MRP ENGINEERING, LLC

SEISMIC RISK EVALUATION

ELIZABETH LOFTS CONDOMINIUMS
333 NW NINTH AVENUE PORTLAND, OREGON

Prepared for:
Elizabeth Lofts Condominium Owners Association

MARCH 2015

SEISMIC RISK EVALUATION

ELIZABETH LOFTS CONDOMINIUMS

333 NW NINTH AVENUE
PORTLAND, OREGON

Prepared by:
MRP Engineering, LLC
601 108th Avenue NE, Suite 1900
Bellevue, WA 98004 USA

MRP Project Number:
1228.04

Prepared for:
Elizabeth Lofts Condominium Owners Association

MARCH 2015

March 2, 2015

Mr. Rod W. Brokenshire
Chair, Board of Condominium Owners
THE ELIZABETH LOFTS CONDOMINIUMS
333 NW Ninth Avenue
Portland, OR 97209

Phone: (503) 972-7281
Fax: (503) 274-8216
Email: rod@macadamforbes.com

SUBJECT: ***Earthquake Risk Evaluation of the Elizabeth Lofts Condominium Complex Located at 333 NW Ninth Avenue in Portland, Oregon***

Dear Rod:

MRP Engineering, LLC, is pleased to present the subject report. This transmittal completes our scope of services on this project. Please note that only the paper copy of this report will include the requisite stamp, signature, and date.

It is a pleasure to be of service to Elizabeth Lofts Condominium Owners Association. If you have any questions regarding this report, or need further assistance in addressing earthquake risks, please do not hesitate to contact us.

Sincerely,

MRP Engineering, LLC

Mark R. Pierepiekarz, P.E., S.E.
President
Oregon PE 60454

Enclosures: *As noted*

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EXECUTIVE SUMMARY

MRP Engineering, LLC, (MRP Engineering) performed an earthquake risk evaluation of the Elizabeth Lofts condominium complex located at 333 NW Ninth Avenue in Portland, Oregon. The purpose of the project was to provide information on the seismic risk to the facility in support of making insurance procurement decisions. Report data and our findings are summarized in Tables E-1 and E-2, respectively.

Table E-1: Report Data

Address:	Elizabeth Lofts Condominiums 333 NW Ninth Avenue Portland, Oregon 97209	**Drawings:**	Reviewed
Prepared for:	Elizabeth Lofts Condominium Owners Association	**Soils Report:**	Reviewed
Report date:	March 23, 2015	**Shaking Intensity:**	MMI VIII (475-year)
Engineers:	Mark R. Pierepiekarz, P.E., S.E.	**Site Visit:**	February 9, 2015

Table E-2: Property Data and Seismic Risk[1] (Shake Damage Only)
Elizabeth Lofts Condominiums, Portland, Oregon

Number of Stories	Design Year (code)	Primary Construction Type	Return Period (years)	MMI Ground Shaking	PML_{50} (SEL_{475})	PML_{90} (SUL_{475})	Downtime (months)	
							PML_{50}	PML_{90}
15 + basement	2003 (1997 UBC)	Reinforced concrete shear wall	475	VIII	7.5%	15%	2	3

1. PML_{50} represents an average (expected) damage level and PML_{90} represents a damage level with a 90% confidence of non-exceedance. The corresponding terms per ASTM E2026-07 (Reference G4) are SEL_{475} and SUL_{475} for a 475-year earthquake. See Appendix B for terminology and definitions. Loss opinions are for earthquake shake damage only and do not include damage from fire following earthquake. Downtime represents a reasonable time period to conduct the repairs (claim settlement time period is not included).

In summary, western Oregon has a history of significant seismic activity. The primary seismic hazard for the site is strong ground shaking. Ground shaking with a Modified Mercalli Intensity (MMI) level VIII is projected for the site for the 475-year earthquake level. This level of ground shaking may cause damage to engineered structures. The 475-year earthquake level is associated with a 10% probability of exceedance in a 50-year period. In addition, the site is located within 0.1 kilometer of the Portland Hills fault which is capable of M7+ earthquakes. Based on a site-specific geotechnical and seismic hazard report (Reference D2), building foundations bear on relatively firm deposits (12 pounds per square foot, allowable soil bearing pressure). The risk of other seismic hazards at the site appears to be low to moderate.

The complex represents of a residential structure over a commercial podium, as described below.

Table E-3: Structural Systems
Elizabeth Lofts Condominiums, Portland, Oregon

Stories:	15-story residential structure with a one-level basement (parking)	
Gravity Systems:	High-rise:	Post-tensioned reinforced concrete floors supported on reinforced concrete columns and walls
	Basement:	Post-tensioned reinforced concrete floor supported on reinforced concrete columns, walls, and perimeter retaining walls (below grade)
Lateral Systems:	High-rise:	Rigid floor diaphragms spanning between reinforced concrete shear walls
	Basement:	Rigid floor diaphragm spanning between reinforced concrete shear walls and reinforced concrete retaining walls

In summary, the complex represents 1997 Uniform Building Code (UBC) seismic zone 3 design criteria. In addition, a site-specific response spectrum was developed for the seismic design of this structure (Reference D2). The area may be affected by subduction zone earthquakes originating on the offshore Cascadia subduction zone. These large-magnitude earthquakes are capable of strong ground shaking lasting a few minutes affecting locations in western Oregon. Some structural damage is possible in the event of a major earthquake, requiring post-event inspections and repairs.

The building contains utility components and piping typical for this occupancy. The natural gas inlet lacked a seismically actuated shutoff valve. Restraint of utility equipment units generally appeared adequate. Seismic restraint of several noted components is recommended.

Please note that this evaluation is intended to provide an opinion of seismic risk based on available information and the scope of work for this project. Detailed engineering analyses and testing were not performed. The data presented is intended to identify and organize potential areas of concern.

1. INTRODUCTION

MRP Engineering, LLC, performed an earthquake risk evaluation of the Elizabeth Lofts condominium complex located at 333 NW Ninth Avenue in Portland, Oregon. The purpose of the project was to provide information on the seismic risk to the facility.

The report includes damage scenarios for the structure, associated probable maximum losses (PMLs), and potential downtimes. The evaluation was based on a brief site visit, available engineering data for the facility, knowledge of performance of similar facilities in past earthquakes, and engineering judgment. It was not the intent to perform detailed structural analyses, develop specific upgrades, perform a condition assessment, estimate associated construction costs, develop facility replacement values, or evaluate regulatory compliance.

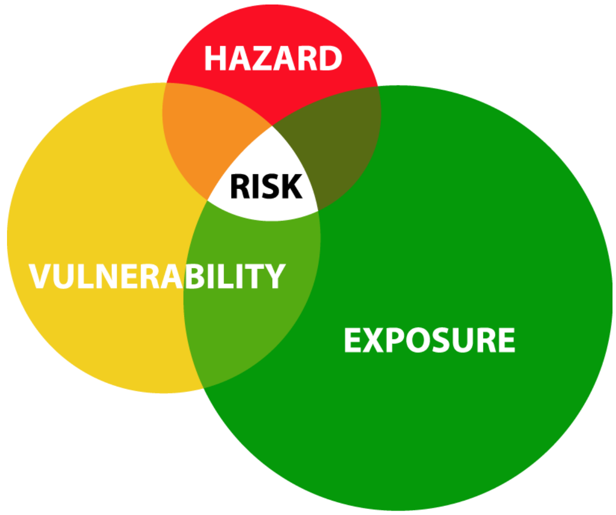
SCOPE OF WORK

The scope of work included the following tasks:

1. Meet with facility personnel to discuss areas of concern, identify critical operations, and locate reference documents such as design drawings and engineering reports.
2. Briefly review available structural drawings to note the primary structural characteristics and the nature of the lateral-load-resisting systems. If available, review soil reports and geologic data to assess seismic site hazards.
3. Walk through representative areas of the facility to visually assess important structural characteristics and note obvious deficiencies. It was not the intent to perform a condition assessment of the property.
4. Review key representative contents and equipment systems to determine general anchorage and bracing, and assess their ability to resist earthquake forces. It was not the intent to develop a comprehensive inventory of equipment and systems.
5. Develop an opinion of probable maximum losses (PMLs) for the facility. Results include an opinion of PMLs with a 50% and 90% confidence of non-exceedance for the 475-year earthquake level.
6. Issue a brief report summarizing our methodology and findings.

In general, risk represents a combination of hazard, vulnerability, and exposure.

Seismic hazard is the potential for strong ground shaking or other earthquake-related hazards such as settlement, landsliding, ground rupture, or tsunami at a site of interest. Vulnerability represents the potential for damage to structures and equipment systems given a facility's construction, configuration, condition, structural elements, and connections. Exposure is a measure of the financial impact should damage occur. Together, vulnerability and exposure describe the potential consequences of the seismic hazards. A reference seismic hazard (ground shaking) map for the United States is presented in Figure 1-1 below.



