Willamette Water Supply
Our Reliable Water

Lessons Learned from the 2011 Tohoku Earthquake, Applied to the Willamette Water Supply System

PNWS-AWWA

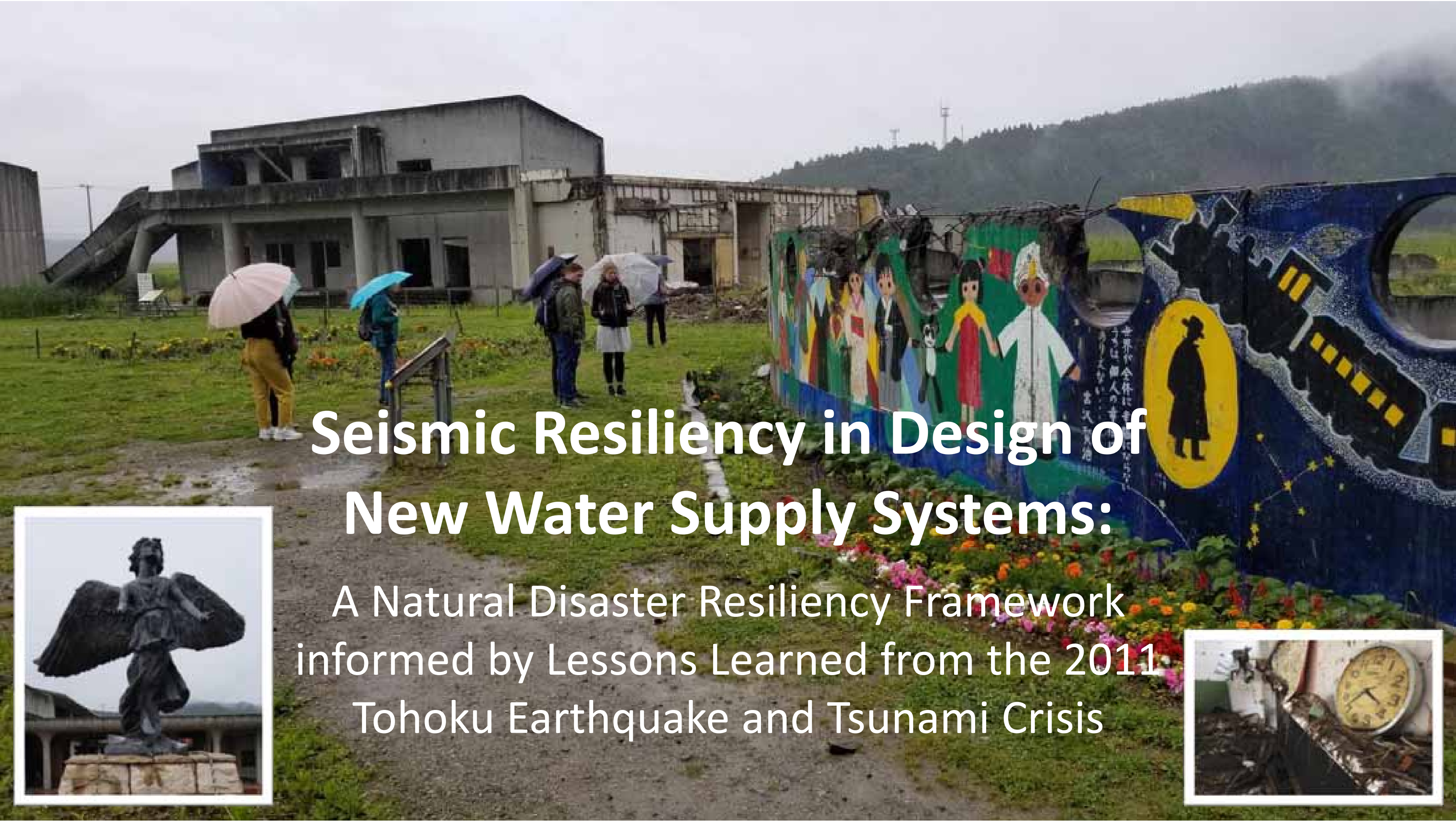
August 12, 2021

Mike Britch, P.E., MPA – WWSP Engineering & Construction Manager

PNWS-AWWA Water 2021 Virtual

Outline

- 1st Part – "*A Natural Disaster Resiliency Framework informed by Lessons Learned from the 2011 Tohoku Earthquake"*
  [11th International Exchange Forum: Seismic and Multi-Hazard Preparedness and Response Practices for Drinking Water Utilities]
  The Water Research Foundation
  October 2019
- 2nd Part – "Willamette Water Supply Program (WWSP) & Tualatin Valley Water District (TVWD): *Seismic Resilience & Mitigation Lessons Learned*" [CREW Lifelines Resilience Series Webinar | Water Utility Earthquake Resilience Symposium]
  CREW Cascadia Region Earthquake Workgroup
  July 2020
- 3rd Part – "System Seismic Operational Strategy: *5-day Seismic Level of Service (LOS) and Battery Backup*" [WWSS Operations Committee]
  Willamette Water Supply Our Reliable Water
  February 2021


Seismic Resiliency in Design of
New Water Supply Systems:
A Natural Disaster Resiliency Framework
informed by Lessons Learned from the 2011
Tohoku Earthquake and Tsunami Crisis

Outline

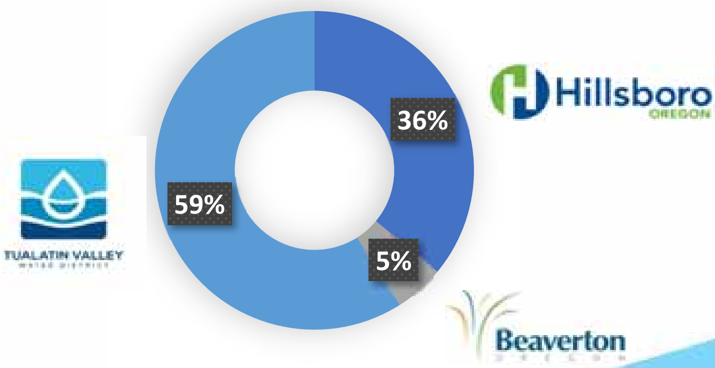
- Willamette Water Supply Program (WWSP) Background
- Tohoku Program Lessons
- Natural Disaster Resiliency Framework
- Application of Framework to WWSP

Willamette Water Supply Program

***Mission Statement: Provide a cost-effective, reliable and resilient water supply system** by July 2026, that benefits current and future generations of the communities we serve and supports a vibrant local economy.*

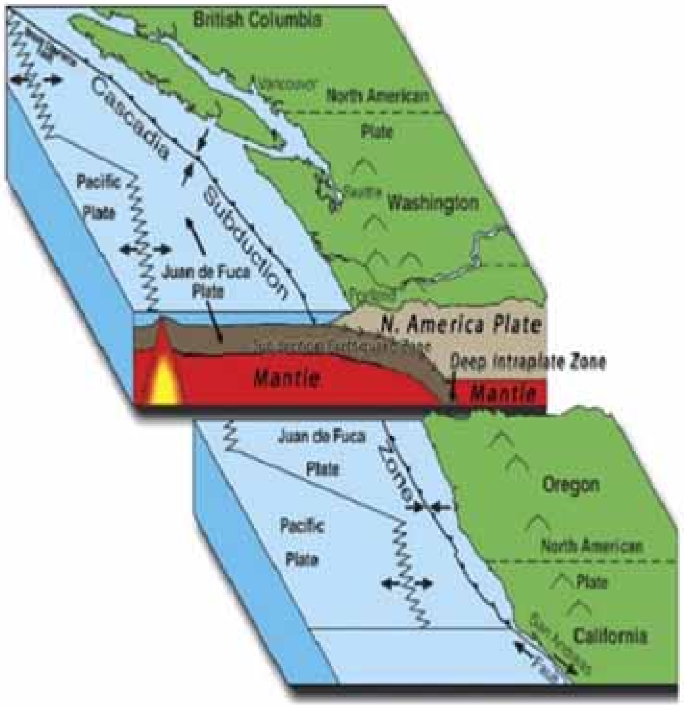
1. Modified water intake
2. New water treatment plant
3. 30+ miles of large diameter pipeline
4. Water storage tanks

Scheduled completion: 2026



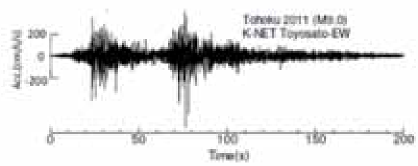
Willamette Water Supply
Our Reliable Water

Seismic hazards are one of the greatest risks to water systems in the NW Region



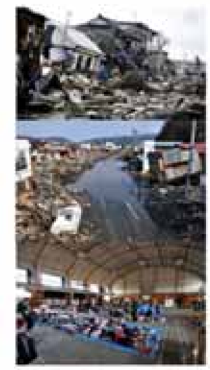
<u>Subduction zone earthquakes:</u>

Tohoku, Japan (March 11, 2011)



FEMA

- 16,447 Deaths
- 4,787 Missing
- 5,888 Injured
- 430,000 Homeless
- 111,944 Buildings destroyed
- 637,277 Buildings damaged
- Honshu Island moved 7.8 feet West
- Nuclear power meltdown
- Cost could exceed $300 billion



Alaska (March 27, 1964)

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

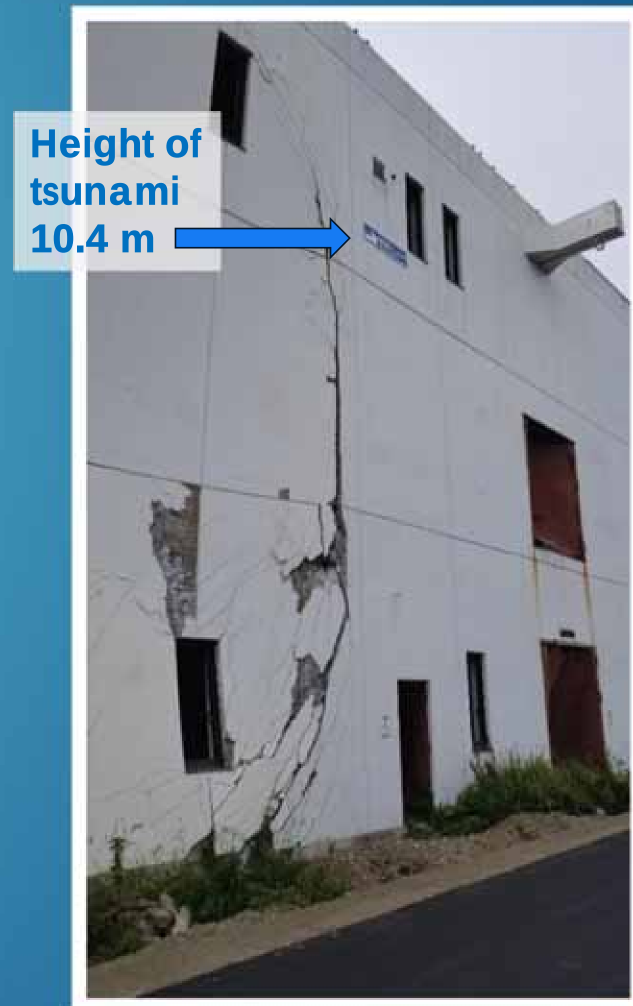
Natural disasters provide important context to understanding

- Tohoku Program (June 2019) – Visit to Miyagi Prefecture
  - Sendai
  - Ishinomaki
  - Kessennma

SENDAI

- MINAMI-GAMO WASTEWATER TREATMENT PLANT


Height of tsunami 10.4 m
(34 feet)


Height of tsunami 10.4 m

SENDAI

(JUNE 23, 2019)
- ARAHAMA ELEMENTARY SCHOOL
- COASTAL VISIT

Four story reinforced concrete school building became a refuge for students and school personnel. The tsunami rose to the 2^{nd} floor. People found safety on the rooftop.

