Willamette Water Supply
Our Reliable Water

A River Runs Through It
2019 PNWS-AWWA Conference
Vancouver, Washington

Water Industry Seismic Guidelines and Practice Updates

May 2, 2019

Outline

- Introduction
- Seismic Design Framework
  - Identify Service Priorities
  - Establish Level of Service Goals
  - Establish Design Earthquake
  - Evaluated Project Specific Seismic Hazards
  - Establish Design Standards and Methods
  - Design for Seismic Risk Mitigation

Seismic hazards are widespread

"Today, approximately 91 percent of Americans live in areas subject to natural disasters or terrorism" (Ripley, 2009).

The United States Geological Survey (USGS) estimates that over 50 percent of the land mass in the contiguous United States would be affected by at least strong shaking (MMI VI level of shaking) from relatively infrequent ground motions from earthquakes

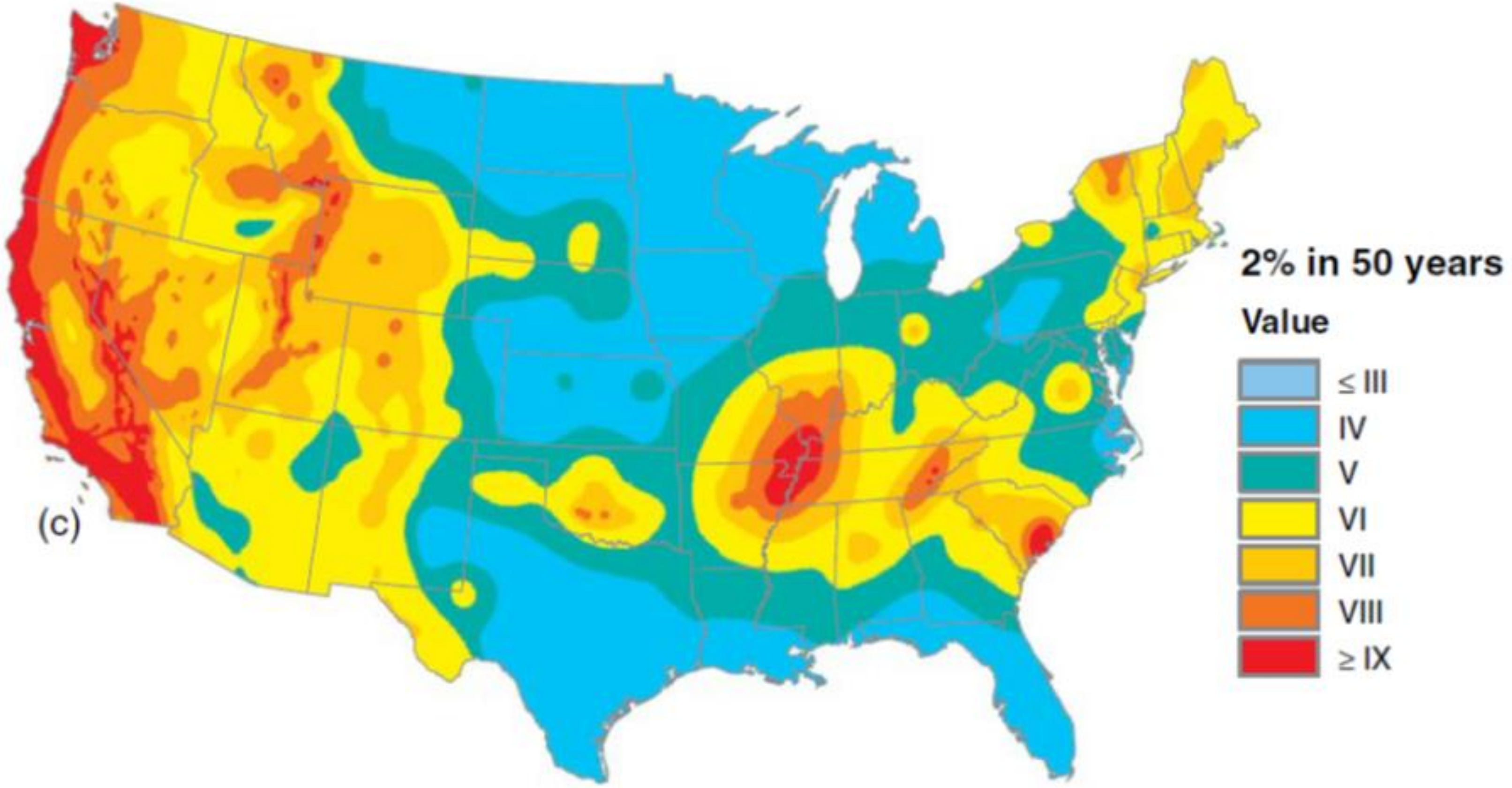


Figure 14.1. 2014 probabilistic seismic hazard map of the contiguous United States shows the predicted levels of earthquake shaking severity in terms of modified Mercalli intensity index for 2 percent probability of exceedance in 50 years (Jaiswal et al, 2015).

The modified Mercalli intensity (MMI) scale indicates the severity of shaking to the observed effects (Jaiswal et al., 2015).