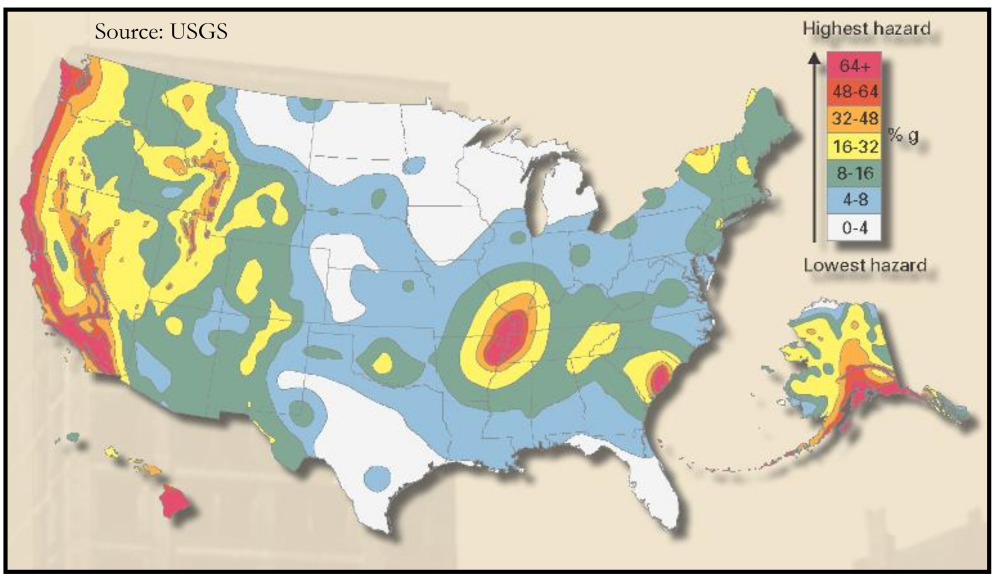
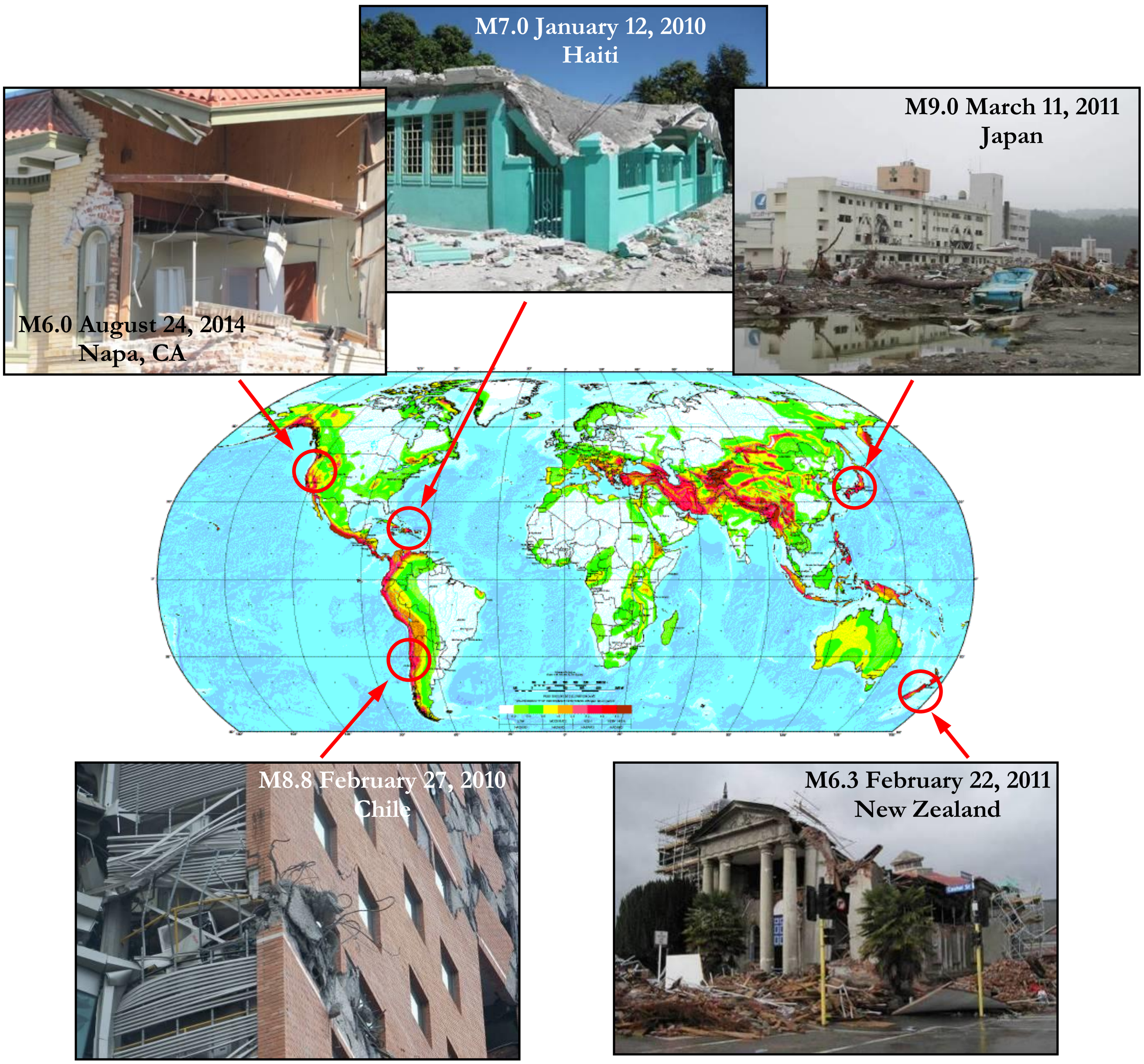


Figure 1-1: 2,475-Year Seismic Hazard Map for United States

Risk is expressed as an opinion of the level of damage for a given hazard, vulnerability, and exposure. The opinion is based on the experience and judgment of MRP Engineering. While an important tool for building evaluation, the opinion expressed in this report should not be considered a precise damage estimate for a particular building given a specific event, but rather a potential damage level with a specified confidence. Appendix B provides definitions of various site hazards, technical terms, and maps noted in this report. Appendix C provides an overview of potential effects for a M6.7 scenario earthquake on the Seattle fault. Recent earthquake investigations by MRP Engineering are noted in the following section.

MRP ENGINEERING EARTHQUAKE INVESTIGATIONS

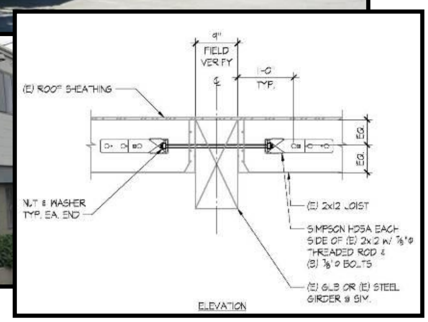
Recent large-magnitude earthquakes, such as the M8.8 Maule, Chile, and M9.0 Japan events, exemplify the potential long-term economic effects on national economies and regional populations. On the other hand, the Port-au-Prince, Haiti, and Christchurch, New Zealand, earthquakes represent devastating shallow crustal events occurring directly under large population centers (thought to be located in moderate seismic hazard zones). Overall economic losses and long-term implications from these events are significant. MRP Engineering visited the impacted areas to document the earthquake impacts and recovery efforts, as highlighted below. Our post-earthquake investigations provide us with first-hand knowledge of seismic performance of structures, industrial installations, and regional lifelines. The value of proactive earthquake risk management actions in preventing damage and business interruption losses was evident during our damage investigations.



EXAMPLE SUCCESS STORIES

MRP Engineering has successfully applied a phased risk management approach for a number of public and private organizations. For example, MRP Engineering was approached by the City of Renton, Washington, to perform a seismic risk evaluation of a critical fire station building. MRP Engineering also designed a seismic upgrade intended to provide "immediate occupancy" seismic performance for this critical facility. The project involved a FEMA matching grant and was completed in 2009.

MRP Engineering performed an initial seismic risk evaluation of the Viox Corporation (now 3M) facility located in Seattle, Washington. The purpose of the evaluation was to assess the current seismic risks and develop a program to reduce unacceptable business exposures. Following the evaluation, MRP Engineering designed a seismic retrofit for one of the structures based on the client's seismic performance criteria for this facility. The upgrade was successfully completed in 2008.



LIMITATIONS

MRP Engineering professional services have been performed using the degree of care and skill ordinarily exercised, under similar circumstances, by reputable engineers currently practicing in the structural field in this or similar localities. No other warranty, expressed or implied, is made as to the professional advice included in this report. This report has been prepared for Elizabeth Lofts Condominium Owners Association, to be used solely for their evaluation of the subject property. This report has not been prepared for use by other parties and may not contain sufficient information for purposes of other parties or uses.