(45 feet)

Technological Forecasting & Social Change

Disaster resilience as a complex problem: Why linearity is not applicable for long-term recovery

Deborah Blackman, Hitomi Nakanishi, Angela M. Benson

Disasters are complex multi-disciplinary problems

Blackman et. al. states that complex problems *"occur within a system, which is made up of interconnected, interdependent elements"* and that they *"cannot be addressed in a piecemeal way, it must be addressed as an entire system"* (p. 91)

Blackman, D., Nakanishi, H., & Benson, A. M. (2017). Disaster resilience as a complex problem: Why linearity is not applicable for long-term recovery. *Technological Forecasting and Social Change, 121*, *89-98.* doi: https://doi.org/10.1016/j.techfore.2016.09.018

TIME ELEMENT

Stages of Time

"Pre-Disaster"	**"Post-Disaster" Stages**		
Preparedness Stage	Relief Stage (short-term)	Rehab. Stage (intermediate)	Recovery Stage (long-term)

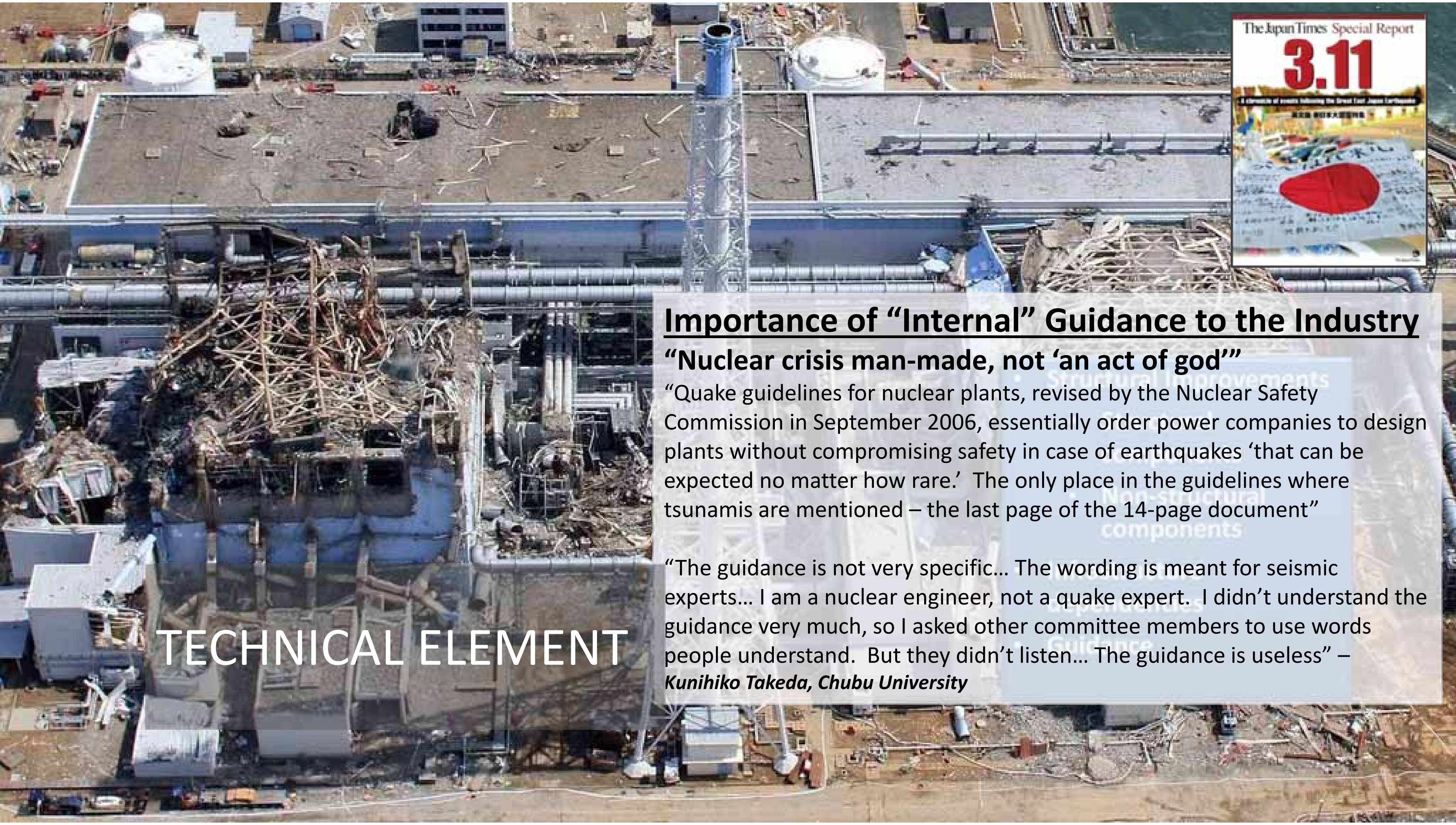
Important to understand what occurs during the different stages of the disaster and the associated needs

+

Coupled with the context understanding of the disaster allows you to form a mental image of the disaster you are trying to plan for

Allows us to anticipate what you will need

Informs the development of measures and guidance needed now



Importance of "Internal" Guidance to the Industry

"Nuclear crisis man-made, not 'an act of god'"

"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***

TECHNICAL ELEMENT

Importance of "External" Guidance to the Community

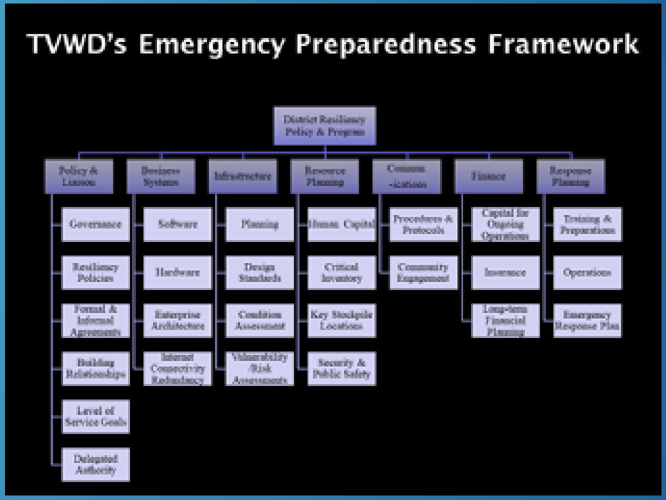
"That day the warnings said there was going to be an 'old' tsunami (meaning huge)" He'd never heard that kind of announcement before.

(Mr. Sato - Kesennuma City Memorial Museum, Koyo High School)

Eight years ago, “but we’re still recovering emotionally”
SOCIAL & ECONOMIC ELEMENT
JUNE 23: SENDAI
- LUNCH & LECTURES – MINAMI GAMO NEIGHBORHOOD
- (NEIGHBORHOOD ASSOCIATION MEMBERS & CITY STAFF)
NIST describes disasters as “social-technical” problems
• People
• Relationships
• Family
• Community
• Economics
• Psychology
• Culture
NIST
National Institute of
Standards and Technology
U.S. Department of Commerce
Growth
&
Achievement
Belonging
Safety and Security
Survival
Figure 10-2: The hierarchy of human needs
(Adapted from Maslow's Hierarchy of Needs – a
psychological perspective [Maslow 1943])

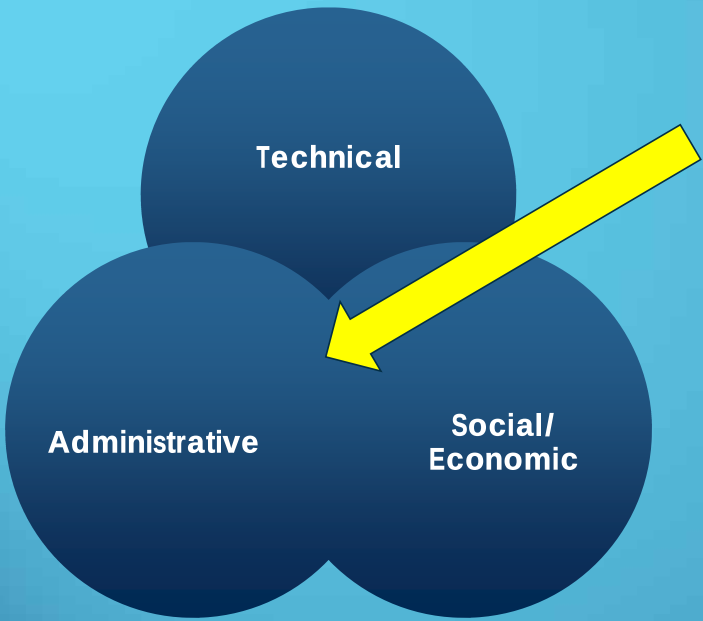
- Planning
- Stakeholders
- Training & education
- Management
- Finances
- Decision-making
- Policy
- Standards & code adoption
- Leadership

Example Administrative Framework



Leadership is a fundamental underpinning of resiliency

ADMINISTRATIVE ELEMENT



All of the functional elements must be addressed to achieve resiliency

Functional Elements	Pre-Disaster Time Element	Post-Disaster Time Elements		
	Preparedness (Stage 1)	Relief (Stage 2)	Rehabilitation (Stage3)	Recovery (Stage 4)
Technical	T1	T2	T3	T4
Social & Economic	S1	S2	S3	S4
Administrative	A1	A2	A3	A4

NATURAL DISASTER RESILIENCY FRAMEWORK

Seismic Resiliency in Design of New Water Supply Systems

APPLICATION OF FRAMEWORK TO WWSP

Technical Element/Preparedness Stage (T1)

- Key components:
  - Guidance
    - Internal
    - External

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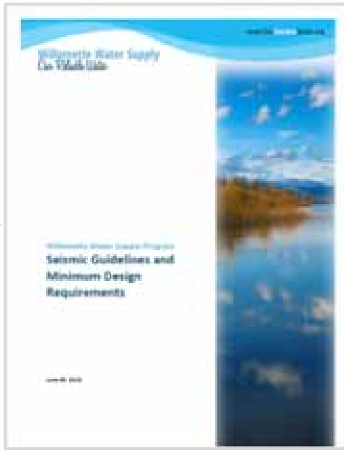
Technical Element/Preparedness Stage (T1)

