to provide a basis for comparison of results from near-fault and far-fault ground motions. The acceleration response spectra of the scaled near-fault ground motions together with the



(a) Spectrally matched far-fault records

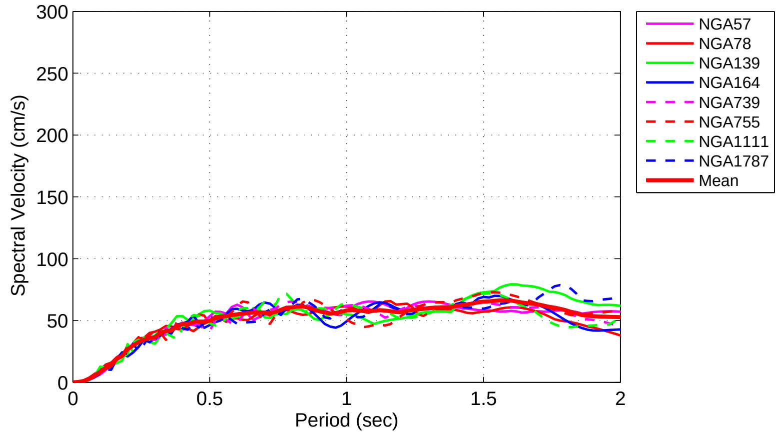


(b) Linearly matched near–fault records

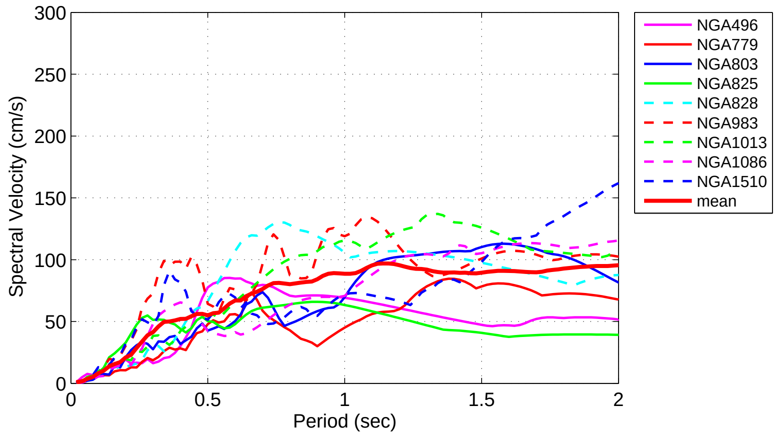
Figure 2: Design spectrum and acceleration response spectra of (a) spectrally matched far fault motions, and (b) linearly matched near-fault motions with forward directivity.

response spectrum defined for NBCC 2010 site class C are illustrated in Figure 2(b).

Figure 3 illustrates the velocity spectra of the far-fault and near-fault and records. This figure shows a great variability in near-fault response spectra especially in the longer periods. The figure demonstrates that near-fault records can impose very larger demands in the longer periods that should be taken into account in the design process.



(a) Spectrally matched far-fault records



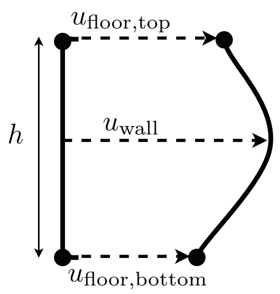
(b) Linearly matched near-fault records

Figure 3: Velocity response spectra of (a) spectrally matched far fault motions, and (b) linearly matched near-fault motions with forward directivity.

An important observation from the near-fault velocity spectrum is the existence of a predominant peak in most of the near-fault records. The predominant peak of the velocity spectrum is used to estimate the pulse periods in the near-fault records which are reported in Table 4.

4 RESULTS OF ANALYSIS AND DISCUSSION

Drift ratio is usually defined as the relative displacement between floor levels divided by story height. The deformation or the relative displacement of the wall at the middle of each basement is calculated as the difference between the displacement of the wall at that level and the displacement of the wall at its base. Drift ratio for each story is calculated as shown in Figure 4. The resulting drift ratio from this figure is a useful indicator to determine the amount of damage to the wall. In this figure h is the floor height, $u_{\text{floor,top}}$ and $u_{\text{floor,bottom}}$ are the wall deformations at the floor levels and u_{wall} is the deformation at the mid height of the wall (between two floors).



$$\text{Drift ratio} = \frac{2u_{\text{wall}} - (u_{\text{floor,top}} + u_{\text{floor,bottom}})}{h}$$

Figure 4: Definition of drift ratio for each story of the basement wall [8, 9].