This report shall not be construed to and is not intended to create a contractual relationship of any kind between any persons other than MRP Engineering and Elizabeth Lofts Condominium Owners Association, or rights in any other persons other than MRP Engineering and Elizabeth Lofts Condominium Owners Association.

Please note that the evaluations are intended to provide an opinion of seismic risk based on available information and the scope of work for this project. Detailed engineering analyses and testing were not performed. The data presented is intended to identify and organize potential areas of concern. This report is not intended to predict the specific impacts from a seismic event on a building, nor will it provide a detailed analysis of work necessary to avoid impacts. The purpose of this analysis is to identify general risks from seismic events against the construction of a building assuming it complied with applicable building standards at the time of construction.

2. SEISMIC HAZARDS

The Pacific Northwest has a history of significant seismic activity, which directly affects western Oregon residents and business owners. The region is located along the boundary of two tectonic plates, which can cause destructive earthquakes as they come into contact with one another. One of the tectonic plates, the Juan De Fuca plate, forms the ocean floor, slides beneath (subducts) the North American plate, and is slowly driven into the earth's mantle (Figure 2-1). The principal sources of potential future earthquakes are illustrated below:

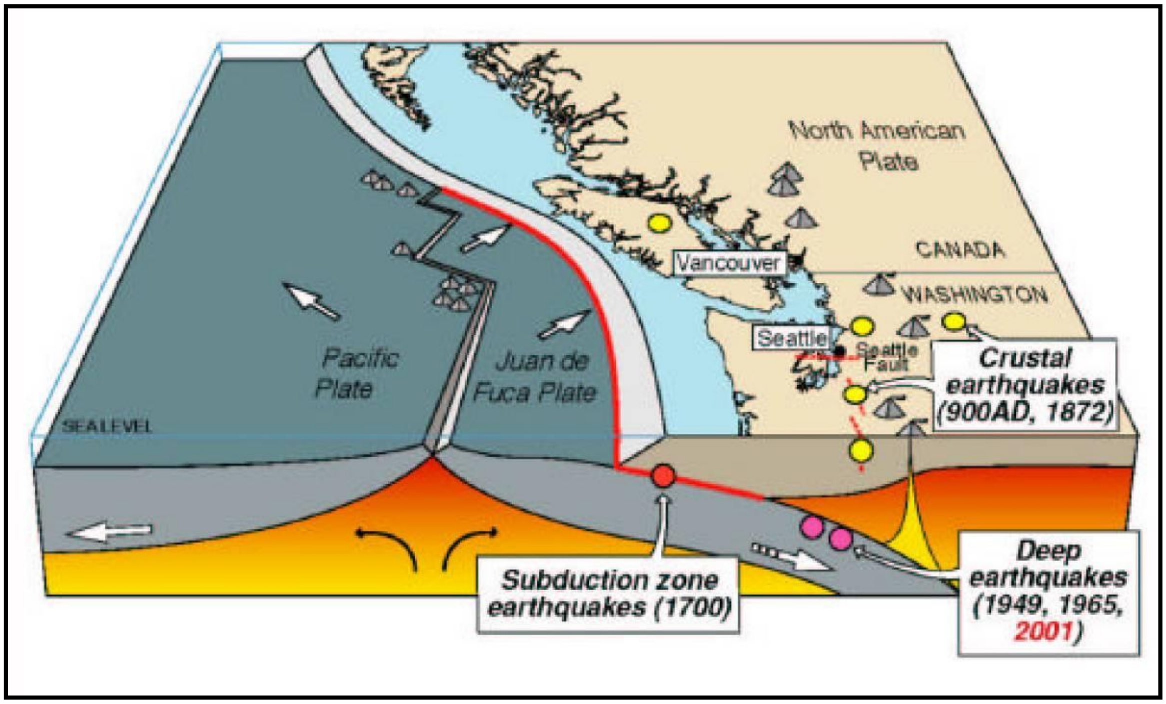


Figure 2-1: Pacific Northwest Tectonic Setting
(Source: USGS and University of Washington)

The principal sources of potential future earthquakes are noted below and in Table 2-1.

- Offshore Cascadia subduction zone is capable of M8 to M9 earthquakes about every 300 to 500 years. The last such event occurred on January 26, 1700.

  Subduction zone earthquakes occur at the convergence between the Juan de Fuca and North American plates as described above. The contact area of the plates extends to a depth of about 40 kilometers. The plates remain locked in frictional contact until the resistance to sliding is overcome. The plates then slide against each other up to several meters in a very short time, releasing tremendous energy. Resulting subduction zone earthquakes may have a great magnitude (M > 8). See map in Figure 2-2 for a M9 scenario ground-shaking levels. Vertical displacement of the sea floor may result in a tsunami along coastal areas, as experienced following the 2010 M8.8 Maule, Chile, earthquake, as well as the 2011 M9.0 Great East Japan Earthquake event. Elevation changes may occur along the coastline. Significant aftershocks (M > 7) may follow.

- Benioff (deep) zone earthquakes occur as the subducted Juan De Fuca plate breaks apart at depths of 40 to 60 kilometers below the surface. This mechanism was responsible for the M6.8 Olympia earthquake in 1949, the M6.5 SeaTac event in 1965, and the M6.8 Nisqually earthquake in 2001.
- Crustal earthquakes are shallow events (within a depth of ten kilometers) that could occur along local faults. These faults, such as the Portland Hills and East Bank faults, have relatively long recurrence periods, but are capable of M6+ events. Examples of recent events affecting portions of western Oregon include the September 1993 M6.0 Klamath Falls earthquake and the March 1993 M5.6 earthquake near Scotts Mills. Appendix C provides an overview of a M6.7 scenario event on the Seattle metropolitan area.

Table 2-1: 475-Year Earthquake Scenarios

Event Type	Source	Magnitude	Distance (kilometers)
Subduction zone	Cascadia	9+	89
Benioff	Deep event	7+	50
Crustal	Portland Hills fault[1]	6+	< 1
	East Bank	6+	2
	Outfield	—	5

1. Current information (References S9 and S10) indicates that the Portland Hills fault, passing beneath the Portland metropolitan area, and the associated East Bank fault, may be capable of M6.8 to M7.2 earthquakes every few thousand years.

GROUND SHAKING

Property damage in earthquakes can occur from ground shaking or from a site soil failure. In general, most earthquake damage occurs due to strong ground shaking. The Modified Mercalli Intensity scale (MMI) is often used to measure ground-shaking intensity at the site of interest. While an earthquake has only one magnitude, it can have many intensities that are influenced by the distance from the epicenter and local soil conditions, as shown in Figure 2-2. The MMI scale has twelve discrete levels. At MMI VI and below, damage is slight. Structures lacking adequate lateral-load-resisting systems can be damaged in MMI VII level shaking. Engineered structures can be damaged at MMI VIII.

Earthquake magnitude is an estimate of the earthquake size, or strength at its source. It is the most familiar earthquake descriptor to engineers, geologists, and the general public. Richter magnitude scale is logarithmic, meaning that each whole-number increase represents a tenfold increase in the recorded amplitude. Each whole-number increase also represents a 32-fold increase in the energy released. Thus, a M7 earthquake releases 1,000 times the energy compared to a M5 earthquake. Appendix B includes MMI scale and magnitude definitions.

The ground-shaking effects for the sites were developed based on ground motions for various earthquake scenarios (ST-RISK™ software), U.S. Geological Survey probabilistic hazard maps, and available site soils information. Please note that although peak ground acceleration (PGA) used in these sources is an important parameter in describing ground shaking, duration and frequency of shaking are also important in projecting the potential for damage.

Table 2-2: Ground Shaking for the Site

Soil Profile	Return Period (years)	MMI	Accelerations[1, 2] (% gravity)		
			PGA	0.2 sec	1.0 sec
Dense soil (C)	475	VIII	25	54	22
	2,475	IX	48	116	48

1. Source: http://geohazards.usgs.gov/hazardtool/application.php
2. Horizontal accelerations are noted in the table. Peak ground acceleration (PGA) represents free-field ground motions. 0.2-second spectral accelerations are significant for low-rise structures. 1.0-second spectral accelerations are significant for high-rise buildings and bridges. The accelerations are based on C soil profile.