WWSP Internal Guidance

- **WWSP Seismic Guidelines and Minimum Design Requirements**



Seismic Design Framework

Step 1 – Identify Service Priorities

Step 2 – Establish Level of Service Goals

Step 3 – Establish Design Earthquake

Step 4 – Evaluate Project Specific Seismic Hazards

Step 5 – Establish Design Standards and Methods

Step 6 – Design for Seismic Risk Mitigation

WWSP External Guidance

- Updates/sharing information to:
  - Policy makers
  - Regional stakeholders
  - Industry
    - AWWA Pacific Northwest Section Conference
    - AWWA ACE Conference
    - AWWA A21 Ductile Iron Pipe Committee (new M41 Chapter, “Seismic Guidelines for Ductile Iron Pipe) – pending
    - ASCE Pipelines Seismic MOP Committee
    - Water Research Foundation projects
  - Others

Technical Element/Preparedness Stage (T_1)

- Key components:
  - Guidance
    - Internal
    - External
  - Structural improvements
    - Structural components
    - Non-structural components

Functional Elements	Pre-Disaster Time Element	Post-Disaster Time Elements		
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The interconnectedness and importance of level of service goals and design hazard event decisions

"Interconnectedness" of Functional Elements

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Technical vs. policy/ financial decisions (**Administrative** element) while understanding impacts on community & economics (i.e. **Social** element)

Source: The Associated Press

Important Considerations (example Tohoku)

- Impacts to people/the community
  - Approximately 602,000 people were in areas inundated by the tsunami (Ranghieri and Ishiwatari, 2014, p. 101).
  - The impact to the region was severe; 15,895 dead, 2,539 missing, 401,885 homes destroyed, and at its peak, 470,000 evacuees (Ito, 2019).
  - Over 90% of the deaths were due to drowning (Ito, 2019).
- Economic Impacts
  - The economic impact and cost of the disaster was estimated at around $225 billion (Ito, 2019).
  - By comparison, this is significantly larger than Hurricane Katrina, the costliest U.S. disaster, estimated to have cost approximately $160 billion (Meyersohn, 2017).

Technical Element/Preparedness Stage (T_1)

- Key components:
  - Guidance
    - Internal
    - External
  - Structural improvements
    - Structural components
    - Non-structural components

Functional Elements	Pre-Disaster Time Element	Post-Disaster Time Elements		
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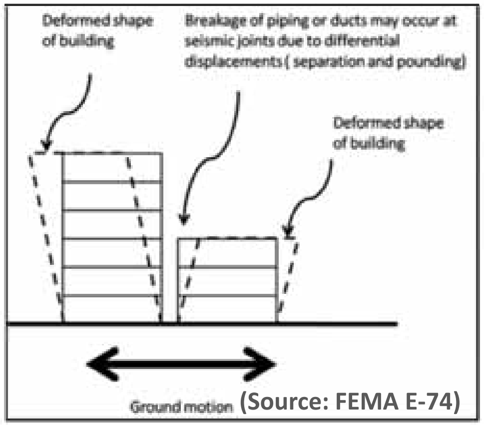
WTP seismic considerations

Structural and Nonstructural Component Considerations

- Inertial forces
- Building deformations
- Building separation
- Component interaction



(Source: FEMA E-74)

Figure 2.2.3-1 Nonstructural damage due to separation and pounding.

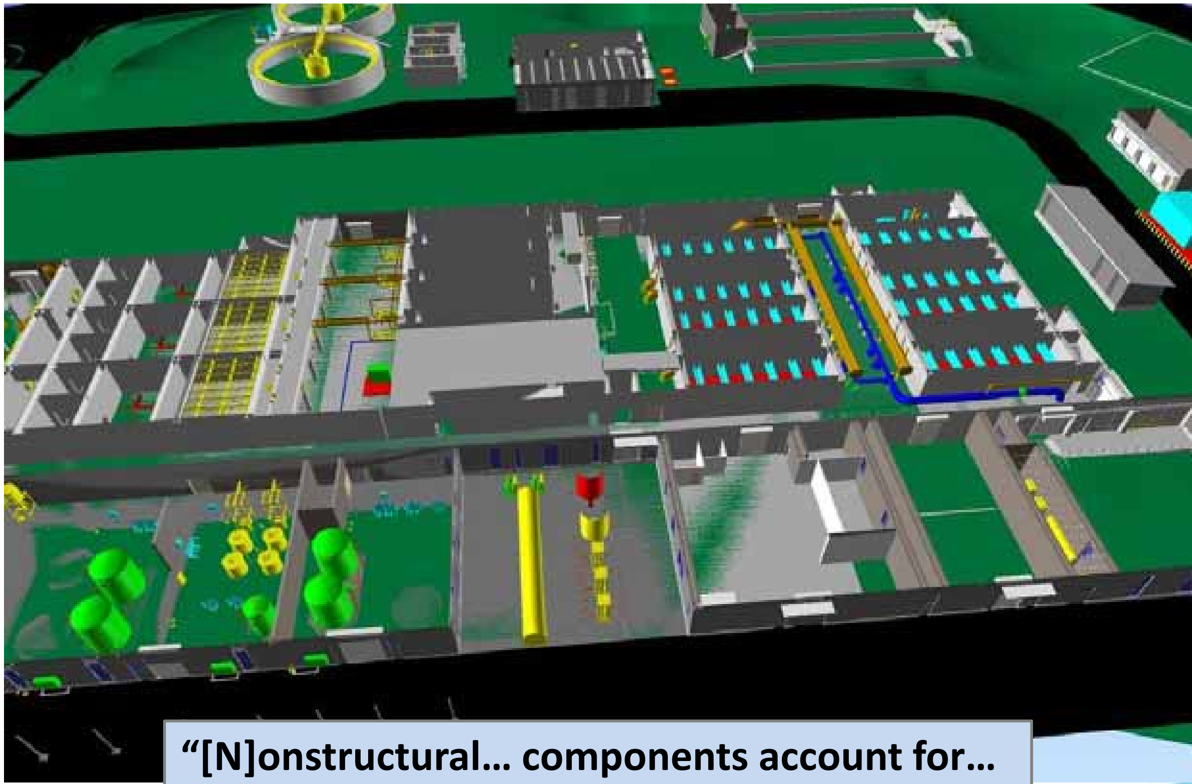
Facility layout shall minimize structural horizontal and vertical irregularities as defined in ASCE 7-16.

WTP seismic considerations

Nonstructural Components Important Including:

- Architectural Components
- Mechanical, Electrical, and Plumbing (MEP) Components
- Furniture, Fixtures & Equipment (FF&E), and Contents

Seismic qualification of nonstructural equipment is an important consideration



"[N]onstructural… components account for… 75-85% of the cost" (FEMA E-74, 2012)

Consideration of nonstructural components important

- Interaction "between adjacent nonstructural components… [can] cause damage"

- Examples: sprinkler systems interact with ceiling, adjacent pipes unbraced collide with one another or adjacent objects, suspended mechanical equipment swings, or ceiling components or equipment falls

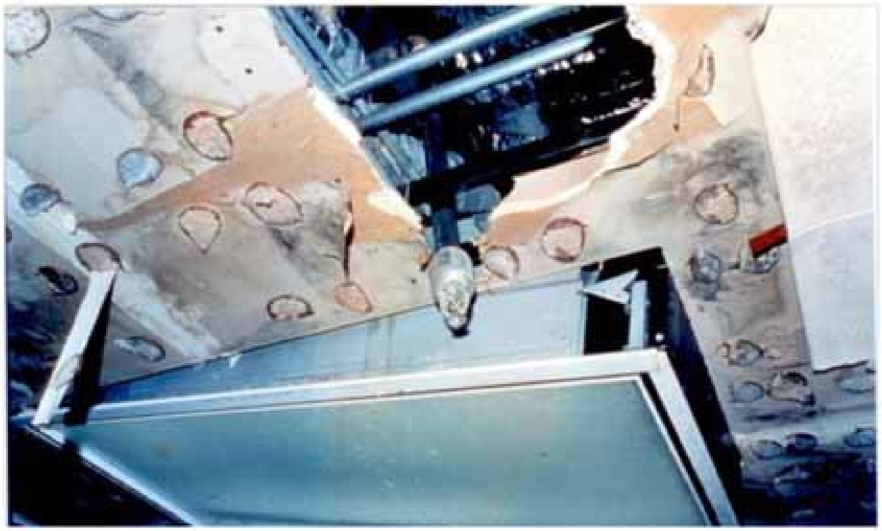


Figure 2.4.3-1 Broken sprinkler pipe at Olive View Hospital in Sylmar, California as a result of the 1994 Northridge, Earthquake. Pipe ruptured at the elbow joint due to differential motion of the pipe and ceiling (FEMA 74, 1994).

> "During the 1994 Northridge Earthquake, nonstructural damage caused temporary closure, evacuation, or patient transfer at ten essential hospital facilities. These hospitals generally had little or no structural damage were rendered temporarily inoperable, primarily because of water damage"

How later stages influence Preparedness

“Interconnectedness” of Time Elements

Functional Elements	Pre-Disaster Time Element	Post-Disaster Time Elements		
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Technical functional element during the **Preparedness Stage** can be influenced by events that occur in later stages (e.g. **Relief Stage** and **Rehabilitation Stage**)

Important Considerations (example WWSP)

- Tabletop exercises to confirm LOS goals can be achieved

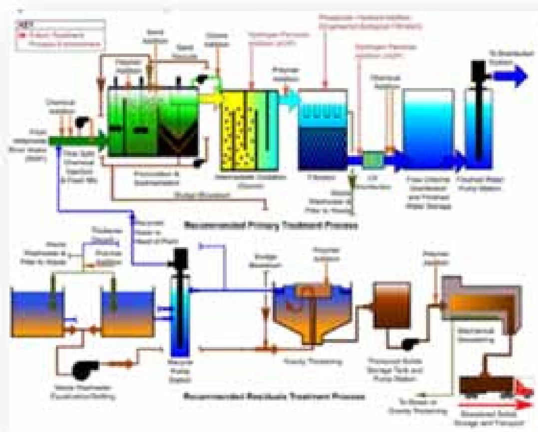
- Future “degraded” raw water quality considerations
- Regional nature of the disaster and access to critical operational supplies

Source water assessment

Various point & non-point sources identified

Influences selection and sizing of treatment processes for physical, biological, and chemical constituents including:

- Turbidity
- Organic materials
- Hydrocarbons
- Agricultural materials
- Emerging contaminants



Willamette Water Supply
Our Reliable Water

Willamette Water Supply Program (WWSP) & Tualatin Valley Water District (TVWD) Seismic Resilience & Mitigation Lessons Learned