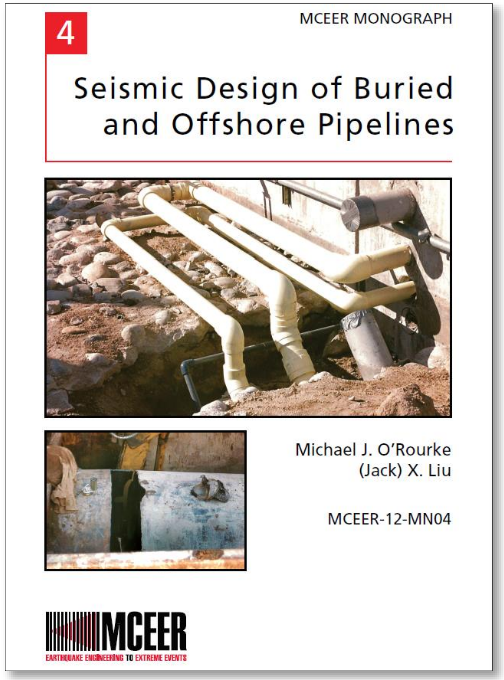

Source: nasa.gov


Source: freecreatives.com

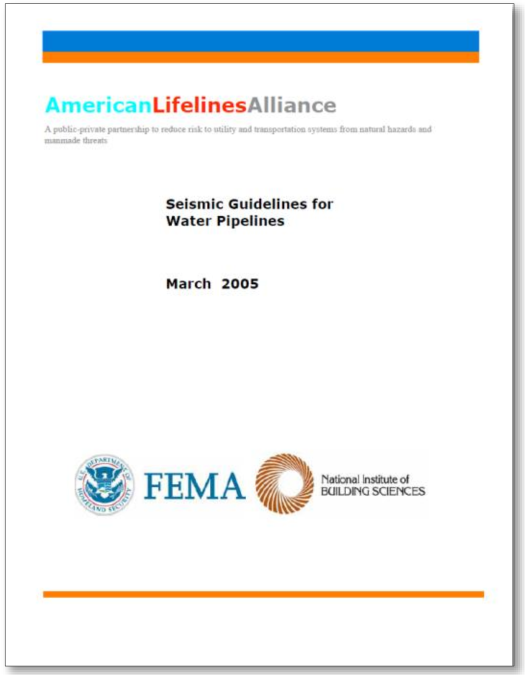
Source: Pinterest

Some of the good industry references

Pipelines

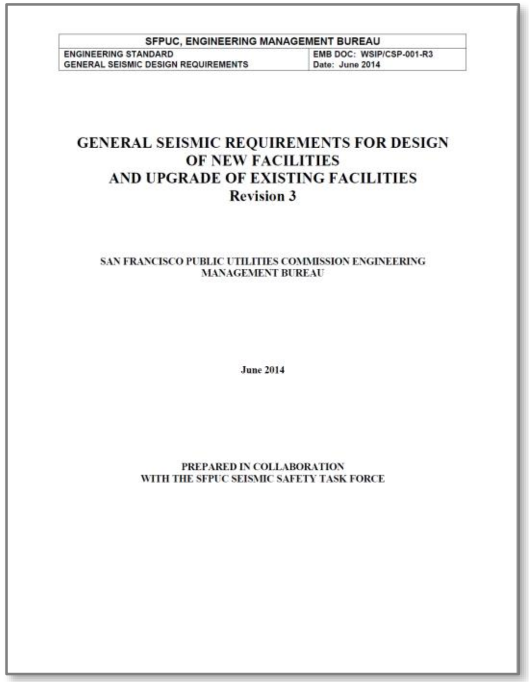


(O'Rourke & Liu, 2012)

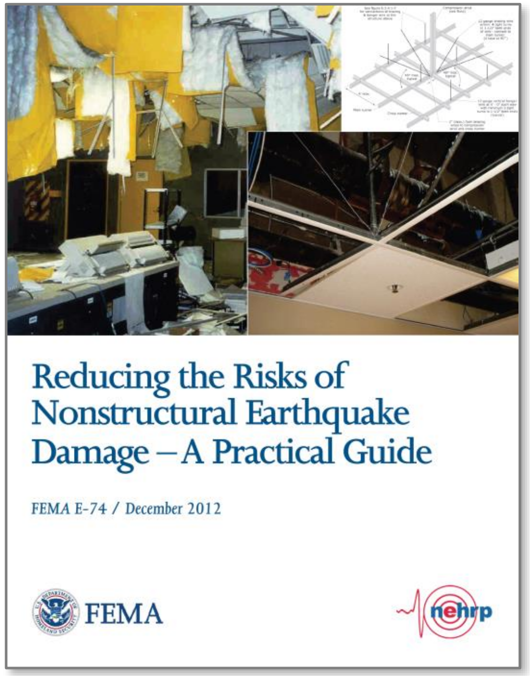


(ALA, 2005)

Facilities

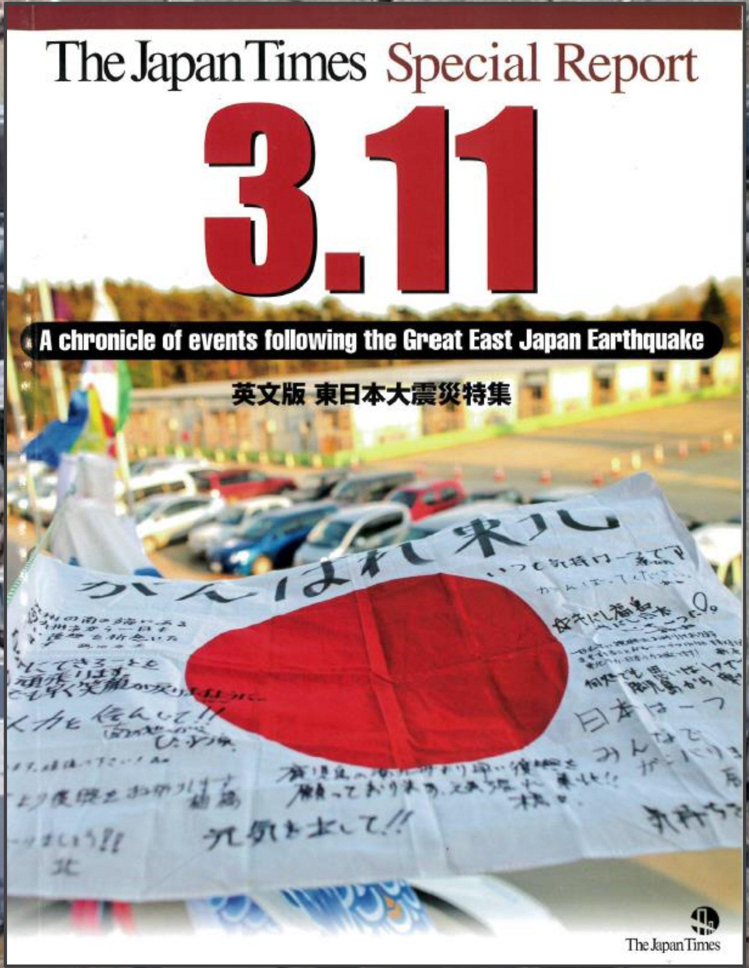


(SFPUC, 2014)



(FEMA, 2012)

Fukushima Nuclear Plant Crisis



“Nuclear crisis man-made, not ‘an act of god’: experts

“Quake guidelines for nuclear plants, revised by the Nuclear Safety Commission in September 2006, essentially order power companies to design plants without compromising safety in case of earthquakes ‘that can be expected no matter how rare.’ The only place in the guidelines where tsunamis are mentioned – the last page of the 14-page document”

“The guidance is not very specific… The wording is meant for seismic experts… I am a nuclear engineer, not a quake expert. I didn’t understand the guidance very much, so I asked other committee members to use words people understand. But they didn’t listen… The guidance is useless” – ***Kunihiko Takeda, Chubu University***

SEISMIC DESIGN FRAMEWORK

Seismic design framework

[Discussion focused on AWWA M41 Proposed Chapter]

AWWA M41 Chapter 14. Seismic Design Guidelines for Ductile Iron Pipe [release with next manual]

AWWA M41 – DRAFT SEISMIC DESIGN CHAPTER

Chapter 14. Seismic Design Guidelines for Ductile Iron Pipe

"Everything should be made as simple as possible, but not simpler"
- Albert Einstein

14.1 INTRODUCTION

One of the most critical resources we have is water. Water is crucial to public health, firefighting, and societal development. People can only survive for a few days without water. A reliable and resilient water supply is necessary to sustain the economy and support responsible growth within a region. A resilient water supply will benefit both current and future generations.