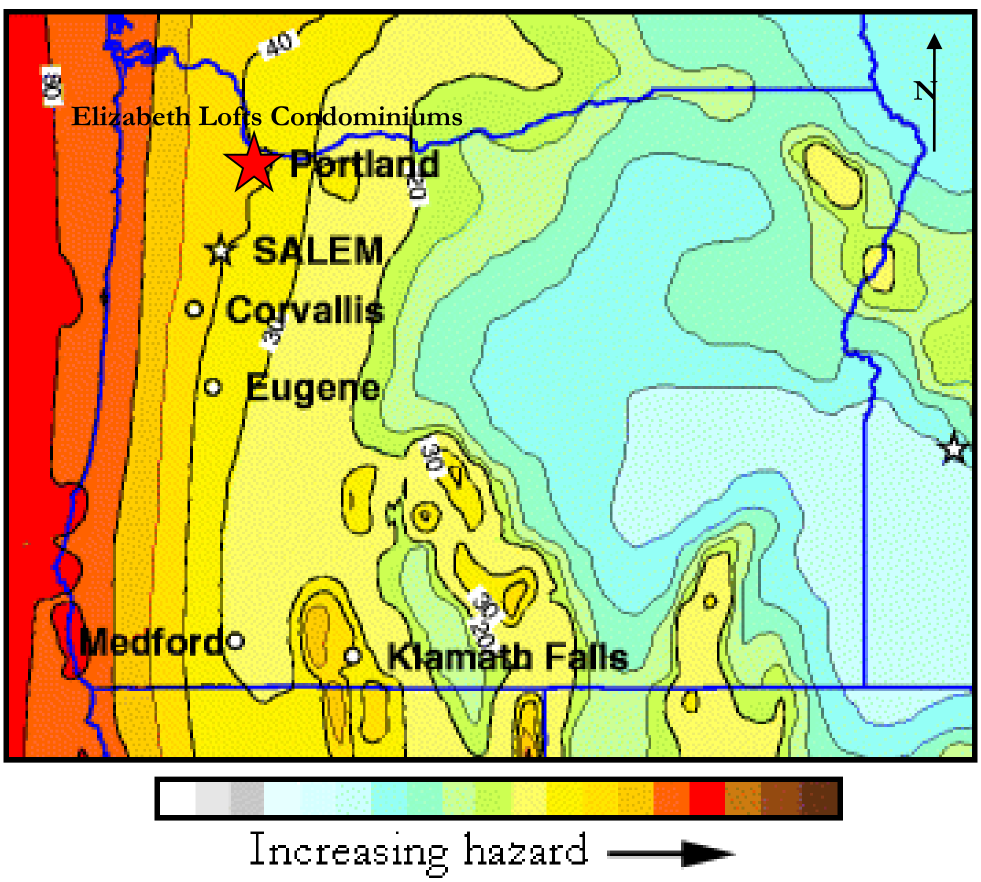


Figure 2-2: Ground-Shaking Levels for a M9.0 Scenario Event on the Cascadia Subduction Zone (Source: USGS)

As noted above, MMI VIII level of ground shaking is capable of damaging engineered structures. Ground shaking is considered the primary hazard for this site. Other site hazards are briefly discussed below.

SITE HAZARDS

Table 2-3: Site Hazards Summary

A site-specific geotechnical report (Reference D2) indicates that the site soils consist of medium dense alluvial deposits (silt and sand), underlain by relatively dense gravel deposits. The report noted that ground water level depth may vary from 10 to 23 feet below ground surface (depending on season). Based on the information presented on the available design documents, the building foundations appear to bear on relatively dense deposits which are considered seismically stable. The risk of site-specific seismic hazards is considered low, as noted in the table below.

Table 2-3: Site Hazards Summary

Hazard	Risk	Comment
Ground rupture	Low[1]	Portland Hills fault is located about 0.1 kilometers from the site (Reference D2). The site-specific seismic hazard analysis report (Reference D2) indicates that no active faults are known to pass beneath the site.
Liquefaction	Low	The structure is supported on spread footings and reinforced concrete mat foundations (under shear walls). Site-specific data (References D1 and D2) indicates that the site soils appear to be relatively firm, with an allowable bearing value of 12,000 psf (pounds per square foot).
Settlement	Low	As noted above, the building foundations rest on relatively firm deposits.
Landsliding	Low	The building is located on a relatively level site.
Tsunami or seiche	Low	The site is not located immediately adjacent to a body of water.

1. An additional site-specific seismic hazard analysis would be required to further quantify ground rupture hazard from the Portland Hills fault zone.

3. FACILITY DESCRIPTION

The Elizabeth Lofts condominium complex is located at 333 NW Ninth Avenue in Portland, Oregon, and represents a 15-story reinforced concrete residential building with a one-level basement. A summary of the structure data is provided in Table 3-1 below. Appendix A includes additional structural information, nonstructural observations, and photographs for this facility.

Table 3-1: Structure Summary
Elizabeth Lofts Condominiums, Portland, Oregon

Structure Address	Year Designed	Building Code Edition	Primary Occupancy
333 NW Ninth Avenue	2003	1997 UBC	Residential

STRUCTURAL AND SEISMIC SYSTEMS

MRP Engineering staff visited the residential facility in February 2015. During the site visit we attempted to observe accessible structural elements and details important to structural behavior in a seismic event. However, many elements were obscured by finishes. Structural design drawings were available for our review. Typical features reviewed included:

- Building layout and separation from adjacent structures
- Roof, floor, and wall configurations
- Representative nonstructural components

The main structural features are summarized in Table 3-2 below. Additional information is presented in Appendix A.

Table 3-2: Structural System
Elizabeth Lofts Condominiums, Portland, Oregon

Stories:	15-story residential structure with a one-level basement (parking)	
Gravity Systems:	High-rise:	Post-tensioned reinforced concrete floors supported on reinforced concrete columns and walls
	Basement:	Post-tensioned reinforced concrete floor supported on reinforced concrete columns, walls, and perimeter retaining walls (below grade)
Lateral Systems:	High-rise:	Rigid floor diaphragms spanning between reinforced concrete shear walls
	Basement:	Rigid floor diaphragm spanning between reinforced concrete shear walls and reinforced concrete retaining walls

The structure appears representative of its construction type and vintage. Based on information noted on the available design documents, the design was based on 1997 Uniform Building Code (UBC) seismic zone 3 criteria. Specific features observed (or noted on the available drawings) include:

Superstructure:

- A site-specific response spectrum was developed for the seismic design of the structure (Reference D2).
- The complex relies on reinforced concrete shear walls to resist lateral forces. The principal shear walls are located at the building core. The shear walls appear to be continuous over the building height. Parking levels (up to level three) include inclined ramps.
- Steel stud rail shear reinforcement of slabs at columns is shown on the drawings. Brick veneer ties are shown on the drawings.
- The structure represents reasonable reinforced concrete design criteria and detailing. For example, the shear walls include boundary reinforcing, and columns include steel confinement reinforcement. As a result of the 2010 M8.8 earthquake in Chile, structural damage resulting in extensive loss of occupancy was experienced in some high-rise reinforced concrete structures, lacking ductile reinforced concrete detailing.
- Torsional response (twisting) is possible due to the plan layout of shear walls (offset north-south walls).

General:

- Based on published regional data, the risk of soil liquefaction appears to be significant. However, based on the information noted on structural drawings, the building foundations appear to rest on relatively firm deposits (12,000 pounds per square foot allowable soil-bearing pressure).
- The area may be affected by subduction zone earthquakes originating on the offshore Cascadia subduction zone. These large-magnitude earthquakes are capable of strong ground shaking lasting a few minutes affecting locations in western Oregon. The site is located in the vicinity of the Portland Hills fault. Strong ground shaking (horizontal and vertical) is possible in the event of a major earthquake on this fault.

Some structural damage is possible in the event of a major earthquake, requiring post-event inspections and repairs.

NONSTRUCTURAL COMPONENTS

As demonstrated by recent earthquakes worldwide, damage to contents and equipment can dominate earthquake losses and delay resumption of occupancy. A walk-through of representative utility equipment was performed to evaluate its expected performance during a major earthquake. This approach, when performed by structural engineers with earthquake engineering experience, represents a reasonable assessment of equipment risks. The intent was to note obvious deficiencies and not to develop an inventory of building nonstructural components.

The building contains utility components and piping typical for this occupancy. The natural gas inlet did not include a seismically actuated shutoff valve at the time of the visit. Restraint of several equipment units appeared marginal. Seismic restraint of these components is recommended (see Appendix A).

4. SEISMIC RISK

This chapter presents the preliminary seismic risk evaluation results for the Elizabeth Lofts condominium complex located at 333 NW Ninth Avenue in Portland, Oregon. The following sections discuss criteria used in the evaluations, findings, and recommendations.

REVIEW CRITERIA

The risk to the subject structure was determined based on the following criteria:

- Visual review of accessible areas to determine general structural systems
- Walk-through of the building to establish relationship with available drawings
- Review of available geological and earthquake data for the site
- Knowledge of seismic performance of similar structures and engineering judgment

STRUCTURE SEISMIC RISK

The table below summarizes our preliminary opinion of seismic risk for the structure for the 475-year earthquake level (shake damage only). The risk is expressed as a probable maximum loss (PML), or a cost to restore the structure to pre-earthquake condition, represented in terms of percentage of replacement value. The PML_{90} figure is based on a 90% confidence level that the actual damage will not be exceeded. The PML_{50} figure represents an average (expected) damage level. In general, a PML_{90} of 10% represents minor damage. A PML_{90} of 30% or more represents the potential for significant structural damage and prolonged loss of function.