CREW Water Utility Resilience Symposium

July 28, 2020

CREW Cascadia Region Earthquake Workgroup

Three Points of Context for Me

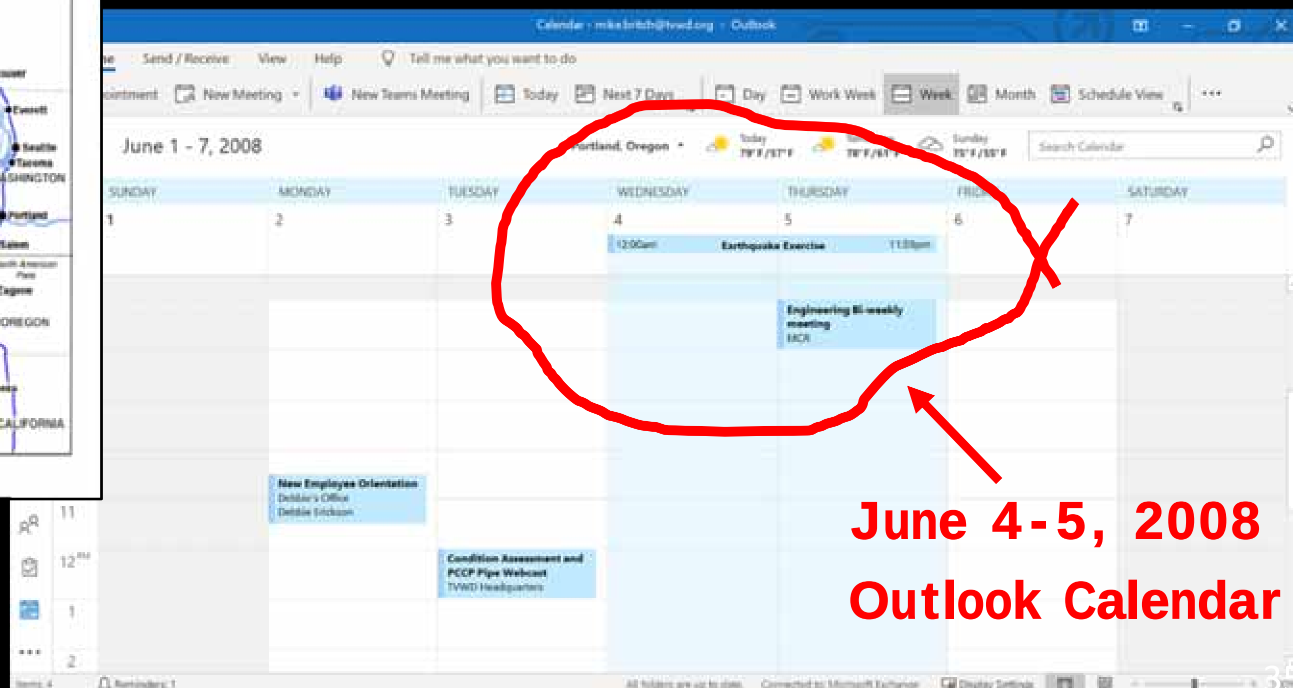
Earthquake Exercise First Week at TVWD

"Planning for seismic resilience can seem overwhelming"

Planning Scenario

- 9.0 m. Earthquake
- February 6, 2012 at 9:41 AM PST
- Direct Impact to 3 States, 2 FEMA Regions
- Complete rupture of the 800 Mile Fault Line
- Impacts affecting over 140,000 sq. mi.
- Ground shaking lasts up to 5 minutes
- Numerous aftershocks with several of M7.0+
- 1,100+ Deaths From Earthquake 24,000+ injuries
- 10,600+ Deaths from tsunami & 2,600 injuries

Source: FEMA

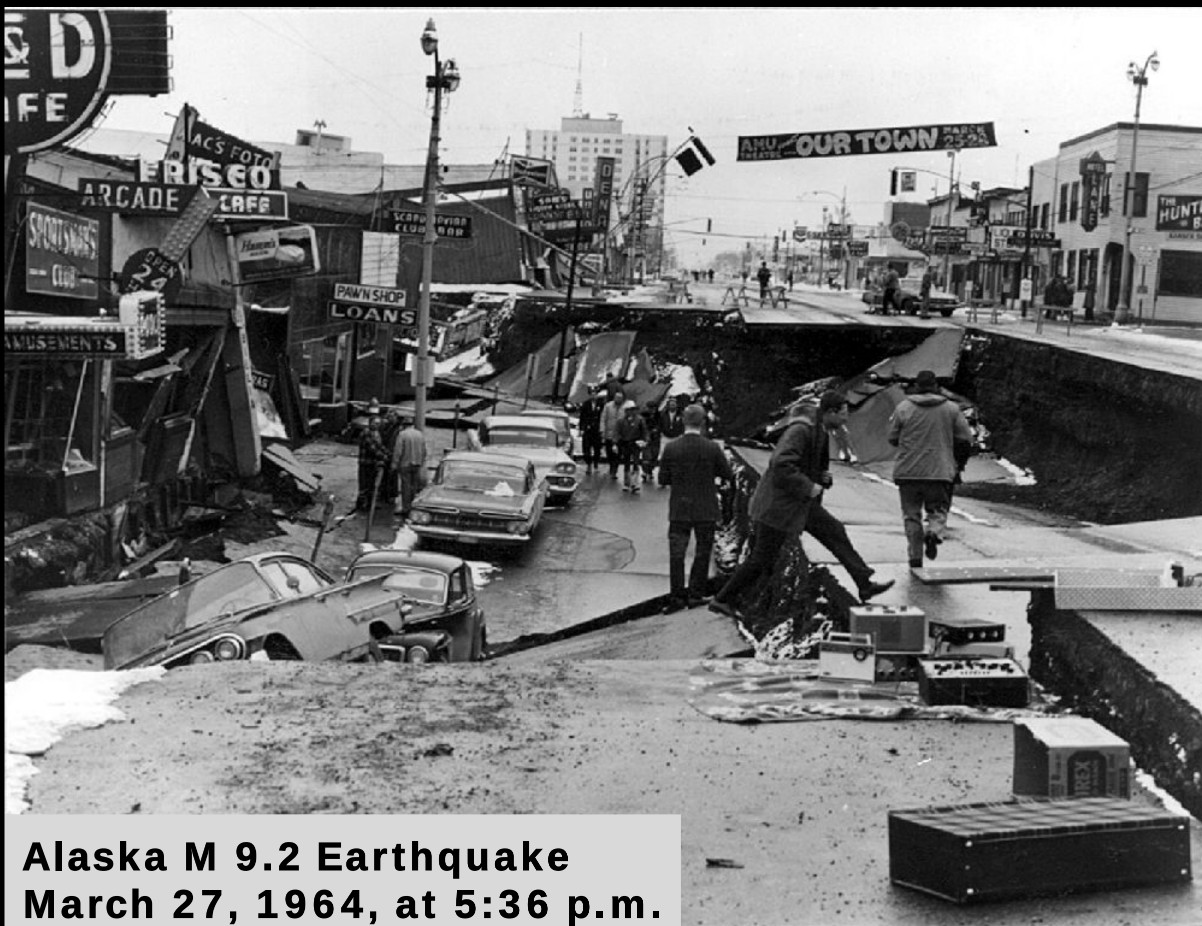


June 4-5, 2008

Outlook Calendar

Three Points of Context for Me

Grew up in Anchorage with Family Stories about the 1964 Alaska Earthquake



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

"Earthquakes can be very scary"

Three Points of Context for Me

PSU Program with Travel to Tohoku Region of Japan from June 22 - July 2, 2019

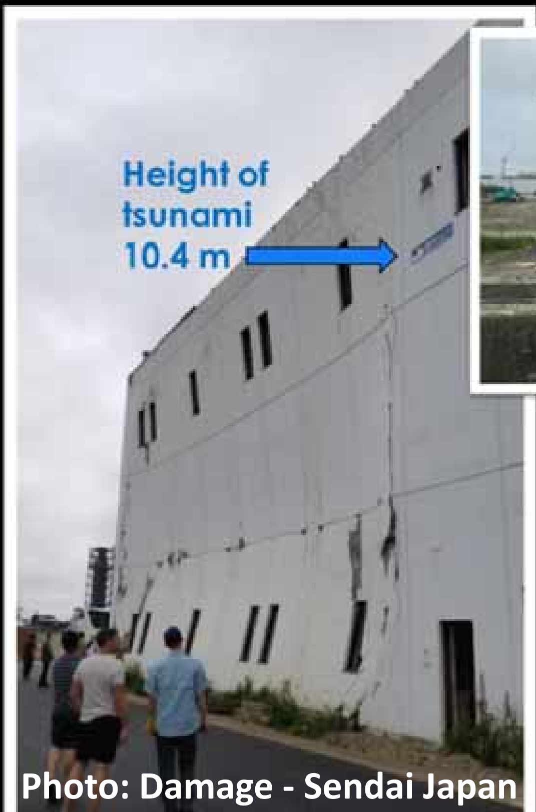
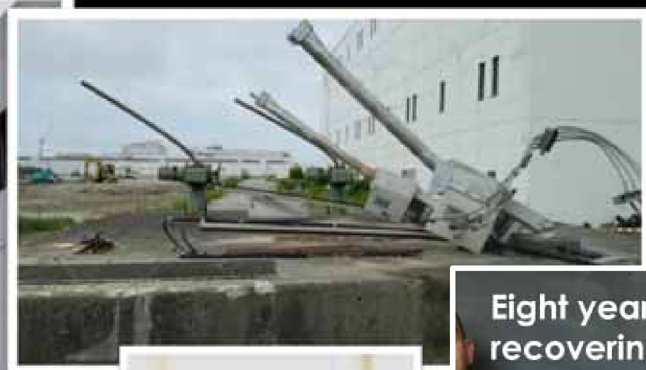


Photo: Damage - Sendai Japan



Tohoku M 9.0 Earthquake
March 11, 2011, at 2:46 p.m.

"The impacts on people and property can be profound"

Fukushima Nuclear Plant Crisis

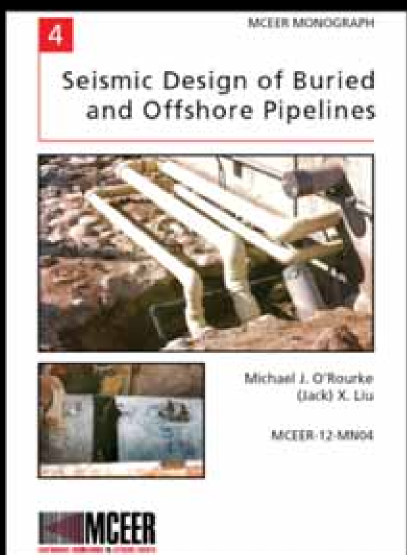
It starts with Guidelines:

"For guidelines to be effective, they need to use 'words people understand'"

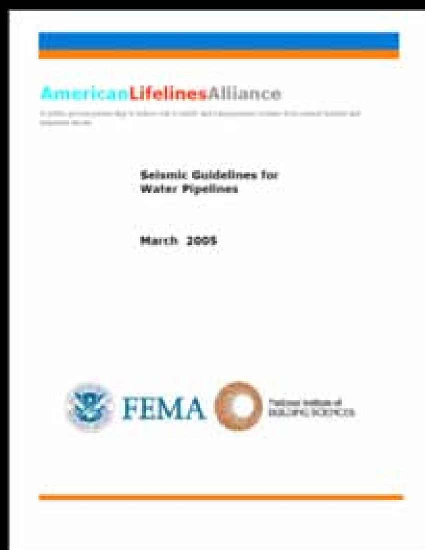
Some of the good industry references

"There are some good guidelines out there, but they are few and far between"