Presidential Policy Directive (PPD) 21 defines the term "resilience" as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents" (PPD-21, 2013). Today, approximately 91 percent of Americans live in areas subject to natural disasters or terrorism (Ripley, 2009). There are many kinds of disasters, both natural and manmade, which can impact a water supply. Water infrastructure is one of the top four most important types of critical infrastructure following disasters (FEMA, 2014). Of all types of natural disasters or other events that can impact water systems, perhaps the most significant are earthquakes. The impact from large earthquakes on water systems and the related communities they serve can be significant. The United States Geological Survey (USGS) estimates that over 50 percent of the land mass in the contiguous United States would be affected by at least strong shaking (MMI VI level of shaking) from relatively infrequent ground motions from earthquakes as shown in Figure 14.1 (Jaiswal et. al., 2015)[1]. It is estimated that 12 percent of fire stations, 12 percent of hospitals, and 15 percent of all schools are located in regions of the contiguous 48 states where there is a 2 percent chance that severe shaking (MMI VIII level of shaking) or higher could occur in the next 50 years. "At such levels of shaking, even well-designed earthquake-resistant construction could experience some damage, while unreinforced masonry or nonductile concrete constructions are expected to perform extremely poorly, that is, experiencing partial or complete collapses" (Jaiswal et al, 2015).

[1] Table 14-3 later in the document describes the different levels of ground shaking associated with the modified Mercalli intensity (MMI) index which is a measure of ground shaking based on observed impacts. Developed in 1931 by American seismologists Harry Wood and Frank Neumann, this scale is "composed of increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, [and] is designated by Roman numerals" (USGS, n.d.).

May 2018 1
Committee_Draft M41 Seismic Design Chapter_rev6_5-7-18

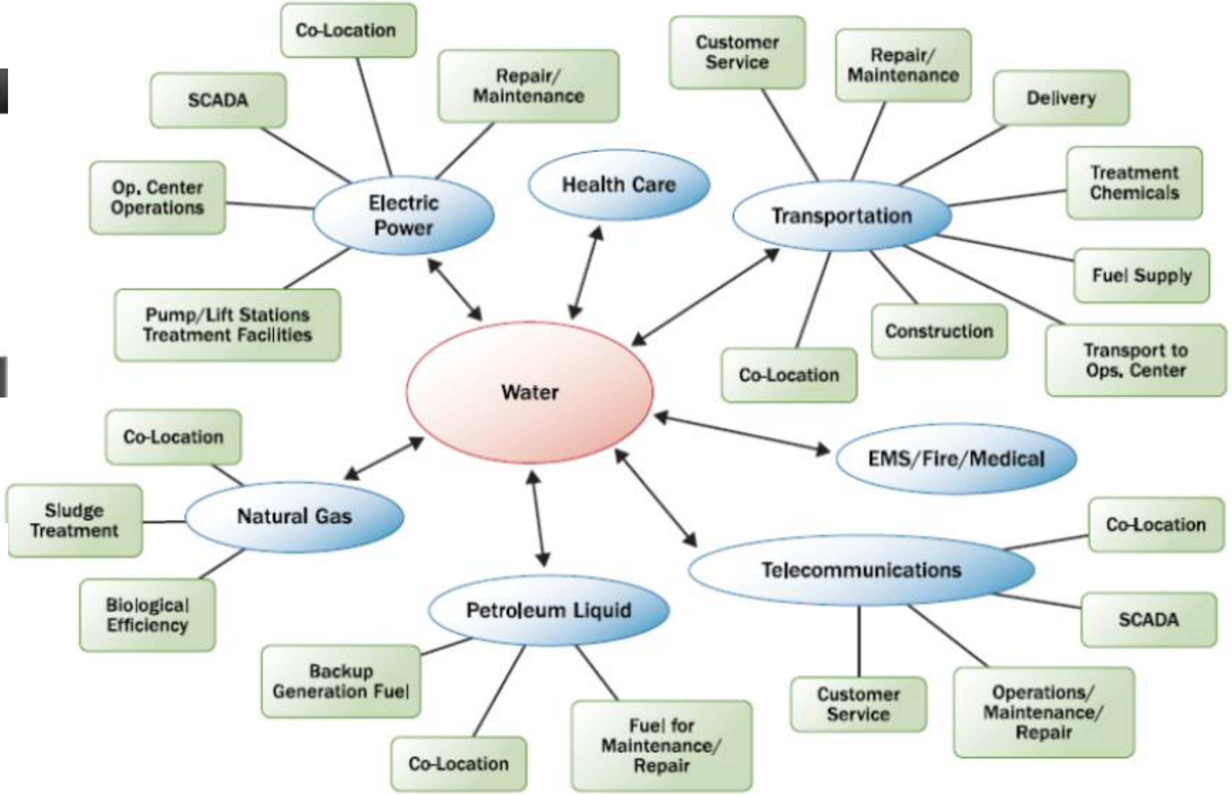
<u>Seismic framework steps:</u>

1. Identify service priorities
2. Establish level of service goals
3. Establish design earthquake
4. Evaluate project specific seismic hazards
5. Establish design standards and methods
6. Design for seismic risk mitigation