Table 4-1: Structure Seismic Risks[1] (Shake Damage Only)
Elizabeth Lofts Condominiums, Portland, Oregon

Number of Stories	Design Year (code)	Primary Construction Type	Return Period (years)	MMI Ground Shaking	PML_{50} (SEL_{475})	PML_{90} (SUL_{475})	Downtime (months)	
							PML_{50}	PML_{90}
15 + basement	2003 (1997 UBC)	Reinforced concrete shear wall	475	VIII	7.5%	15%	2	3

1. PML_{50} represents an average (expected) damage level and PML_{90} represents a damage level with a 90% confidence of non-exceedance. The corresponding terms per ASTM E2026-07 (Reference G4) are SEL_{475} and SUL_{475} for a 475-year earthquake. See Appendix B for terminology and definitions. Loss opinions are for earthquake shake damage only and do not include damage from fire following earthquake. Downtime represents a reasonable time period to conduct the repairs (claim settlement time period is not included).

Loss-of-occupancy losses are not included. Reduced operations and associated losses can result from building closures for damage inspections, engineering design and repairs, and local jurisdiction reviews. A contingency for cleanup and recovery (10% of direct losses) should be considered to address costs associated with expedited restoration of operations. A demand surge (20% of direct losses) should be applied to account for a temporary rise in construction costs following a major earthquake.

FINDINGS AND RECOMMENDATIONS

The tower appears representative of its construction type and vintage. Based on information noted on the available design documents, the design was based on the 1997 Uniform Building Code (UBC) seismic zone 3 criteria. This report does not verify that construction actually met or exceeded these standards; construction conforming to the UBC standards is a critical assumption in providing an opinion. Some structural damage is possible in the event of a major earthquake, requiring post-event inspections and repairs. We recommend installation of a seismic shutoff valve (at the main natural gas inlet) as well as seismic bracing/restraints for noted nonstructural components and equipment.

Please note that this evaluation is intended to provide a general opinion of seismic risk based on available information, scope of work for this project, and knowledge of how similar structures have performed in past earthquakes. Detailed engineering analyses and testing were not performed. The data presented is intended to identify and organize potential areas of concern and may not address all retrofitting measures that may be found necessary after a more complete seismic analysis is performed.

5. REFERENCES

GENERAL

G1. ASCE 31-03, "Seismic Evaluation of Existing Buildings—ASCE Standard," American Society of Civil Engineers.

G2. ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures—ASCE Standard," American Society of Civil Engineers.

G3. ASCE/SEI 41-06, "Seismic Rehabilitation of Existing Buildings," American Society of Civil Engineers.

G4. ASTM E2026-07, "Standard Guide for Estimation of Damageability in Earthquakes," American Society for Testing and Materials, West Conshohocken, Pennsylvania.

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SEISMICITY

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S5. ST-RISK™ Seismic risk modeling software, Version 4.51, Risk Engineering, Inc., Boulder, Colorado, 2012.

S6. USGS, Seismic Design Maps Application, http://earthquake.usgs.gov/hazards/designmaps/usdesign.php.

S7. Wang, Y., and J. L. Clark, “Earthquake Damage in Oregon: Preliminary Estimates of Future Earthquake Losses,” Oregon Department of Geology and Mineral Industries, Special Paper 29, 1999.

S8. Wang, Y., et al., “Earthquake Risk Study for Oregon’s Critical Energy Infrastructure Hub: Final Report to Oregon Department of Energy & Oregon Public Utility Commission,” Oregon Department of Geology and Mineral Industries, August 2012.

S9. Wong, I., et al., “Earthquake Scenario and Probabilistic Ground Shaking Maps for the Portland Metropolitan Area,” State of Oregon Department of Geology and Mineral Industries, 2000.

S10. Wong, I., et al., “The Portland Hills Fault: An Earthquake Generator or Just Another Old Fault?,” Oregon Geology, Volume 63, No. 2, Spring 2001.

SITE DATA

D1. Kramer Gehlen Associates, Structural Drawings for “Elizabeth Lofts,” Sheets S1.0-S6.04, August 27, 2003.

D2. GRI, “Geotechnical Investigation for “Elizabeth Lofts, NW 9th and 10th Avenues between NW Everett and Flanders Streets, Portland, Oregon,” August 23, 2002.

APPENDIX A
FACILITY DATA SHEET

Table A-1: Summary of Facility Data
Elizabeth Lofts Condominiums, 333 NW Ninth Avenue, Portland, Oregon

Vintage:	2003 (1997 UBC)	**Construction:**	Reinforced concrete shear walls	**Foundation Soils:**	Firm
Occupancy:	Residential/ commercial	**Drawings:**	Reviewed	**Site Hazard:**	Low
Stories:	15 + basement	**Soils Report:**	Reviewed	**Ground Shaking:**	MMI VIII
Approximate Area:	372,571 ft^2	**Site Visit:**	February 9, 2015	**PML$_{90}$:**	See Chapter 4

STRUCTURAL SYSTEM

The complex comprises a 15-story reinforced concrete structure with a one-story basement level. Typical construction consists of post-tensioned reinforced concrete floor slabs spanning between reinforced concrete columns and reinforced concrete shear walls. The complex is located on a relatively level site. The structure rests on spread footings and reinforced concrete mat foundations.

LATERAL-FORCE-RESISTING SYSTEM

The lateral loads are resisted by a reinforced concrete floor slabs spanning between reinforced concrete shear walls.

FINDINGS AND RECOMMENDATIONS

The structure appears representative of its construction type and vintage. Based on information noted on the available design documents, the design was based on 1997 Uniform Building Code (UBC) seismic zone 3 criteria. Specific features observed (or noted on the available drawings) include:

Superstructure:

- A site-specific response spectrum was developed for the seismic design of the structure (Reference D2).
- The complex relies on reinforced concrete shear walls to resist lateral forces. The principal shear walls are located at the building core. The shear walls appear to be continuous over the building height. Parking levels (up to level three) include inclined ramps.

- Steel stud rail shear reinforcement of slabs at columns is shown on the drawings.
- The structure represents reasonable reinforced concrete design criteria and detailing. For example, the shear walls include boundary reinforcing, and columns include steel confinement reinforcement. As a result of the 2010 M8.8 earthquake in Chile, structural damage resulting in extensive loss of occupancy was experienced in some high-rise reinforced concrete structures, lacking ductile reinforced concrete detailing.
- Torsional response (twisting) is possible due to the plan layout of shear walls (offset north-south walls).
- Brick veneer ties are shown on the drawings.

General:

- Based on published regional data, the risk of soil liquefaction appears to be significant. However, based on the information noted on structural drawings, the building foundations appear to rest on relatively firm deposits (12,000 pounds per square foot allowable soil-bearing pressure).
- The area may be affected by subduction zone earthquakes originating on the offshore Cascadia subduction zone. These large-magnitude earthquakes are capable of strong ground shaking lasting a few minutes affecting locations in western Oregon.
- The site is located in the vicinity of the Portland Hills fault. Strong ground shaking (horizontal and vertical) is possible in the event of a major earthquake on this fault.

Some structural damage is possible in the event of a major earthquake, requiring post-event inspections and repairs.

NONSTRUCTURAL OBSERVATIONS

The following table presents our observations of nonstructural elements that appear to lack adequate seismic restraint and merit consideration of seismic upgrade. The data in the tables represents observations only in building areas that we visited. The table does not represent a comprehensive inventory of nonstructural components and systems, or related seismic concerns.

Table A-2: Nonstructural Deficiency Observations
Elizabeth Lofts Condominiums, Portland, Oregon

Location	Priority	Component	Concern	Recommendations
General	H	Fire extinguisher	A – E	Provide wall bracket with strap
	M	Elevator guide rails	A, B, C	DD
	H	Sprinkler piping	A – F	Verify adequate clearance at adjacent components
Penthouse	H	Boilers	A – E	DD, EE
	H	Natural gas piping	A – E	BB
	M	Suspended piping	A, C, E	BB
Elevator room	M	Fire extinguisher	A – E	Provide wall strap
	M	Suspended HVAC	A, C, E	BB
Mechanical room (roof)	M	Suspended water piping	A, C, E	BB
Mechanical room (7th floor)	M	Suspended piping	A, C, E	BB
Parking level 3	M	Electrical conduit	A, C	BB
Basement	H	CO_2 fan	A, C, F	BB
Street level	H	Main natural gas inlet	A – E	GG

PRIORITY
H High
M Medium
L Low

CONCERNS
A Function interruption concern
B Safety (egress) or falling concern
C Property damage concern
D Potential fire concern
E Piping rupture concern
F Potential interaction with sprinklers

RECOMMENDATIONS
AA Provide adequate anchorage
BB Provide adequate bracing
CC Analyze and retrofit as needed
DD Verify anchorage, and anchor as needed
EE Provide flexible piping coupling
FF Provide C-clamp restrainers
GG Provide seismic shutoff valve