Pipelines



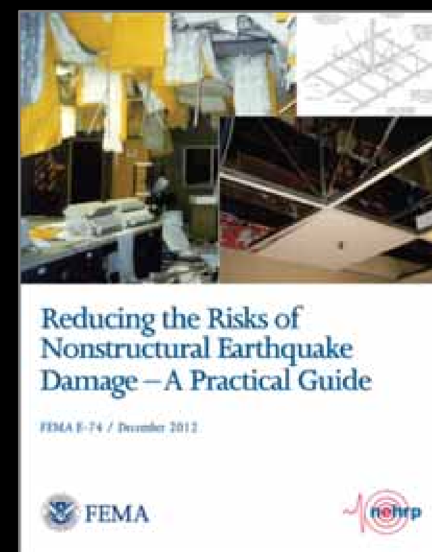
(O'Rourke & Liu, 2012)



(ALA, 2005)

Facilities

(SFPUC, 2014)



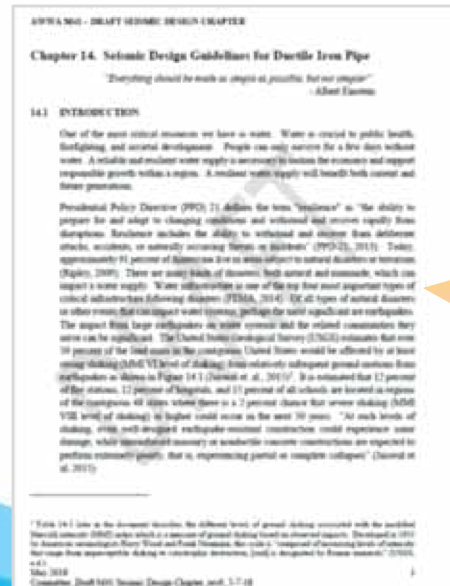
(FEMA, 2012)

Seismic Guidelines Created

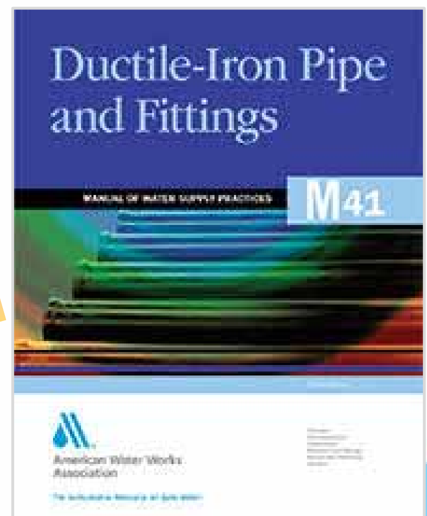
"These two guidelines were created to fill a gap in the industry"

- WWSP Seismic Guidelines and Minimum Design Requirements
- AWWA Manual M41 Chapter, "Seismic Guidelines for Ductile Iron Pipe" **(scheduled for next release)**

June 10, 2020 Version 1.1


Chapter 14. Seismic Design Guidelines for Ductile Iron Pipe

14.1 INTRODUCTION



Seismic Guidelines Created

“This framework provides a way to get your head around all the complex, multi-dimensional issues to achieve improved resilience”

Seismic Design Framework (at the core of the guidelines):

Step 1 – Identify Service Priorities

Step 2 – Establish Level of Service Goals

Step 3 – Establish Design Earthquake

Step 4 – Evaluate Project Specific Seismic Hazards

Step 5 – Establish Design Standards and Methods

Step 6 – Design for Seismic Risk Mitigation

Step 1 - Identify Service Priorities

[Project Identification (WWSP)]

“Water systems are complex and it’s important to understand really well how your system works”

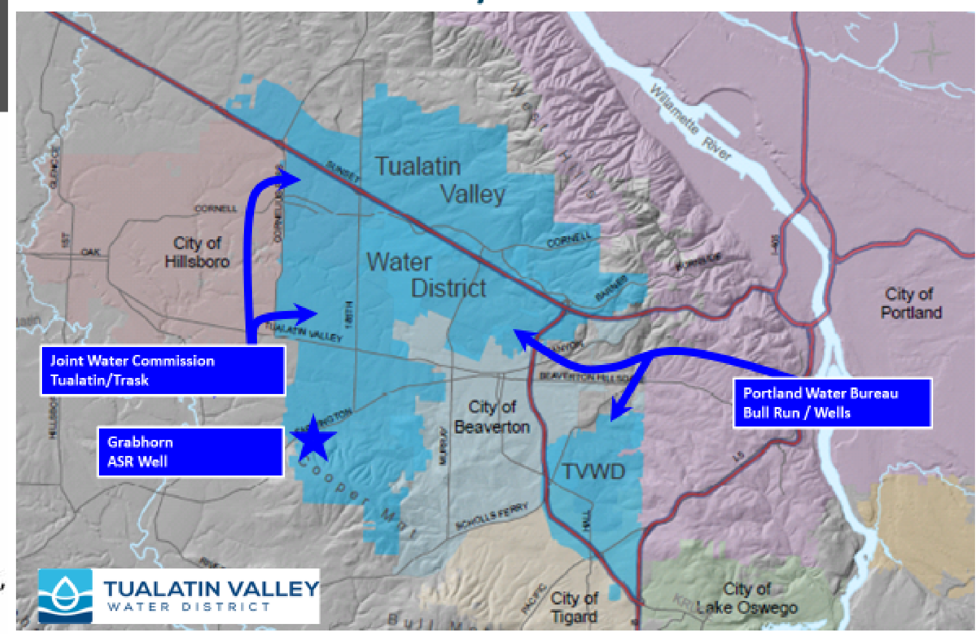
Willamette Water Supply Program

***Mission Statement: Provide a cost-effective, reliable and resilient water supply system** by July 2026, that benefits current and future generations of the communities we serve and supports a vibrant local economy.*

- Modified water intake
- New water filtration plant
- 30+ miles of large diameter pipeline
- Water reservoirs
- Tualatin Valley Water District: 59%, City of Hillsboro: 36%, City of Beaverton: 5%
- Scheduled completion: 2026

TUALATIN VALLEY WATER DISTRICT Hillsboro OREGON Beaverton OREGON

Tualatin Valley Water District



Step 1 - Identify Service Priorities

"Need to think about:

1) who are your most are your most critical customers following an earthquake (and what are their needs),

2) what part of the system is needed to serve them, and

3) develop a plan for needed improvements over time

(the ORP talks about a 50-yr plan)

- Identifying critical customers & infrastructure to serve them

SHERIFF

WASHINGTON COUNTY OR

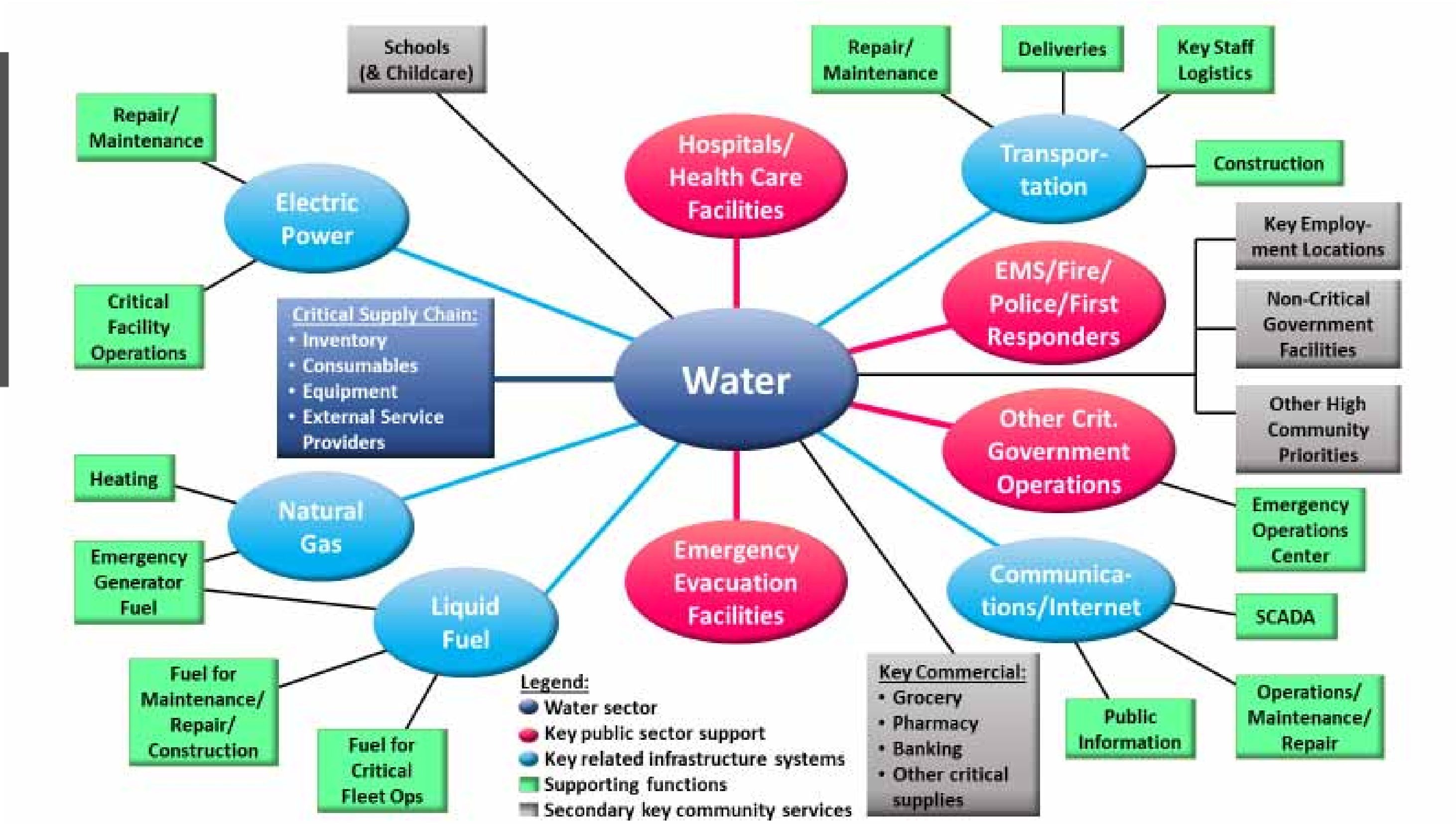
TVF&R

Tualatin Valley Fire & Rescue

WASHINGTON COUNTY OREGON

Step 1 - Identify Service Priorities

"Your critical customers might not always be obvious"



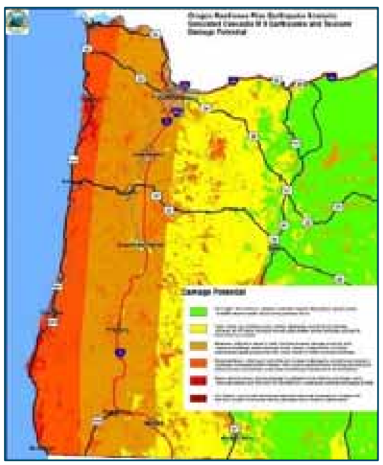
Water Sector Interdependencies

Source: Britch et al., 2020 [adapted from 2010 Water Sector Specific Plan (DHS, 2015)]

Step 2 - Establish Level of Service Goals

"Establish a classification system, but keep it simple"

The ORP identifies a two-classification system



Classification of Infrastructure

- Classification 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).