Identify service priorities

- Identifying Critical Customers

TVF&R Tualatin Valley Fire & Rescue



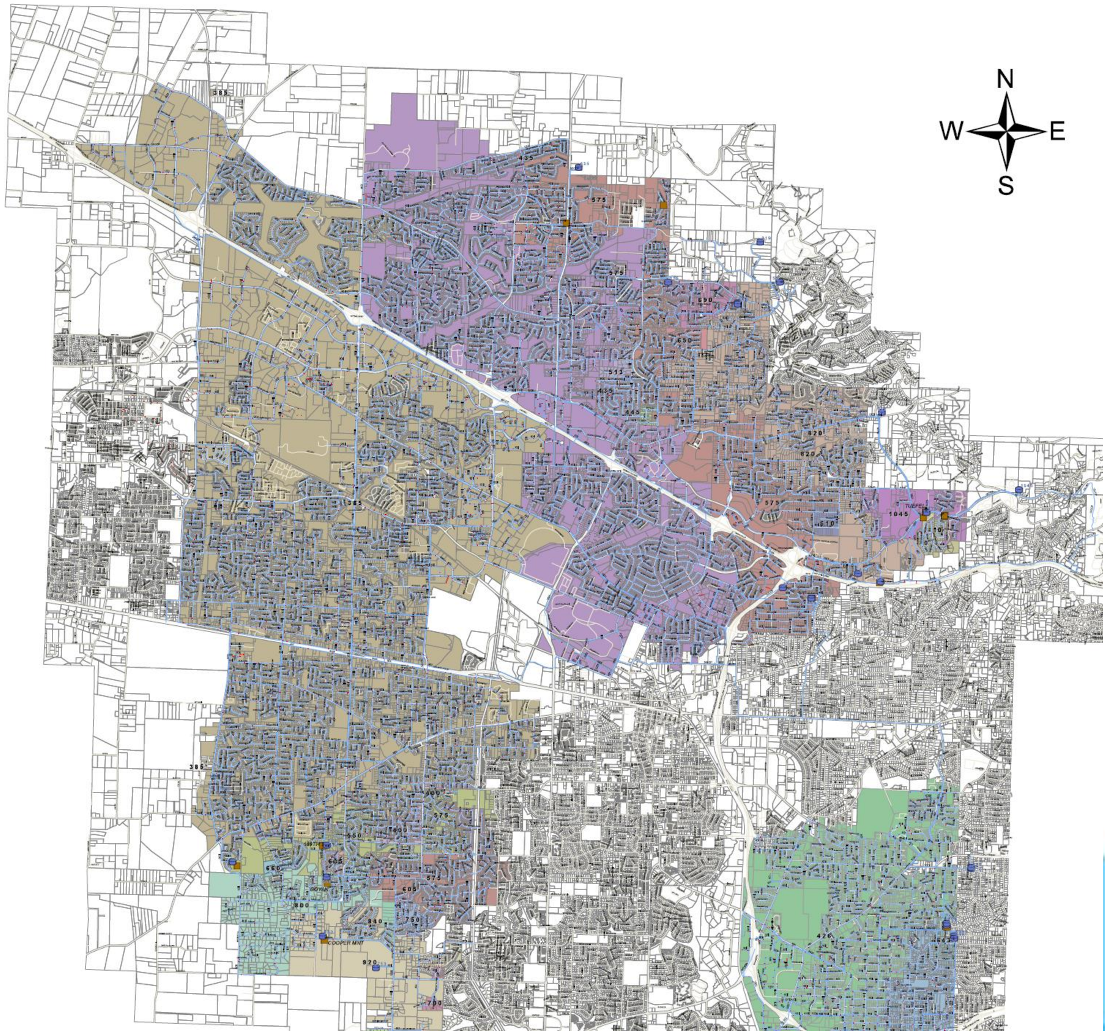
Water Sector Interdependencies (Source: 2010 Water Sector Specific Plan) (DHS, 2015)

Identify service priorities

- Understanding Infrastructure Components
  - understand the various components of the system
  - know how the system operates hydraulically
- Identify Infrastructure to Serve Critical Customers

Planning for water systems as an important part of the built environment, should consider both the broader and specific needs of the community as part of the identification of required critical customers and associated critical water infrastructure.

The process needs to take into consideration the complete system of infrastructure required to convey water from the source to the service connection.



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Identify service priorities

- Evaluation process

> It can be as straightforward as having a critical system element that is known to be vulnerable up to complete system evaluations that require a much greater level of effort and resources to complete the work. A practical approach to complete that work is to evaluate seismic resilience as part of the normal master planning activities that occur for water systems.

- Additional steps as part of a master planning activity for buried pipelines recommended by NIST (2015) include the following:
  - In GIS, superimpose the pipeline distribution system onto maps of the scenario hazard (peak ground velocity, liquefaction potential, and landslide potential).
  - Use empirical relationships developed by the American Lifelines Alliance (ALA) to predict the number of breaks and leaks in the pipeline system.
  - Estimate the time required to repair the predicted number of breaks and leaks based on historical crew productivity data and restore system functionality.
  - Consider the anticipated damage states of dependent systems (transportation, liquid fuel, etc.).

Seismic level of service goals

You have to understand what you're trying to achieve

"If you don't know where you're going, any road will get you there"

– *Lewis Carroll*

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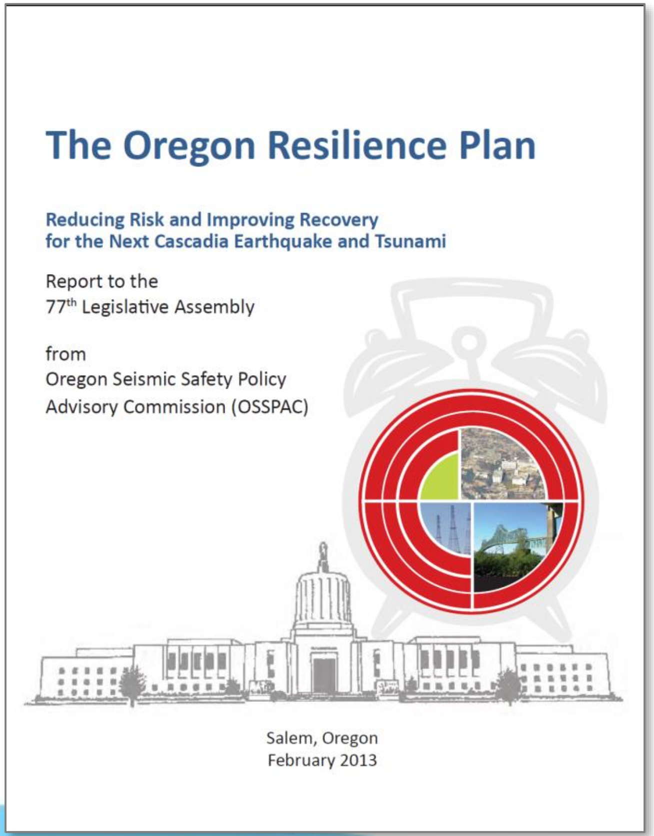
LOS goals based on guidance from the Oregon Resilience Plan