Photo A-1: Southwest elevation

Photo A-2: East elevation

Photo A-3: Northeast elevation

Photo A-4: South elevation

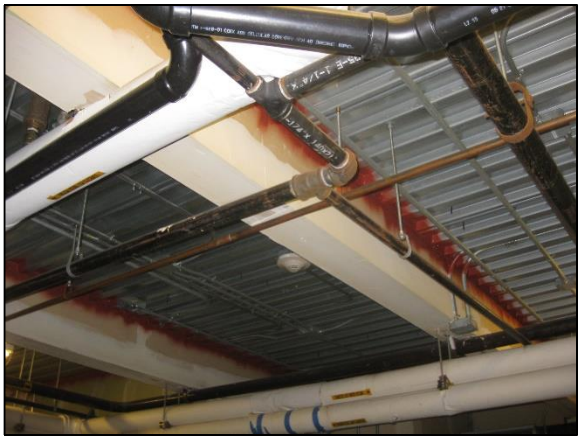


Photo A-5: Roof penthouse—natural gas piping

Photo A-6: Roof penthouse—boilers

Photo A-7: Roof penthouse—suspended piping

Photo A-8: Roof mechanical room—suspended piping

Photo A-9: Level 3—suspended drain piping

Photo A-10: Level 3—suspended sprinkler piping

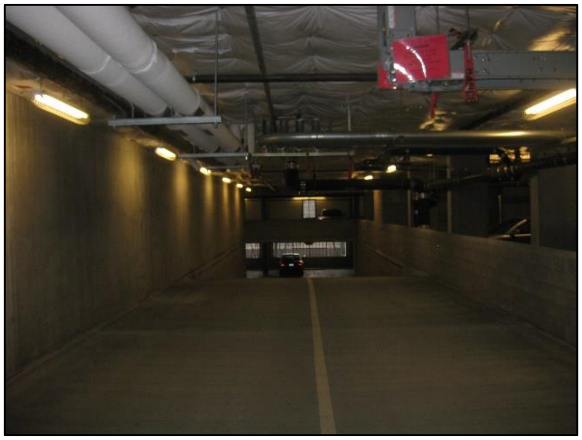


Photo A-11: Parking ramp

Photo A-12: Level 3—suspended conduits

Photo A-13: Natural gas main inlet

APPENDIX B
TERMINOLOGY AND DEFINITIONS

The following is a glossary of terms used in the report.

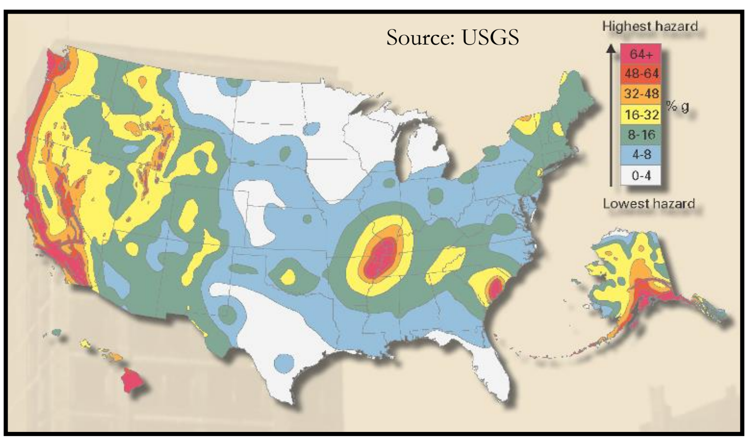
475-YEAR EARTHQUAKE

Until recently, the design practice in the United States was nominally based on the use of ground motions associated with events having a 90% probability of non-exceedance in a 50-year period. This choice was based on protecting structures and occupants against extreme events within the lifespan of the structures, which is assumed to be about 50 years. This event can also be expressed as a 475-year event, which is sometimes rounded to a 500-year event. In general, insurance-related studies are also based on this level of ground motion.

BUILDING CODES

Until recently, the most widely accepted code regulations in the western United States for seismic design of structures and nonstructural components were those found in the Uniform Building Code (UBC). The basic design philosophy of the UBC, including the 1997 edition, was that structures should be able to resist earthquake ground motions as follows:

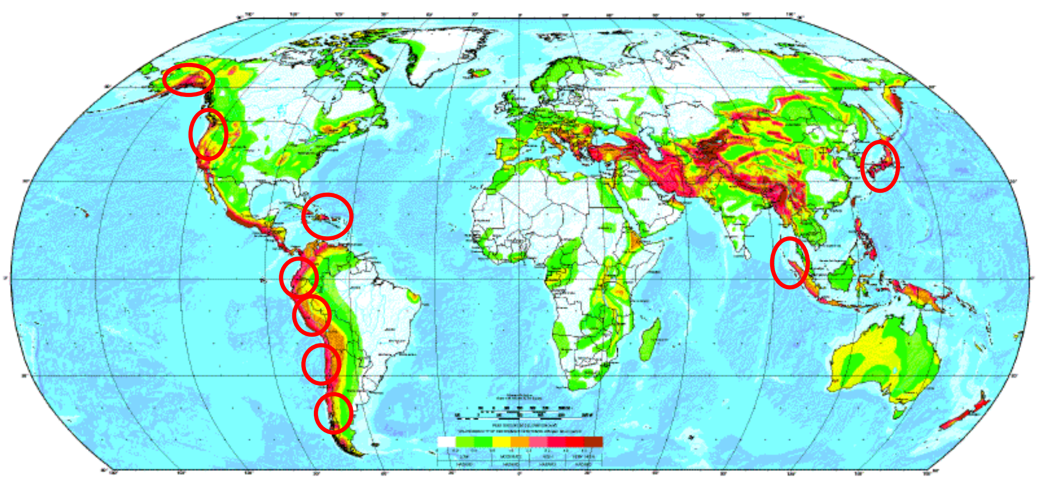
Ground Motion Level	Damage Level
Minor	None
Moderate	No structural damage, some nonstructural damage
Major	No collapse, but possible structural and nonstructural damage



To implement this approach, the UBC specified ground motion criteria, equivalent static force equations, analysis procedures, load combinations and factors, structural detailing requirements, and acceptance criteria.

The International Building Code (IBC) is the current generation of building codes currently used in the United States and represents a substantial update of seismic design for new construction. The 2012 IBC has been adopted in throughout the U.S. One major IBC update is the seismic hazard zoning (see above figure showing 2,475-year ground motions) which provides for a more uniform hazard consideration in the United States.

GLOBAL SEISMIC HAZARD MAP



Source: Reference S3

The map was produced by the Global Seismic Hazard Assessment Program (GSHAP). The above map indicates worldwide 475-year ground-shaking levels, not including the effects of soil conditions. Areas in dark red indicate the highest potential seismic hazard. Circled areas indicate potential zones of M8+ subduction mega-earthquakes.

GROUND RUPTURE

The consequences of a major fault rupture at the surface can be extreme. Buildings may be torn apart, gas lines severed, and roads made impassable. Damage by faults is more localized than the widespread damage caused by ground shaking. Nevertheless, the identification of active surface faults is an important part of estimating future earthquake losses.

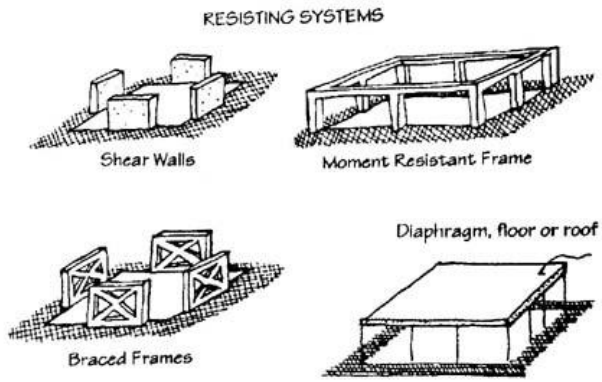
LANDSLIDING

Sites with steep slopes may be susceptible to landslides. Such sites may include steep bluffs of eroded glacial deposits, steep rocky slopes along river gorges, and rugged mountain terrain. Dozens of ancient landslides have been identified in the bluffs along Puget Sound, indicating their susceptibility to ground failure. The landslides may also be susceptible to further failure if the headwall or toe areas are steepened by erosion or excavation.

LATERAL-LOAD-RESISTING SYSTEM

A structure may be significantly damaged if its response to ground motion exceeds design limits. The response and extent of damage depends on the design of structural elements and connections, as well as the intensity, frequency, and duration of ground motion at the site. These factors must be considered to produce a building design that prevents unacceptable damage level during earthquakes. Buildings lacking proper design may be exposed to risk of collapse.