This definition is consistent with the definition of hinge rotation used by Task Committee on Blast Resistance Design [13]. This committee related hinge rotation to structural performance. They specified two performance categories which may apply to basement walls; low and medium response categories. The Low Response Category is defined as 3.5% drift ratio: "localized building/component damage. Building can be used; however repairs are required to restore integrity of structural envelope. Total cost of repairs is moderate". The Medium Response Category is defined as 7% drift ratio: "widespread building/component damage. Building cannot be used until repaired. Total cost of repairs is significant". Tentatively a drift ratio of 3.5% or less is taken as an index of satisfactory performance in this study, consistent with the performance criterion in the previous studies of the authors on this subject [8, 9].

Calculated drift ratios for the far-fault and near-fault motions are presented in Tables 3 and 4, respectively, and are illustrated in Figure 5. The orientation of the structure with respect to the fault direction may determine the severity of the ground motion that the structure will experience in the near-fault region of a fault rupture. So regarding to the current selection of the near-fault motions, in some cases the fault-normal component causes the higher drift ratio in the basement wall and in other cases, the fault-parallel component. As mentioned previously, the component of the near-fault motion that causes the more severe deformation is reported in the tables.

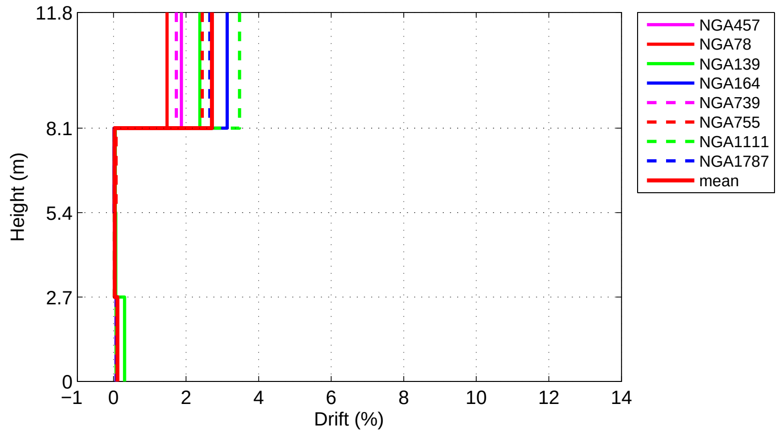
Table 3: Spectral values of the selected component of the far-fault records and the corresponding max

NGA	Event	Selected Comp.	PGA (g)	PGV (cm/s)	PGD (cm)	M
57	San Fernando	FN	0.36	24.82	5.36	
78	San Fernando	FP	0.34	18.11	4.25	
139	Tabas- Iran	FN	0.36	24.98	8.79	
164	Imperial Valley-06	FN	0.26	19.51	4.94	
739	Loma Prieta	FN	0.32	21.21	7.19	
755	Loma Prieta	FP	0.45	34.60	10.68	
1111	Kobe- Japan	FN	0.36	34.91	8.70	
1787	Hector Mine	FN	0.37	32.02	11.45	

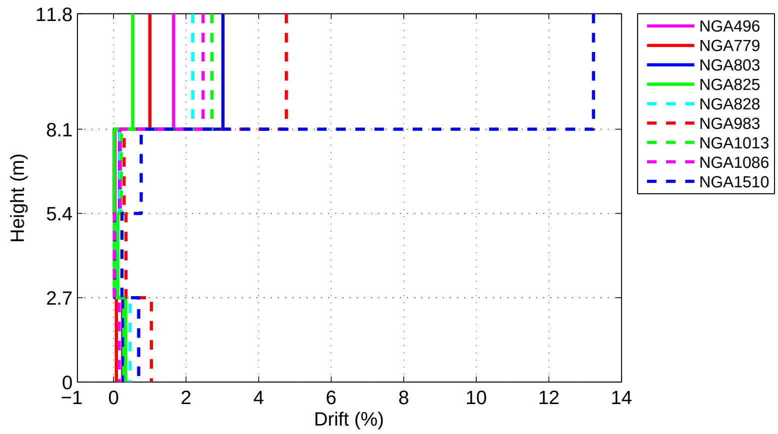
Table 4: Spectral values of the selected component of the near-fault records and the corresponding ma

NGA	Event	Selected Comp.	PGA (g)	PGV (cm/s)	PGD (cm)	Pulse Period
496	Nahanni-Canada	FP	0.41	41.81	9.30	0.81
779	Loma Prieta	FP	0.28	38.34	16.24	3
803	Loma Prieta	FN	0.49	73.60	36.54	1.9
825	Cape Mendocino	FP	0.62	51.32	16.55	4.9
828	Cape Mendocino	FN	0.42	41.33	17.81	0.95
983	Northridge-01	FP	0.63	38.38	13.70	3.5
1013	Northridge-01	FN	0.53	37.75	14.83	1.7
1086	Northridge-01	FN	0.43	32.27	6.39	2.44
1510	Chi-Chi-Taiwan	FN	0.47	53.73	45.32	5.1