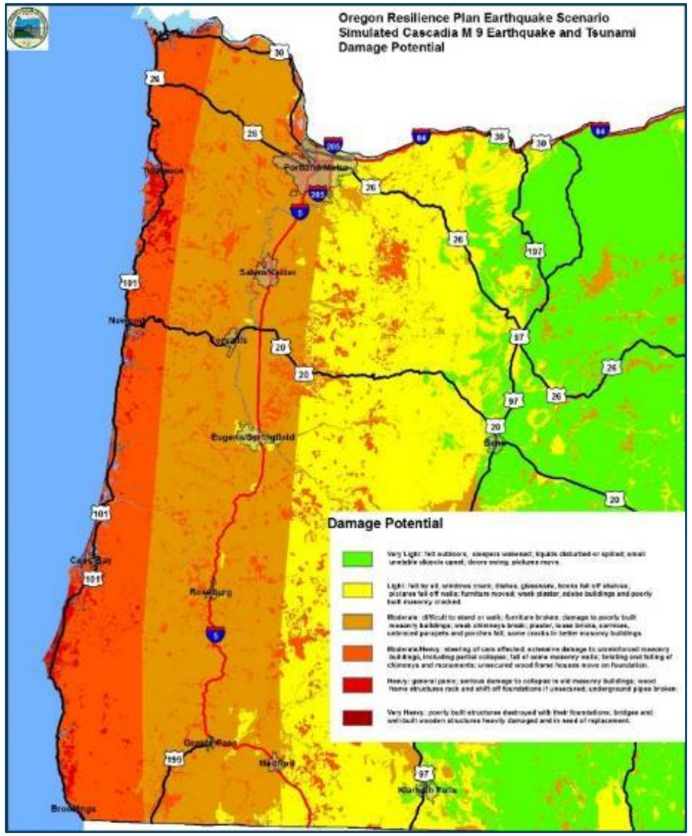

The Oregon Resilience Plan

Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami

Report to the
77th Legislative Assembly

from
Oregon Seismic Safety Policy
Advisory Commission (OSSPAC)

Salem, Oregon
February 2013



WWSP seismic level of service goals

System Components	WWSP LOS Goals	Oregon Resilience Plan Guidance
Intake & Raw Water Facilities	50% capacity w/n 48 hrs * (25% capacity w/n 24 hrs)	Source 20-30% (0-24 hrs) Source 50-60% (1-3 days) Source 80-90% (1-2 wks)
Treatment Plant	50% capacity w/n 48 hrs * (25% capacity w/n 24 hrs)	Source 20-30% (0-24 hrs) Source 50-60% (1-3 days) Source 80-90% (1-2 wks)
Terminal Storage Reservoir	Same as ORP	Transmission 80-90% (0-24 hrs)
Transmission Lines	Same as ORP	Transmission 80-90% (0-24 hrs)
Appurtenances	Same as ORP	Transmission 80-90% (0-24 hrs)
Turnouts	Same as ORP	Transmission 80-90% (0-24 hrs)

Oregon Resilience Plan Operational Level of Service Guidance - Target States of Recovery following an Earthquake

ORP – Oregon Resilience Plan

* Full capacity when electrical power, transportation and other required infrastructure capacity restored

Seismic level of service goals

- Classification of Infrastructure – Options:
  - Oregon Resilience Plan (ORP)

"The backbone water system would be capable of supplying key community needs, including fire suppression, health and emergency response, and community drinking water distribution points, while damage to the larger (non-backbone) system is being addressed." (OSSPAC, 2013)

  - Japan Water Works Association (JWWA)

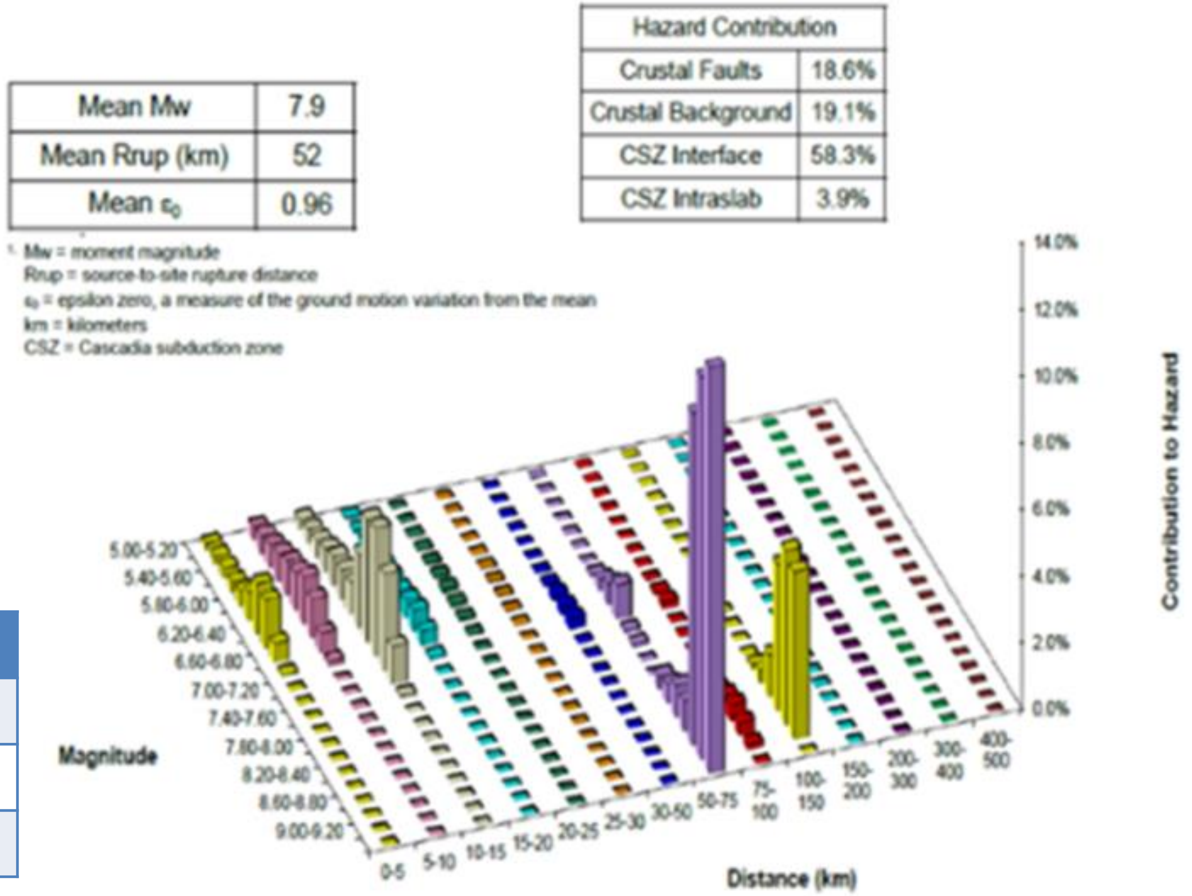
Like the ORP, the Japan Water Works Association (JWWA) considers two levels of importance ranking for water facilities, those facilities with a high level of importance (Rank A) and other facilities (Rank B).