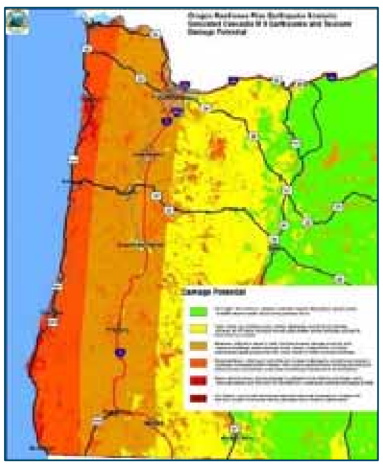
  - ALA & ASCE Pipelines Seismic Subcommittee

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.

Step 2 - Establish Level of Service Goals

"You have to understand what you're trying to achieve"

The ORP identifies target states of recovery



WWSP facility level of service goals based on the Oregon Resilience Plan

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)

ORP – Oregon Resilience Plan (* Full capacity when electrical power, transportation and other required infrastructure capacity restored)

Step 3 – Establish Design Earthquake

"You need to think about how important is specific infrastructure to the community served, and hence what level of design earthquake is appropriate"

Table 2. Summary of three hazard levels defined as a function of hazard types and intensity (adapted and modified from [13])

Hazard	Routine	Design	Extreme
Ground Snow	50 yr MRI or 64% in 50 years	300 to 500 yr MRI[1] or 15 to 10% in 50 yr	Locally determined
Rain	Locally determined[2]	Locally determined	Locally determined
Wind – Non-Hurricane	10 to 100 yr MRI or 99% to 39% in 50 years	700 to 3,000 yr MRI or 7% to 1.6% in 50 yr	Not typically considered
Wind – Hurricane	10 to 100 yr MRI or 99% to 39% in 50 yr	700 to 3,000 yr MRI or 7% to 1.6% in 50 yr	10,000 yr MRI or 0.5% in 50 yr
Wind – Tornado	Not typically considered	Not typically considered	Variable[4]
Earthquake	50 yr MRI or 64% in 50 years	500 yr MRI or 10% in 50 yr[5]	2,500 yr MRI or 2% in 50 yr[6]
Tsunami	Locally determined[3]	2,475 yr MRI or 2% in 50 yr	Locally determined[3]
Flood	Locally determined	100 yr MRI or 39% in 50 yr	500 yr MRI or greater or 10% or less in 50 yr[7]
Fire – Wildland Urban Interface	Locally determined[7]	Locally determined[7]	Locally determined[7]
Fire – Urban	Locally determined[7]	Locally determined[7]	Locally determined[7]

Note – Mean Recurrence Interval (MRI) values from ASCE 7-16 unless otherwise noted.

Code design earthquake

WWSP design earthquake

Source: NIST Special Publication 1224 (2018)

Step 3 – Establish Design Earthquake

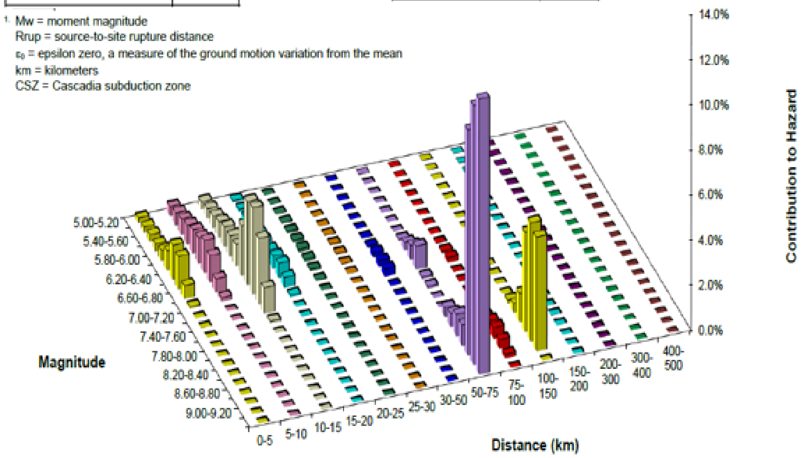
> **"A probabilistic seismic hazard analysis (PSHA) allows you to consider all the seismic hazards you're at risk to"**

- 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
  - This is consistent with ALA (2005) recommendations and other industry guidance for critical water infrastructure

Mean Mw	7.9
Mean Rrup (km)	52
Mean ε_0	0.96

Hazard Contribution	
Crustal Faults	18.6%
Crustal Background	19.1%
CSZ Interface	58.3%
CSZ Intraslab	3.9%

1. Mw = moment magnitude
Rrup = source-to-site rupture distance
ε_0 = epsilon zero, a measure of the ground motion variation from the mean
km = kilometers
CSZ = Cascadia subduction zone



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

Step 4 – Evaluate Project Specific Seismic Hazards

"You don't know if your pipelines are seismically resilient unless you understand what's going on with the ground"

Step 4 – Evaluate Project Specific Seismic Hazards

"These are the kinds of hazards you need to think about"

- Hazard Categories

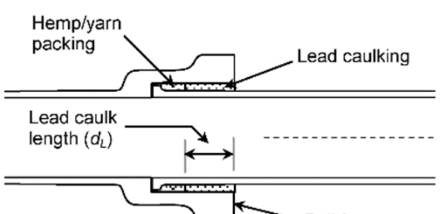
Hazard Category	Subcategory/Description		
A. Ground Shaking (Section 6.3)	Transient Ground Motions and Ground Strain		Separate Slide
B. Permanent Ground Deformation	1. Liquefaction (Section 6.4)	a. Liquefaction-Induced Settlement (Section 6.6)	Separate Slide
		b. Lateral Spreading (Section 6.7)	
	2. Soft or Weak Soils below Infrastructure (Section 6.8)		
	3. Seismically-induced Landslides (Section 6.9)		
	4. Abrupt Offsets (Section 6.10)	a. Transitions to Structures (Section 6.10.1)	
		b. Soil Transitions (Section 6.10.2)	
		c. Surface Fault Ruptures (Section 6.10.3)	
C. Nearby Infrastructure by Others Designed to Lesser Standards (Section 6.11)			
D. Other Applicable Hazards (Section 6.12)			

Step 4 – Evaluate Project Specific Seismic Hazards

- Ground Shaking (examples resulting in failure)

"Many times ground shaking is not the cause of pipeline failure"

Ground Shaking. *Ground shaking represents transient ground motions that are propagated through the ground due to the seismic fault movement. This hazard includes loading on the infrastructure that only exists while the ground shaking is ongoing. Once the ground shaking stops, the transient loading imposed on the infrastructure subsides.*



Fragile and/or Unrestrained Pipe Joints

■ Figure 4.2 Tear at Wrinkle in Ciudad Nezahualcoyotl Pipeline (Mexico City, 1985)

Local Site Effects. 1) Circumferential tear in pipe wall. [Mexico City (1985) M 8.0 > 200 miles away], 2) Broken utility lines [Marina District, Loma Pieta Earthquake (1989) M 6.9]

Photo by AP Photo/George Nikitin

Near Field Source (< 15 km). Gas from a ruptured supply line burns with flooding from broken water main [Northridge Earthquake (1994) M 6.7]

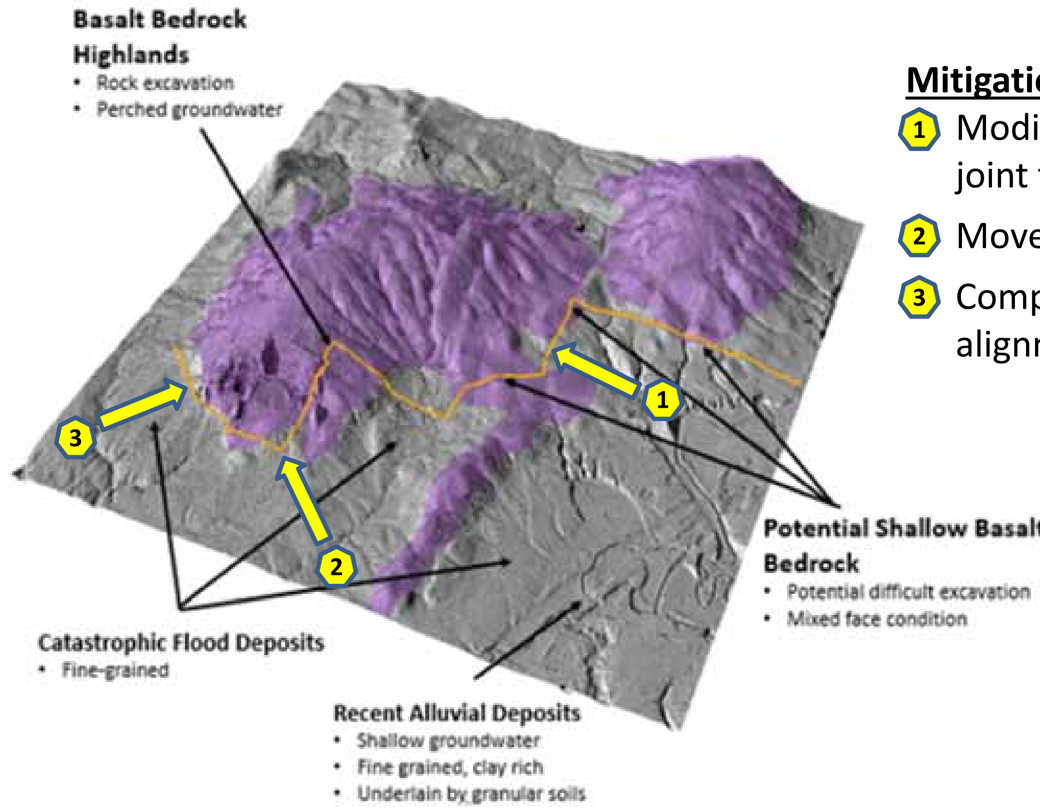
Photo by AP Photo/Lenny Ignelzi

Step 4 – Evaluate Project Specific Seismic Hazards

"PGD can cause severe loading on pipelines and result in failure"

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.*

- Permanent Ground Deformation (PGD)



Mitigation for PGD:

1. Modify pipe wall thickness, joint type, and profile
2. Move alignment uphill
3. Completely change alignment

Anchorage, AK M 7.1 Earthquake
November 30, 2018, at 8:29 a.m.

Step 5 – Establish Design Standards and Methods

“Compressive loading at pipe joints is the most severe loading for welded steel 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.*

- Limit States for Welded Steel Pipe

(Strain-based design approach)

“Compressive deformation… represents the most severe type of loading imposed on welded steel pipelines during an earthquake” (O’Roarke and Jones, 2006) [Photo: Smith, 2006]

Four (4) limit states pertain to the design of continuous welded steel pipelines (Karamanos et al., 2017)

- Tensile Strain Capacity
- Local Buckling
- Beam Buckling
- Joint Resistance

Step 5 – Establish Design Standards and Methods

"Need to understand the loading on the joints and their performance capacity"

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.*

- Limit States for Ductile Iron Pipe

  (Design based on joint performance)

  Two (2) limit states pertain to the design of segmented ductile iron pipelines (Wham et al., 2018)

  - Serviceability (pertains to allowable leakage)
  - Ultimate ("structural failure or fracture of the pipeline resulting in the inability of the system to sustain adequate levels of internal pressure.")