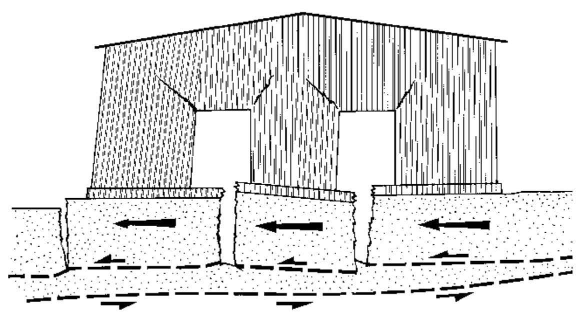
Structures can withstand the vertical component of the earthquake-induced ground motion because they are designed to resist the large vertical loads generated by their own weight. Resistance to horizontal motion is provided by specific elements (moment-resisting frames, braced frames, or shear walls) and connections to hold structural elements together. Horizontal elements such as floors and roofs acting as diaphragms distribute the lateral forces to the vertical elements.



Construction that provides a continuous path to transfer the lateral load from roof to foundation is critical to allow the structure to respond as a unit to ground shaking. For example, a well-nailed wood frame house resists ground shaking better than an unreinforced brick house; once the brick cracks, the path along which the lateral load is transferred is broken. Proper ties between the foundation and the structure and between the various elements of the structure are essential for good earthquake resistance. Buildings or other structures that are poorly attached or unattached to their foundations may shift off the foundation during an earthquake.

LIQUEFACTION

Liquefaction represents reduction in soil strength and stiffness by earthquake shaking or other rapid loading. Liquefaction occurs in saturated soils, that is, soils with groundwater levels near the surface. As demonstrated in recent earthquakes around the world, soil liquefaction, as well as related settlement and lateral spreading, can cause significant damage to supported structures, buried utilities, or waterfront structures.



MAGNITUDE

Earthquake magnitude is an estimate of the earthquake size, or strength at its source. It is the most familiar earthquake descriptor to engineers, geologists, and the general public. Richter magnitude (also known as the local magnitude or M_L) is a measure of the amplitude of a standard instrument located a standard distance away. The scale is logarithmic, meaning that each whole-number increase represents tenfold increase in the recorded amplitude. Each whole-number increase also represents a 32-fold increase in energy released. Thus a M7 earthquake releases 1,000 times the energy of a M5 earthquake. Other magnitude scales have also been devised by scientists to better characterize large damaging earthquakes or deep events.

MODIFIED MERCALLI INTENSITY

The Modified Mercalli Intensity scale (MMI) measures the intensity of how an earthquake affects a given site. The data used for assigning intensities is based on firsthand reports. While an earthquake has only one magnitude, it can have many intensities, which are influenced by distance and soil conditions. Engineered structures can be damaged at MMI VIII. The abridged MMI scale is provided in the table below.

MMI Level	Damage Level
I to V	None
VI	Felt by all. Damage slight.
VII	Damage negligible to buildings of good design and construction. Considerable damage to poorly built or badly designed structures.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse; great damage in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving vehicles disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out-of-plumb; great damage in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rail bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.
XI to XII	Nearly total or total damage. Landscape permanently distorted.

PROBABLE MAXIMUM LOSS

Probable maximum loss (PML) is a term devised to represent potential damage level in the event of an earthquake. It represents the cost to return the structure to pre-earthquake condition, expressed as a percentage of the structure replacement value. The subscript refers to the percent confidence of non-exceedance. A correlation with terms used in ASTM E2026-07 is provided below.

Probable Maximum Loss	ASTM E2026-07 Terminology	Confidence Level
PML_{50}	Scenario expected loss SEL_{475}	Average or expected loss
PML_{90}	Scenario upper loss SUL_{475}	90% of non-exceedance

A relationship between a damage factor and extent of potential damage is noted in the table below.

ATC-13 Damage Factor	Damage Risk	Extent of Damage
< 10%	Low	Small cracks in walls; falling of plaster in large bits over large areas; damage to nonstructural parts like chimneys, projecting cornices, etc. The load-carrying capacity of the structure is not reduced appreciably.
10% to 30%	Moderate	Large and deep cracks in walls; widespread cracking of walls, columns, piers, and chimneys. The load-carrying capacity of the structure is partially reduced.
30% to 60%	High[1]	Gaps occur in walls; inner or outer walls collapse; failure of ties between separate parts of building. Approximately 50% of the main structural elements fail. The building takes a dangerous state.
60% to 100%	Very high[1]	A large part or the whole building collapses.

1. Potential life safety concerns. Source: Reitherman, R., "Background Paper on the Conversion of Damage Probability Matrices into Fragility Curves," Panel on Earthquake Loss Estimation, National Research Council, December 12, 1986.

SEICHE

A seiche is a standing wave in an enclosed or partly enclosed body of water and is analogous to the sloshing of water that occurs when a large object is suddenly dropped into a basin. Earthquakes may induce seiches in lakes, bays, and rivers. Seiches are usually only a few feet high, but they can still flood or knock down houses and tip over trees.

SETTLEMENT

Settlement occurs when soils beneath a building's shallow foundation (spread footing) compress or compact. Structural damage commonly occurs when soils beneath portions of a building compact unevenly. Sites adjacent to bodies of water are particularly susceptible to differential settlement.

SUBSIDENCE

Subsidence is a sudden elevation change (uplift or drop) during an earthquake. It can have severe impact on coastal communities. During the 1964 Alaska earthquake, some parts of Prince William Sound were uplifted by several meters. Submerged marshlands in several estuaries along Pacific Northwest coast suggest that similar episodes of sudden subsidence have also occurred in the region. The Seattle Fault event that occurred about 900 years ago resulted in a vertical offset as the fault crosses the Puget Sound.

TSUNAMI

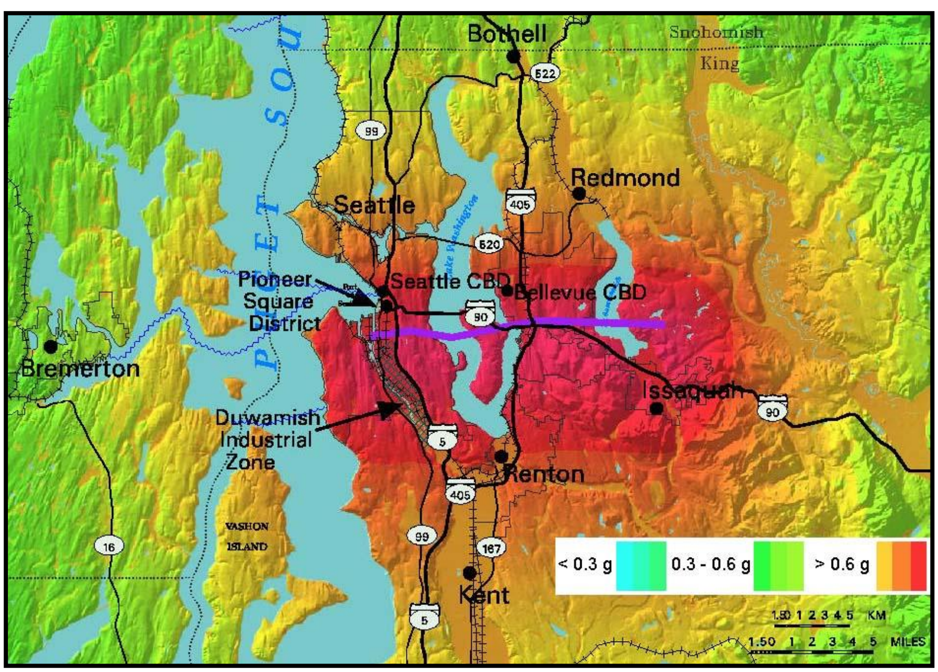
A tsunami is a large wave caused by a change in the elevation of the ocean floor due an earthquake. Tsunamis can be tens of feet high when they hit the shore and can cause significant damage to the coastline. Large subduction earthquakes causing vertical displacement of the sea floor and having magnitudes greater than 7.5 are the most common cause of destructive tsunamis. This was the case in the recent tsunami following the December 26, 2004 M9.3 subduction earthquake off Northern Sumatra, as well as the M8.8 2010 Chile and M9.0 2011 Great East Japan earthquake events. Large waves produced by an earthquake or a submarine landslide can overrun nearby coastal areas in a matter of minutes. Tsunamis can also travel thousands of kilometers across open water and wreak destruction on distant shores hours after the earthquake that generated them.