  - ALA & ASCE Pipelines Seismic Subcommittee

Pipeline Function Class	Description
I	Pipelines that represent a low hazard to human life and have a low economic impact in the event of failure. These pipelines are not required to be functional immediately following an earthquake and can endure longer restoration times without impact to the water utility. These pipelines primarily serve agricultural or irrigation usage, certain temporary facilities, or minor (non-water) storage facilities, which do not have a significant role in local or regional economy.
II	Pipelines that provide water for typical use within the utility where only a limited impact would be realized in the event of failure. These pipelines require less restoration time than Class I pipelines to limit the impact to the surrounding community. This category provides water for typical domestic use within the system and includes all pipelines not identified in Class I, III, and IV.
III	Pipelines that represent a higher criticality than the typical pipelines within a utility. These pipelines deliver water to many customers and may also result in significant social or economic impacts in the event of failure and outage. Pipeline restoration times would need to be minimal following a major event.
IV	Pipelines that provide water to essential facilities for post-earthquake response, public health, and safety. These pipelines are intended to remain functional during and after a designed earthquake without an immediate required restoration time. These pipelines provide water for post-earthquake firefighting and emergency support.

Establish design earthquake

- WWSP seismic design parameters are based on a Probabilistic Seismic Hazard Analysis (PSHA) [can also use a Deterministic Seismic Hazard Analysis (DSHA)]
- The WWSP has adopted the 2% probability of exceedance in 50 years for its Design Earthquake



Probability of Exceedance (PE)	Recurrence Interval
50 percent PE in next 50 years	~ 72 years
10 percent PE in next 50 years	~ 475 years
2 percent PE in next 50 years	~ 2,475 years

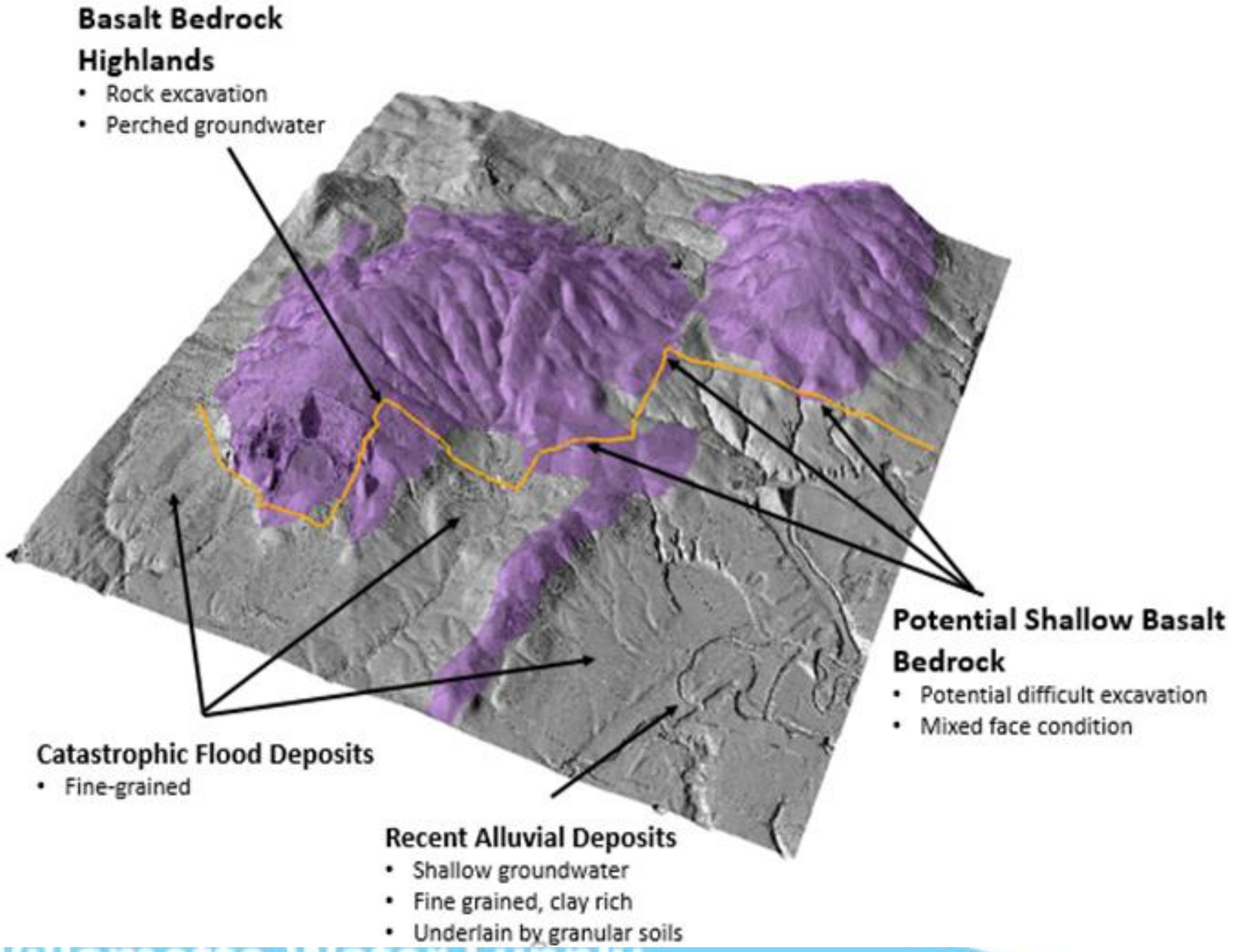
Evaluate project specific seismic hazards


ONE WAY
D STREET 400
4th AVE
ARMY
NAVY
The Avenue BAR
AVENUE BAR
2

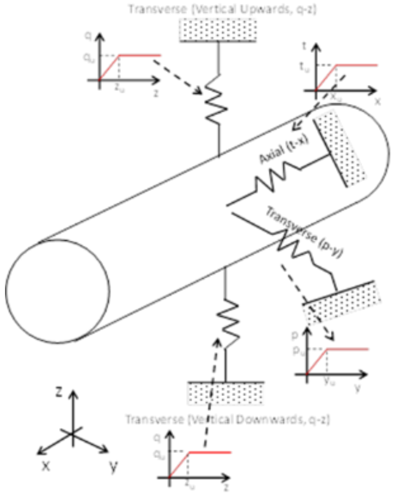
Alaska 9.2 M Earthquake March 27, 1964, at 5:36 p.m.