"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." [Singhal and Benavides (1983)]

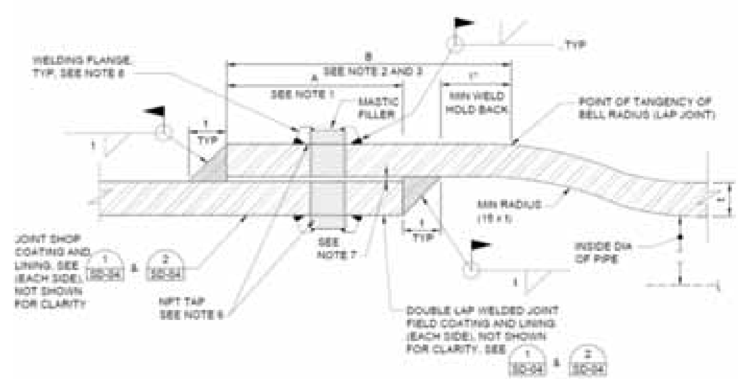
Step 6 – Design for Seismic Risk Mitigation

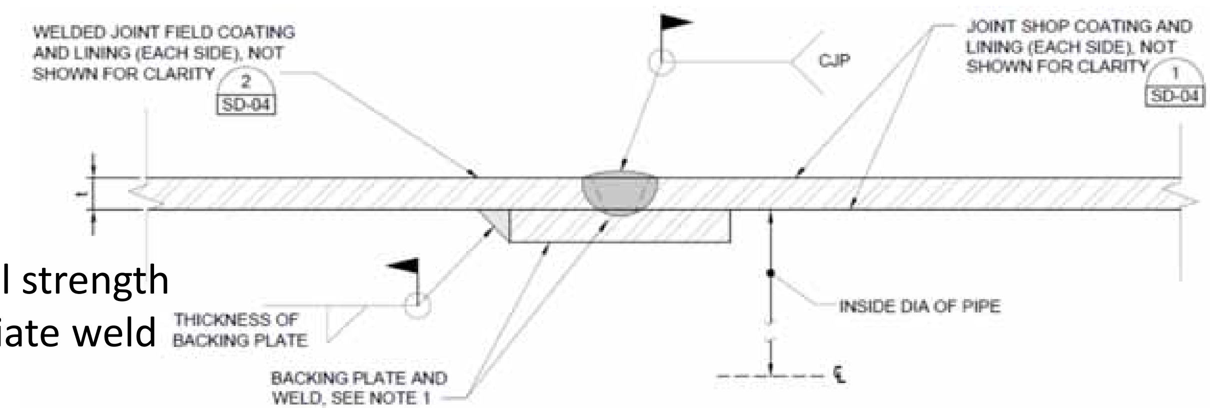
"Welded steel pipe: Use double welded lap joints as a minimum, butt joints where needed, & understand the site specific strain demands imposed by the earthquake"

- Performance Categories for Welded Steel Pipe

(Strain-based design approach)

Double welded lap joints. The ultimate strength of the pipe joint may be between 45 – 60% (or more) of the pipe wall depending on pipe wall thickness and other factors (detailed analysis required)

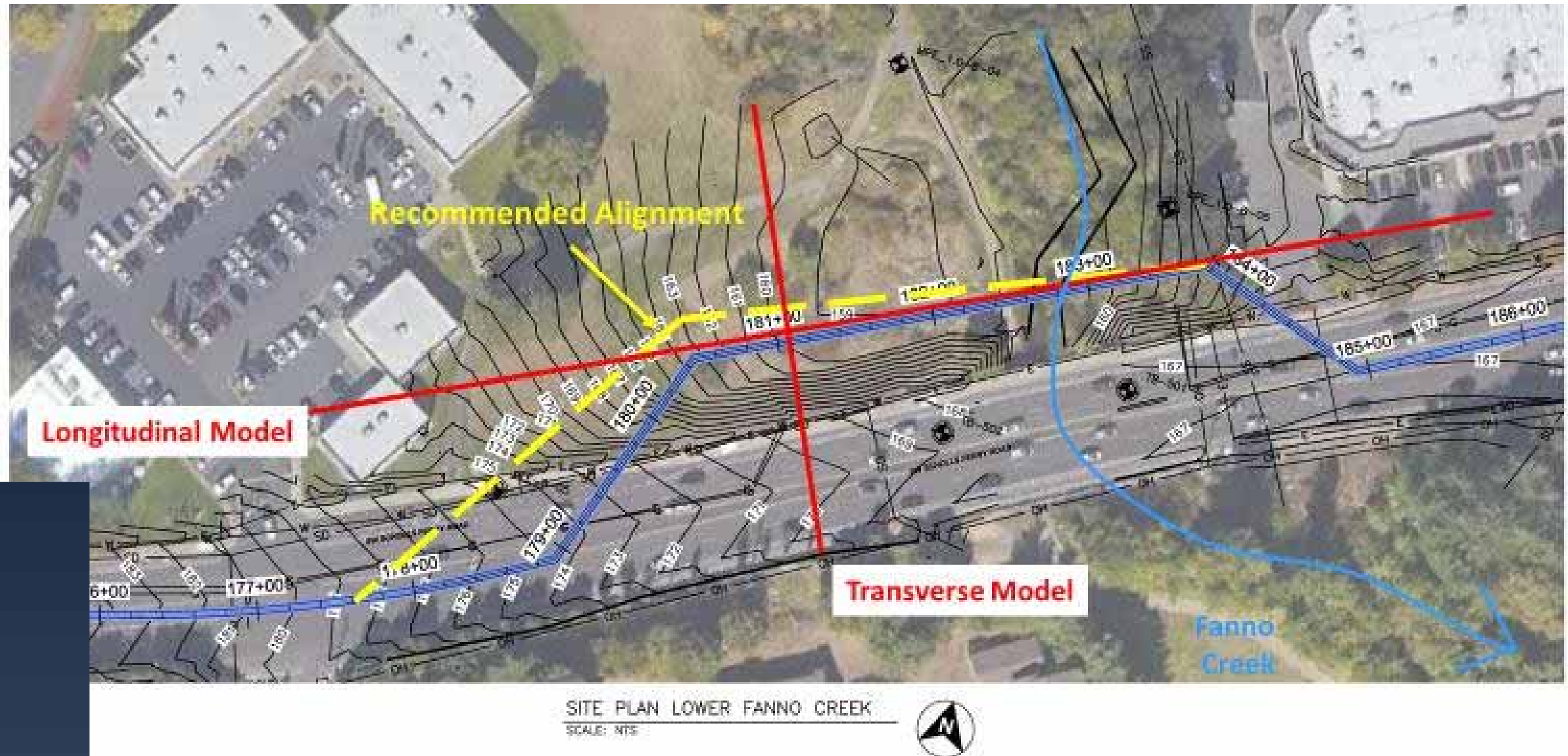


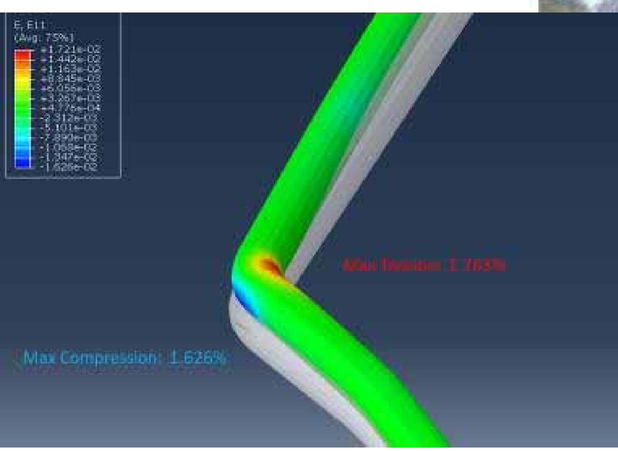


Butt welded joints. 90 – 100% of the pipe wall strength depending on type of butt weld (with appropriate weld inspections and testing)

Step 6 – Design for Seismic Risk Mitigation

"Welded steel pipe: Alignment & profile decisions are important. Understand pipe strain at key locations"





Step 6 – Design for Seismic Risk Mitigation

"Ductile iron pipe: Restrain all joints & and use boltless locking segments (or greater) for critical pipes"

- Performance Categories for Ductile Iron Pipe

  (Design based on joint performance)

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.

EBAA IRON's MEGALUG® used sparingly

Category 3: Joints with integral restraint bead and boltless locking segments. This category provides improved performance due to integrated joint restraining mechanisms.

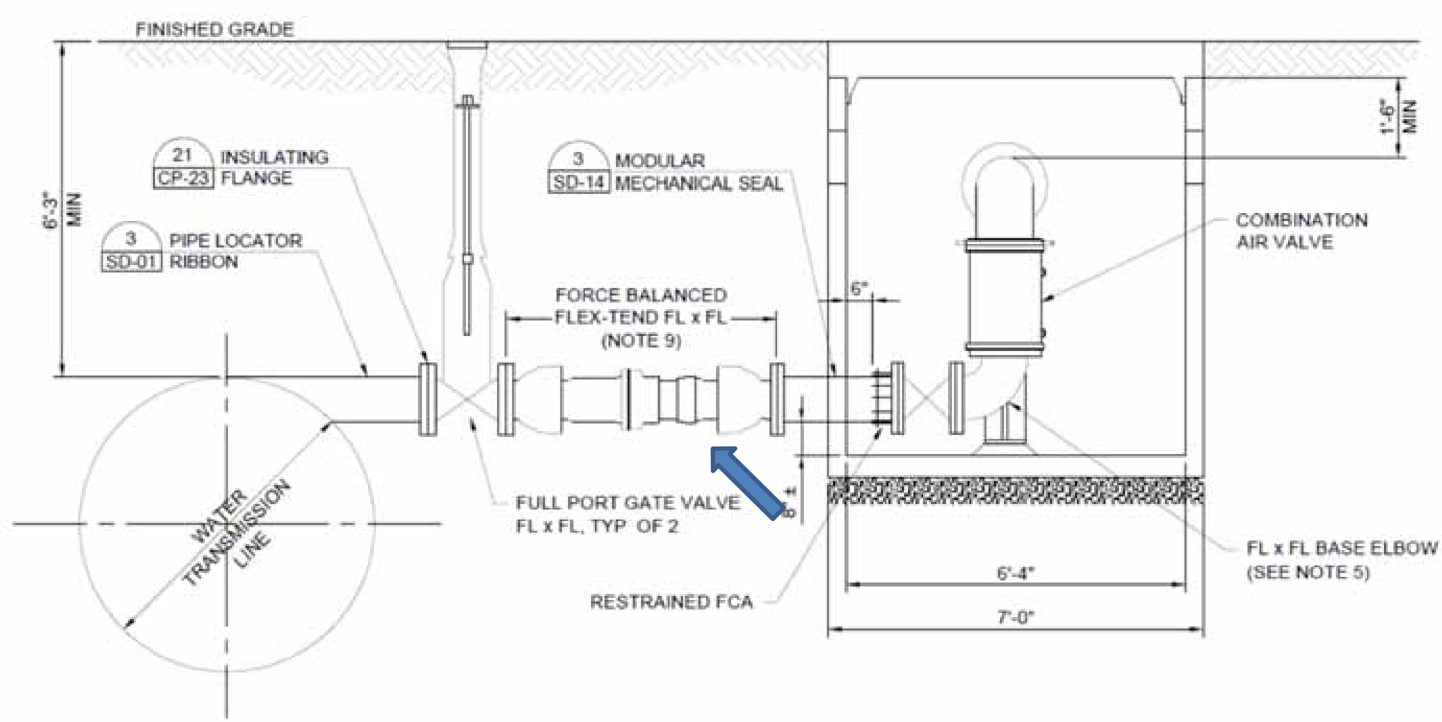
Including US Pipe's TR FLEX® & AMERICAN Ductile Iron Pipe's Flex Ring joints

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.