APPENDIX C
SCENARIO FOR A M6.7 EARTHQUAKE ON THE SEATTLE FAULT

A major earthquake on the Seattle fault would have a significant impact on the central Puget Sound population and economy. The return period for a M6.7 event on this fault is 1,000 or more years. The fault passes under a heavily urbanized region (see peak ground acceleration map below) and the potential disruptions would be felt for years. Since the fault is much shallower than the deep events such as the 2001 Nisqually earthquake, its impact would be comparable to the 1994 M6.7 Northridge earthquake in southern California. Potential scenario losses would be:

Impact	Magnitude
Property damage and economic loss	$33 billion
Deaths (injuries)	1,600 (> 24,000)
Buildings destroyed	9,700
Fires	130, causing $500 million in property loss

The impact of a major urban earthquake can be significantly reduced by proactive actions to protect lives, property, and the economy. The Seattle Fault Earthquake Scenario Project (Washington State Emergency Management Division, "Scenario for Magnitude 6.7 Earthquake on the Seattle Fault," May 2005) was the result of the vision and effort of local professionals to improve the earthquake safety in the Puget Sound region. MRP Engineering was actively involved in this three-year effort. The scenario report is available at: https://www.eeri.org/projects/earthquake-scenarios/seattle-fault-scenario/



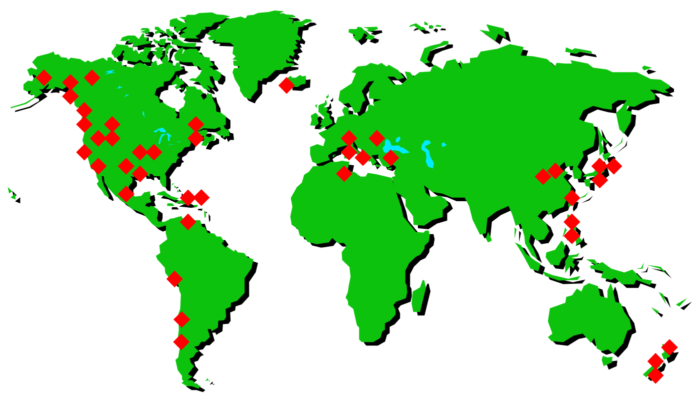
APPENDIX D
MRP ENGINEERING QUALIFICATIONS

MRP Engineering is a structural risk analysis and engineering consulting company that assists clients to protect their business operations from risks to physical assets resulting from the adverse impacts of natural and manmade disasters, such as earthquakes, hurricanes, and explosions. Our philosophy is to listen to your needs and provide you with practical, cost-effective structural engineering-based risk reduction solutions.

SERVICES

Our services include the following:

- **Structural risk analysis** for earthquake, severe wind, blast, and other natural and manmade hazards affecting buildings, equipment, piping, bridges, other structures, and lifelines
- **Structural engineering design** for selective upgrade or rehabilitation of existing facilities
- **Structural engineering expert opinion** in support of insurance claims or mediation



Changing building codes, particularly in the area of earthquake engineering, reflect that most existing buildings may not meet expected life-safety and business continuity performance objectives. This has increased the awareness of and need for adequately managing business property risks.

Structural risk analysis entails a systematic approach and methodology, beginning with risk screening, followed by in-depth analysis of highly vulnerable structures or components. The process culminates in a mitigation phase involving design of structural upgrades, or the implementation of other risk mitigation strategies.

Structural engineering expert opinion is sought when problems occur with existing construction, either following a natural or manmade disaster, or as a result of design or construction deficiencies. MRP Engineering staff has investigated hurricane- and earthquake-damaged buildings. Services available include site damage investigations, root-cause structural analysis, emergency repair, and rehabilitation design.

We provide high-quality technical expertise in evaluating the risks or structural issues, and recommend to you the appropriate risk mitigation strategies or other options, given your risk tolerance and concern for your organization's personnel safety and business continuity. In providing these services, MRP Engineering balances innovation with tested approaches in providing practical and cost-effective solutions that contribute to your safety and success as an organization.

APPENDIX E
RESUME — MARK R. PIEREPIEKARZ

MRP Engineering, LLC, Newcastle, Washington, President, 2002 to Present
ABS Consulting (EQE International), Seattle, Washington, Group Manager, 1995 to 2002
EQE International, Inc., Irvine, California, Principal Engineer, 1986 to 1995
Merritt CASES, Inc., Redlands, California, Engineer/Scientist, 1985 to1986

PROFESSIONAL EXPERIENCE

Mark Pierepiekarz has nearly 30 years of professional experience focusing on structural and natural hazard engineering. He has performed structural analysis, pro-active retrofit and upgrade design, and repair of impacted commercial, industrial, and public buildings and other facilities throughout the United States and abroad. His structural engineering experience also includes wind and earthquake analysis and upgrade design and analysis of bridges, reservoirs, and lifeline systems. Actual strong-motion earthquakes have tested his structural designs with successful results. He investigated damaged and distressed buildings and structures, and performed root-cause analyses following damaging earthquakes, tsunamis, and hurricanes.

Mark remains at the forefront of structural engineering technologies. He has authored and presented a number of technical papers on the seismic design of structures. He is also active in providing input into the development of building codes and standards. Mark has previously served as the Director and President of the Structural Engineers Association of Washington (SEAW, Seattle Chapter), and represented this organization in the "Seattle Fault Scenario" project. He was named 2009 SEAW Seattle Chapter Engineer of the Year. The award recognizes individuals who have provided service to SEAW and the profession, have brought visibility to the profession that is favorable in the public eye, have exhibited distinguished technical and creative achievement, and have encouraged and nurtured others in their professional development. Mark is currently serving on the City of Seattle's Unreinforced Masonry Policy Committee, advising the city on seismic retrofit policy for unreinforced masonry buildings.

Mr. Pierepiekarz has personally performed post-earthquake damage investigations and has written reconnaissance reports following the South Napa, California (2014), Japan (2011), Chile (2010), Haiti (2010), Nisqually (2001), Northridge (1994), Landers/Big Bear (1992), Upland (1990), Loma Prieta (1989), Whittier Narrows (1987), Superstition Hills (1987), and Satsop, Washington (1999) earthquakes. He has performed damage investigations following 2005 Katrina and Rita hurricanes.

EDUCATION

UNIVERSITY OF ILLINOIS, Champaign-Urbana, M.S. Structural Engineering, 1985

UNIVERSITY OF ILLINOIS, Champaign-Urbana, B.S. Civil Engineering, 1984

PROFESSIONAL ENGINEER REGISTRATIONS

California (PE and SE), Louisiana, Mississippi, Nevada, Oregon, and Washington (PE and SE)

MEMBERSHIPS

American Society of Civil Engineers (ASCE); Earthquake Engineering Research Institute (EERI): Director (Seattle Chapter); Structural Engineers Association of Washington (SEAW): 2009 Engineer of the Year, former Director and President (Seattle Chapter)

SEMINARS AND WORKSHOPS

Structural Engineers Association of Washington, "The Great Japan Earthquake and Tsunami: Lessons for the Pacific Northwest," Seminar Presenter, Seattle, Washington, June 15, 2011.

Structural Engineers Association of Washington, "Seismic Design Using the 2006 International Building Code", Seminar Presenter, Seattle, Washington, 2007.

Structural Engineers Association of Washington, "Seismic Rehabilitation of Buildings", Seminar Co-Chairman, Seattle, Washington, April 12, 2002.

Structural Engineers Association of Washington, "Seismic Design Using the 1997 UBC", Seminar Co-Chairman, Seattle, Washington, April 4, 1998.

Canadian Risk and Insurance Management Society, "An Intelligent Approach to Natural Hazard Risk Management Worldwide", Calgary, Canada, October 4 and 5, 1998.

Irvine Institute of Technology, "Seismic Principles for Professional Engineers", Course Instructor, 1994 to 2004.

ASCE, "Earthquake Risk Reduction for Utility Lifelines", "Seismic Design for Tanks and Nonstructural Components", May 14 and 15, 1993.

PUBLICATIONS

Contributing Author, "Implications of the Great East Japan Earthquake for the Pacific Northwest Region of the United States," International Symposium on Engineering Lessons Learned from the Giant Earthquake, Tokyo, Japan, March 3 to 4, 2012.

Contributing Author, "Great East Japan (Tohoku) Earthquake Lessons for Pacific Northwest, Alaska, and Hawaii," Post-Earthquake Reconnaissance Report by the Structural Engineers Association of Washington, October 2011.

Contributing Author, "Scenario for Magnitude 6.7 Earthquake on the Seattle Fault," Washington State Emergency Management Division, May 2005.

With J. Shipp, D. Smith, and K. Binder, "Seismic Design of a Combined Standpipe and an Elevated Tank in San Diego County," 11th World Conference on Earthquake Engineering, Mexico, 1996.

With S. Shekerlian, "Seismic Principles Design Manual," California State University, Long Beach, 1995.

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With M.W. Johnson, "Northridge Building Case Studies Project, The Broadway Store and The Newhall Land and Farm Building," California Seismic Safety Commission, Prepared by Rutherford and Chekene, Second Draft, September 26, 1994.

With M.W. Johnson, "Seismic Strengthening Methods for Unreinforced CMU Partitions and Infill Systems," Proceedings, 1993 National Earthquake Conference, Memphis, Tennessee.

"Uniform Building Code Anchorage to Concrete Provisions," Building Standards, July to August 1993, International Conference of Building Officials, Whittier, California.

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Structural Engineering

Natural Hazard Risk Analysis

Expert Opinion

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