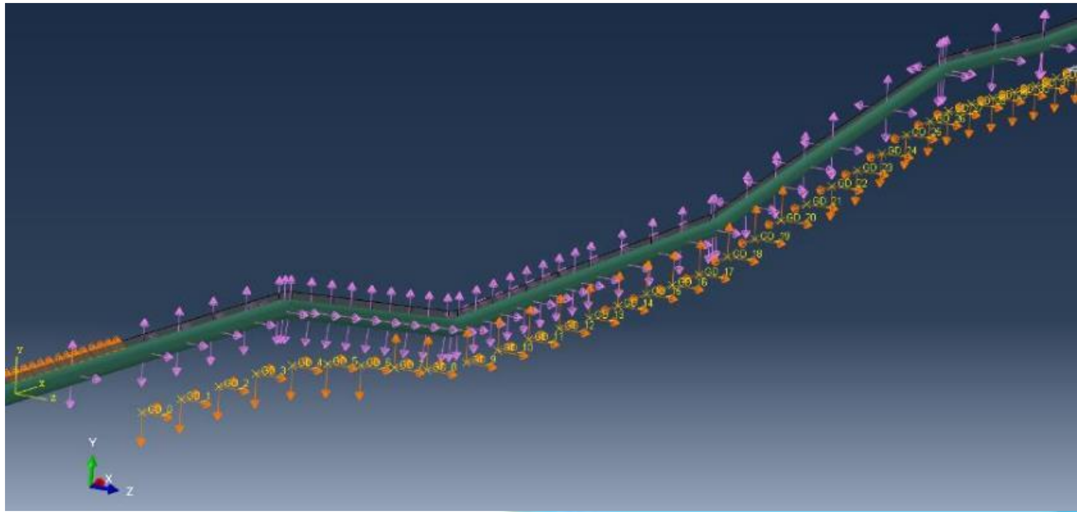
"AlaskaQuake-FourthAve" by U.S. Army - http://libraryphoto.cr.usgs.gov/

PLM_5.0 transitions into & out of rock



Soil/pipe interaction modeling





Anchorage, Alaska November 30, 2018
Southbound lanes near Mirror Lake

Consistent approach to pipeline seismic hazards & limit states

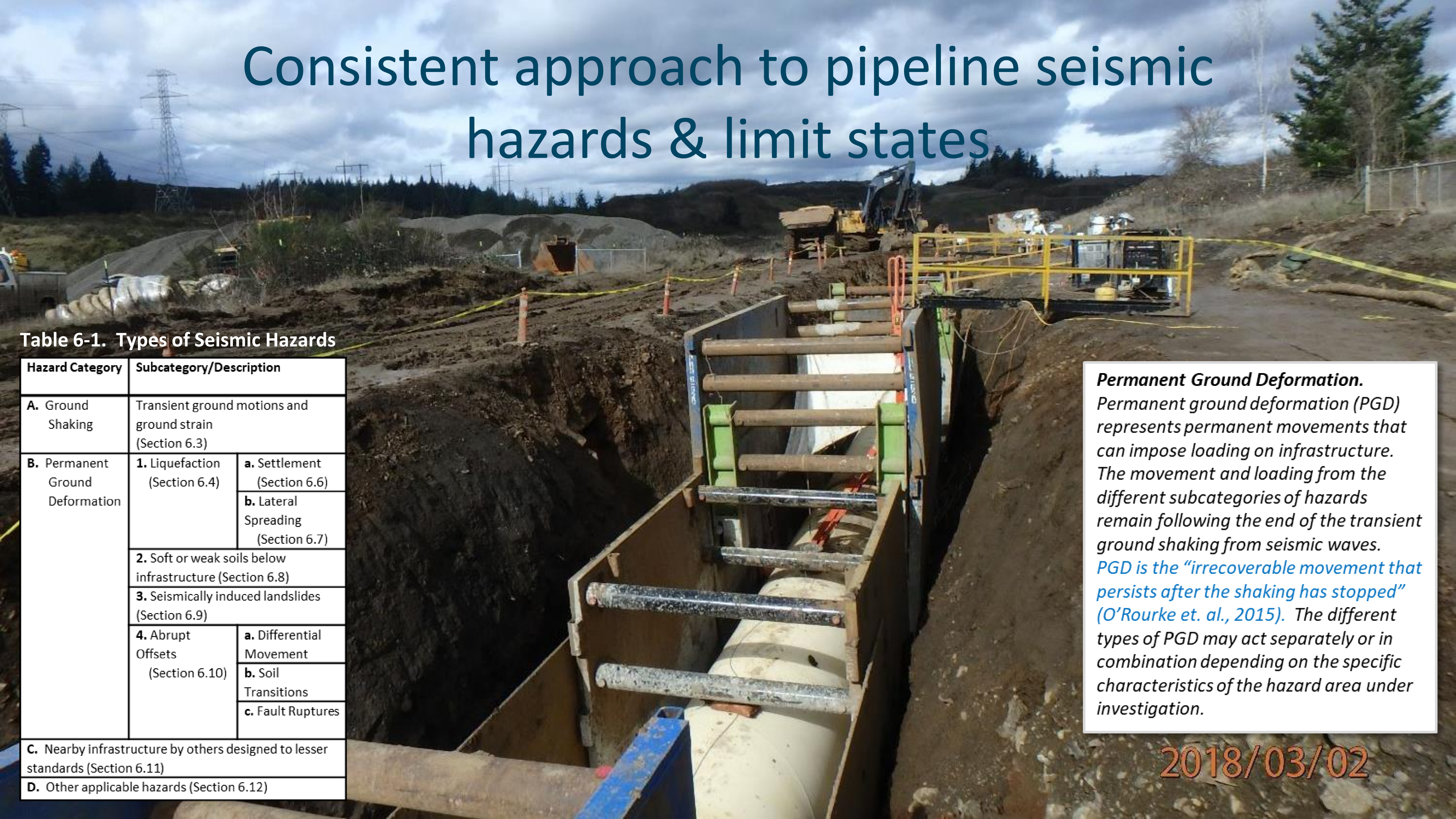


Table 6-1. Types of Seismic Hazards

Hazard Category	Subcategory/Description	
A. Ground Shaking	Transient ground motions and ground strain (Section 6.3)	
B. Permanent Ground Deformation	**1.** Liquefaction (Section 6.4)	**a.** Settlement (Section 6.6)
		b. Lateral Spreading (Section 6.7)
	2. Soft or weak soils below infrastructure (Section 6.8)	
	3. Seismically induced landslides (Section 6.9)	
	4. Abrupt Offsets (Section 6.10)	**a.** Differential Movement
		b. Soil Transitions
		c. Fault Ruptures
C. Nearby infrastructure by others designed to lesser standards (Section 6.11)		
D. Other applicable hazards (Section 6.12)		

Permanent Ground Deformation.
Permanent ground deformation (PGD) represents permanent movements that can impose loading on infrastructure. The movement and loading from the different subcategories of hazards remain following the end of the transient ground shaking from seismic waves. PGD is the "irrecoverable movement that persists after the shaking has stopped" (O'Rourke et. al., 2015). The different types of PGD may act separately or in combination depending on the specific characteristics of the hazard area under investigation.