In both far-fault and near-fault motions, the maximum drift ratio is concentrated at the top story of the basement wall. There is no significant difference between the behavior of the wall excited by far-fault or near-fault motions. In both cases the amount of maximum drift ratio occurs at the top story is around 2.5%, except for the Chi-Chi record NGA 1510, which produced 13% inter-story drift ratio at the top story. This is related to the high PGV of this motion compared with the other near-fault records and the fact that the Chi-Chi record has a peak in its ARS at the fundamental period of the system (0.4 sec) (Figures 2 and 3). The Northridge record NGA 983 leads to a higher drift (5.5%) compared with the rest of the near-fault records for the same reason.



(a) Analysis results for far-fault motions



(b) Analysis results for near-fault motions

Figure 5: Result of the analysis for the model excited by (a) far-fault motions (b) near-fault motions.

5 CONCLUSIONS

The key conclusions of the study are as follows:

- According to the low fundamental period of the system, 0.4 second, generally there is not any significant difference in the drift ratio profiles along the basement wall due to near-fault and far-fault motions.
- For both near-fault and far-fault motions the highest drift ratio occurs at the top story of the basement wall. This level is taller and less confined than the lower levels.
- A peak in the spectral acceleration and velocity plots at the predominant period of the system, will cause more drift at the top story level of the basement wall.

Acknowledgements

The materials presented in this paper are part of an ongoing study conducted by the authors as members of a task force committee for evaluation of seismic pressure on basement walls; struck by the Structural Engineers Association of British Columbia (SEABC). The authors are grateful for many constructive discussions with committee members: Ali Amini, Don Anderson, Peter Byrne, Mat Kokan, Jim Mutrie, Ernest Naesgaard, Rob Simpson, and Doug Wallis. Support to conduct this study is provided in part by the Natural Sciences and Engineering Research Council of Canada (NSERC).

REFERENCES

[1] J. D. Bray and A. Rodriguez-Marek, “Characterization of forward-directivity ground motions in the near-fault region,” *Soil Dynamics and Earthquake Engineering*, vol. 24, no. 11, pp. 815–828, 2004.

[2] E. Kalkan and S. K. Kunnath, “Effects of fling step and forward directivity on seismic response of buildings,” *Earthquake Spectra*, vol. 22, no. 2, pp. 367–390, 2006.

[3] S. Okabe, “General theory of earth pressure,” *Proceedings of the Japan Society of Civil Engineers*, vol. 12, no. 1, pp. 123–134, 1926.

[4] N. Mononobe and H. Matsuo, “On the determination of earth pressures during earthquakes,” in *Proceedings of World Engineering Conference*, pp. 176–182, 1929.

[5] National Building Code of Canada, *NBCC*. Institute for Research in Construction, National Research Council of Canada, Ottawa, ON, Canada, 1995.

[6] National Building Code of Canada, *NBCC*. Institute for Research in Construction, National Research Council of Canada, Ottawa, ON, Canada, 2005.

[7] National Building Code of Canada, *NBCC*. Institute for Research in Construction, National Research Council of Canada, Ottawa, ON, Canada, 2010.

[8] M. Taiebat, A. Ahmadnia, W. D. L. Finn, C. E. Ventura, E. Naesgaard, and R. H. Devall, "Seismic assessment of basement walls for different design criteria," in *Proceedings of the 4th Pan-American and 64th CGS conference*, (Toronto, ON, Canada), pp. Paper ID: 1069, 7 pages, 2011.

[9] M. Taiebat, W. Finn, A. Ahmadnia, E. Amirzehni, and C. Ventura, "Seismic evaluation of existing basement walls," in *Computational Methods in Earthquake Engineering* (M. Papadrakakis, M. Fragiadakis, and V. Plevris, eds.), vol. 2 of *Computational Methods in Applied Sciences*, p. 20 pages, Springer, 2013.

[10] Itasca Consulting Group, Inc., Minneapolis, Minnesota, *FLAC: Fast Lagrangian Analysis of Continua, Version 7.0*, 2012.

[11] PEER, "Pacific Earthquake Engineering Research Center strong motion database." `http://peer.berkeley.edu/peer_ground_motion_database`, accessed on 7 January 2013.

[12] Seismosoft, "SeismoMatch version 1.0.3." `http://www.seismosoft.com/`, 2009.

[13] TC-ASCE, "Design of blast-resistant buildings in petrochemical facilities," tech. rep., Task Committee on Blast-Resistant Design of the Petrochemical Committee of the Energy Division of ASCE, 1997.