Establish design standards and methods

Design Considerations

The characterization of pipe systems for the purposes of seismic design typically involves two classifications, *segmented pipe* and *continuous pipe* systems. These two classifications are defined as follows (O'Rourke and Lui, 2014):

Segmented Pipe. A pipeline with lower axial and rotational stiffness at the joints than the rest of the pipeline. Ductile iron and cast iron pipe are examples of a segmented pipe.

Continuous Pipe. A pipeline joined by connections that exhibit axial and rotational stiffness comparable to the rest of the pipe. Welded pipe (i.e. with welded joints) and fused pipe (i.e. with fused joints) are examples of a continuous pipe.

Establish design standards and methods

Pipe Design Performance Standards

Table 14-6. Ductile Iron Pipe Seismic Performance Classifications (from ISO Standard 16134, 2006, Table 2)

Parameter	**Class**	**Component Performance**
Expansion/contraction performance	S-1	± 1% of *L* or more
	S-2	± 0.5% to less than ± 1% of *L*
	S-3	Less than ± 0.5% of *L*
Slip-out resistance	A	3*d* kN or more
	B	1.5*d* kN to less than 3*d* kN
	C	0.75*d* kN to less than 1.5*d* kN
	D	Less than 0.75*d* kN
Joint deflection angle	M-1	$\pm 15^{\circ}$ or more
	M-2	$\pm 7.5^{\circ}$ to less than $\pm 15^{\circ}$
	M-3	Less than $\pm 7.5^{\circ}$

L is the component length, in millimeters (mm)

d is the nominal diameter of the pipe, in millimeters (mm)

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Design for seismic risk mitigation

Ductile iron pipe is considered a segmented pipe. The design for risk mitigation with ductile iron pipe primarily focuses on the performance characteristics of the joint as this is where the damage is usually found to occur. Singhal and Benavides (1983) state:

> "The most frequent and severe damage usually occurs at or near a pipeline joint. Most failures result from ground strains that develop axial or shear forces in the pipelines and at the joints."

Design for seismic risk mitigation

Limit States for Ductile Iron Pipe

Limit states establish design thresholds to consider as part of seismic risk mitigation and achieving desired levels of service performance. The primary goal is to maintain pipeline pressure integrity and avoid loss of containment. For ductile iron pipe systems there are few guidelines to follow related to limit states. Wham et al. (2018) proposed two limit states based primarily on internal pressure integrity, quantified by leakage rates, associated with large deformation performance of ductile iron pipe joints. These include the following:

- Limit State 1: Serviceability
- Limit State 2: Ultimate

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Design for seismic risk mitigation

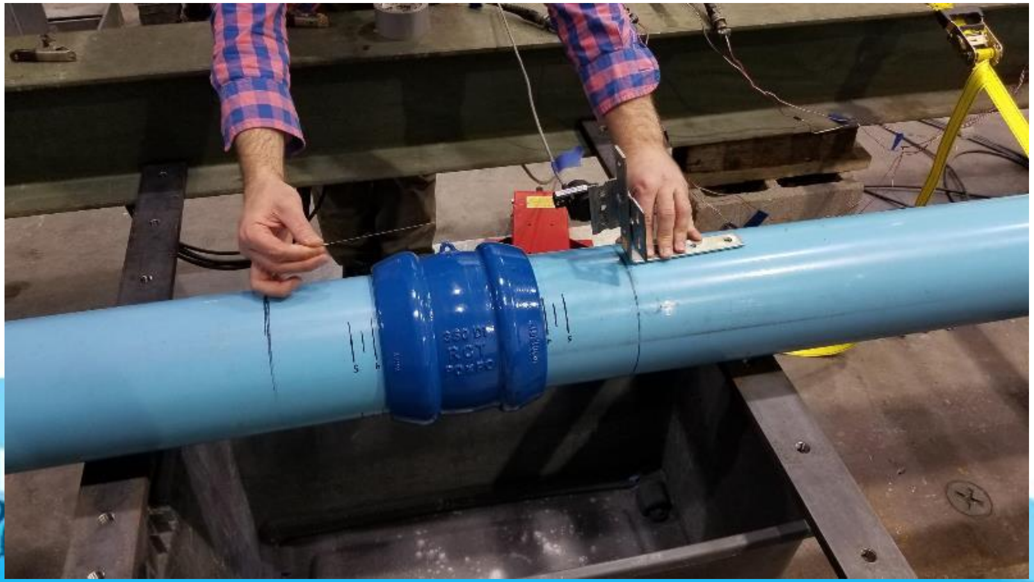
Performance Categories for Ductile Iron Pipe:

Category 1: Non-restrained joints. These include standard push-on joints not designed to provide pull-out resistance.
Category 2: Joints with gripper gaskets/gripping wedges. This category includes those restrained joint systems that rely on wedges that grip the pipe.
Category 3: Joints with integral restraint bead and boltless locking segments. This category provides improved performance due to integrated joint restraining mechanisms.
Category 4: Joints specially designed for combined seismic performance. These joints provide the highest level of seismic performance. By design they are intended to provide a high level of joint axial movement, axial joint strength, and joint deflection/rotation, either individually or when used in combination with other joint systems.

Select other discussion topics

- Testing to establish ductile iron pipe performance characteristics

> Wham et al. (2018) suggest that "each component of a hazard-resilient system (including couplings, valves, tees, etc.) can, and should, be evaluated for seismic performance… and qualified for expected levels of ground movement."



Select other discussion topics

- Other considerations for risk mitigation

> The in-depth analysis may show that even greater performance requirements than those associated with the highest ISO component performance levels may be required.

- Seismic policies
- Existing infrastructure

Select other discussion topics

- Other design issues

Ductile iron pipe products can be used in a variety of combinations to achieve the desired system performance. Consult manufacturers for the performance characteristics of specific ductile iron pipe products.

As one designs a portion of a water system, it is important to recognize that elements of the system that may behave differently than other portions of the system and can result in an unexpected outcome. These may be in the form of discontinuities between elements of the system or where portions of the system perform differently and act as anchors for the system in the ground.

Select other discussion topics

A final design consideration relates to creating redundant supplies to critical customers or working with them specifically to make sure adequate emergency response plans are developed. This will help mitigate any shortfalls in supply if that is to be expected. Understanding a customer's needs and critical demand requirements is in itself a step forward towards achieving system resilience.

- Installation

With fittings that allow axial movement, the common joint installation position is "at the mid-point, which allows for both joint expansion and contraction" (Gaston and Ratcliffe, 2016).

All installations should be performed in accordance with AWWA standards and the specific written recommendations of the manufacturers.

- Critical repair parts

Thank you!

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