Including force-balance FLEX-TENDS®

Step 6 – Design for Seismic Risk Mitigation

"Build in flexibility at transitions and avoid creating discontinuities and additional loading in areas of PGD"



Other considerations:

- Keep isolation valves close coupled
- CLSM may created additional loading on pipe
- Limit compressive strain in "inaccessible areas" for WSP
- Follow manufacturer's recommendations for DIP

Including force-balance FLEX-TENDS®

Polling question:

What measures improve seismic resiliency for pipelines?

A) Use restrained joints

B) Provide flexibility at transitions

C) Use stronger types of joints

D) All of the above

Answer: D) All of the above

Willamette Water Supply
Our Reliable Water

Willamette Water Supply
Our Reliable Water

WWSS Operations Committee

System Seismic Operational Strategy

"5-day Seismic Level of Service (LOS) and Battery Backup"

February 24, 2021

Outline

Part I – Changing Our Thinking

- Changing our *"Thinking"* about Resilience

Part II - 5 Day WWSS LOS Requirement

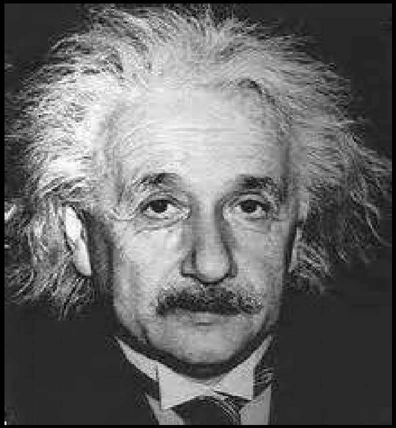
- WWSP Seismic Level of Service (LOS) Goals
- Where "5-Days" Came From
- Learning from Japan's *"Thinking"*

Part III – Battery Backup at Facilities

PART I – CHANGING OUR THINKING

How Do You Solve the Problem?

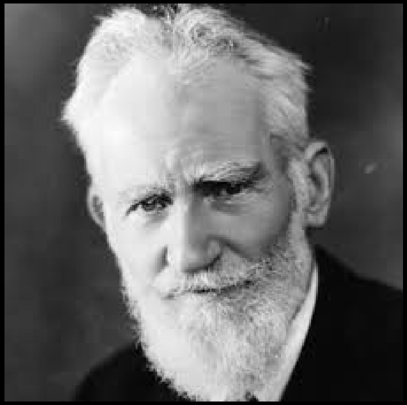
It's complicated



"We cannot solve our problems with the same thinking we used when we created them"

Albert Einstein

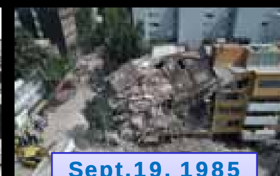
How Do You Solve the Problem?



"Progress is impossible without change, and those who cannot change their minds cannot change anything"

George Bernard Shaw

Timeline Related to Changing Our *"Thinking"*



Jan. 26, 1700
Last Cascadia Subduction EQ

Feb. 14, 1859
Oregon Statehood

Mar. 27, 1964
M 9.2 Alaska Earthquake

Sept.19, 1985
M 8.1 Mexico City EQ

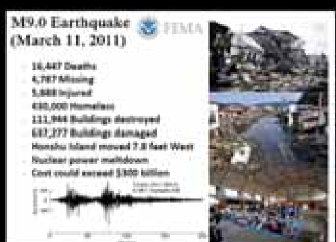
February 1987
"Pacific Northwest is Earthquake Country"

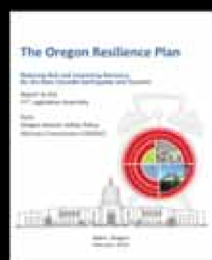
1994
OR Code changed to highest level

OR Pop. 1850 ~ 12k

OSU Prof. of Geology – Robert Yeats

UBC Seismic Code





Mar. 11, 2011
M 9.0 Tohoku Earthquake

Feb. 2013
Oregon Resilience Plan

April 2014
WA Co. EQ Scenario

July 13, 2015
"The Really Big One"

June 2019
Trip to Tohoku Region Japan

June 10, 2020
SGMDR Public Release Ver.1.1

Today
2021

PSU MPA [Sept. 2013 –June 2015]

Capstone: *"TVWD's Emergency Preparedness Framework"*

OR Pop. ~ 4.3 M

Polling question:

When was the Pacific Northwest determined to be “Earthquake Country”?

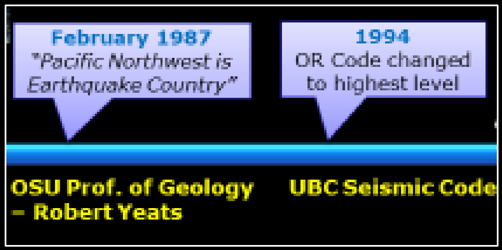
A) Prior to 1960

B) 1960 to 1980

C) 1980 to 2000

D) After 2000

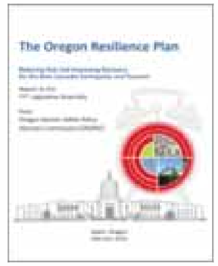
Answer: C) 1980 to 2000



PART II - 5 DAY WWSS LOS REQUIREMENT

WWSP Seismic Level of Service (LOS) Goals

- Target States of Recovery modeled off the ORP

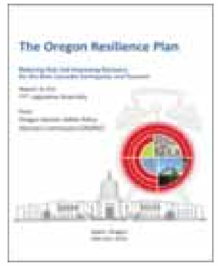


TARGET STATES OF RECOVERY: WATER & WASTEWATER SECTOR (VALLEY)	Event occurs	0–24 hours	1–3 days	3–7 days	1–2 weeks	2 weeks–1 month	1–3 months	3–6 months	6 months–1 year	1–3 years	3+ years
Domestic Water Supply											
Potable water available at supply source (WTP, wells, impoundment)		R	Y		G			X			
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational		G					X				
Water supply to critical facilities available		Y	G				X				
Water for fire suppression—at key supply points		G		X							
Water for fire suppression—at fire hydrants				R	Y	G			X		
Water available at community distribution centers/points			Y	G	X						
Distribution system operational			R	Y	G				X		

***Critical Backbone** [different levels of infrastructure criticality]* – *"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."*

WWSP Seismic Level of Service (LOS) Goals

- Target States of Recovery modeled off the ORP
- Added “5 days of self-sufficiency”



TARGET STATES OF RECOVERY: WATER & WASTEWATER SECTOR (VALLEY)

	Event occurs	0–24 hours	1–3 days	3–7 days	1–2 weeks	2 weeks–1 month	1–3 months	3–6 months	6 months –1 year	1–3 years	3+ years
Domestic Water Supply											
Potable water available at supply source (WTP, wells, impoundment)		R	Y		G			X			
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational		G					X				
Water supply to critical facilities available		Y	G				X				
Water for fire suppression—at key supply points		G		X							
Water for fire suppression—at fire hydrants				R	Y	G			X		
Water available at community distribution centers/points			Y	G	X						
Distribution system operational			R	Y	G				X		

Turnouts also part of maintaining 5 days of operational capacity of the WWSS overall “System Operations”

Table 4-2 WWSP LOS Goals

System Components	Proposed
Intake and RWF	• 25% capacity within 24 hours • 50% capacity within 48 hours • 90% to full capacity when power transmission and transportation is restored • 5 days of self-sufficiency for all consumables required for operations • Fire suppression systems shall be autonomous and fully operable at 90-100% capacity immediately after a seismic event
WTP	• 25% capacity within 24 hours • 50% capacity within 48 hours • Full treatment process available immediately for critical components[7] • 90% to full capacity when power transmission and transportation is restored • 5 days of self-sufficiency for all consumables required for operations • Fire Suppression systems shall be autonomous and fully operable at 90-100% capacity immediately after a seismic event
Terminal Storage Reservoir	• Same as ORP, Main Transmission System • RES_1.0 Water Quality Building and related infrastructure shall meet the requirements of other "Facilities" as identified for the "Intake and RWF" and the "WTP"
Transmission Lines	• Same as ORP, Main Transmission System
Appurtenances	• Same as ORP, Main Transmission System
Turnouts	• Same as ORP, Main Transmission System
System Communications	• All critical systems to be hardwired • All critical systems must be able to operate independent of Internet (including wireless) • Include cyber security protocols
Distributed Control System	• Primary and secondary communication systems to be determined
System Infrastructure	• All facilities and transmission system components shall sustain no structural or mechanical damage that impairs system capacity or operability

Key: ORP = Oregon Resilience Plan; RWF = Raw Water Facilities; WTP = Water Treatment Plant

Where "5-Days" Came From

- "Perspective" from **Washington County** *Seismic Training Exercise*

- Week-long Session
  - Real-life earthquake event scenario
  - Integrated command staff
  - 70 participants
  - Reporting out

Take-aways:
- *WA Co. lead response*
- *Complex command structure*
- *Will take time to get running*
- *Deployment of resources to follow*

Where "5-Days" Came From

- "Perspective" from **Washington County** *Seismic Training Exercise*

Universe of Critical Infrastructure

Energy
- Petroleum
- Electrical
- Natural Gas
- Nuclear
- Temp Power Gen
- Steam

Transportation

Linear:
- Roads
- Rail
- Waterways

Non-Linear:
- Airports
- Seaports

Public / Private Infrastructure
- Hospitals
- Police / Fire Stations
- Water
- Wastewater
- Dams / Locks / Levees
- EOCs
- Financial
- Manufacturing
- Agriculture
- Government Facilities / Monuments

Communications
- Telephones
- Cell Phones
- Internet
- High Frequency
- Microwave
- SATCOM
- Fiber Optic
- TELCO Hotels
- IXPs

Where “5-Days” Came From

- Lots of “*resiliency”* initiatives at that time (Chief Engineer/MPA):
  - Evaluated Resiliency as Part of TVWD’s Water Master Plan
  - Hwy 26 PRV “Backdown System”
  - Ridgewood View Park Reservoir & Pump Station Project

Photo series: Main part of the “Backdown System”

Where "5-Days" Came From

Ridgewood View Park Reservoir & Pump Station Project

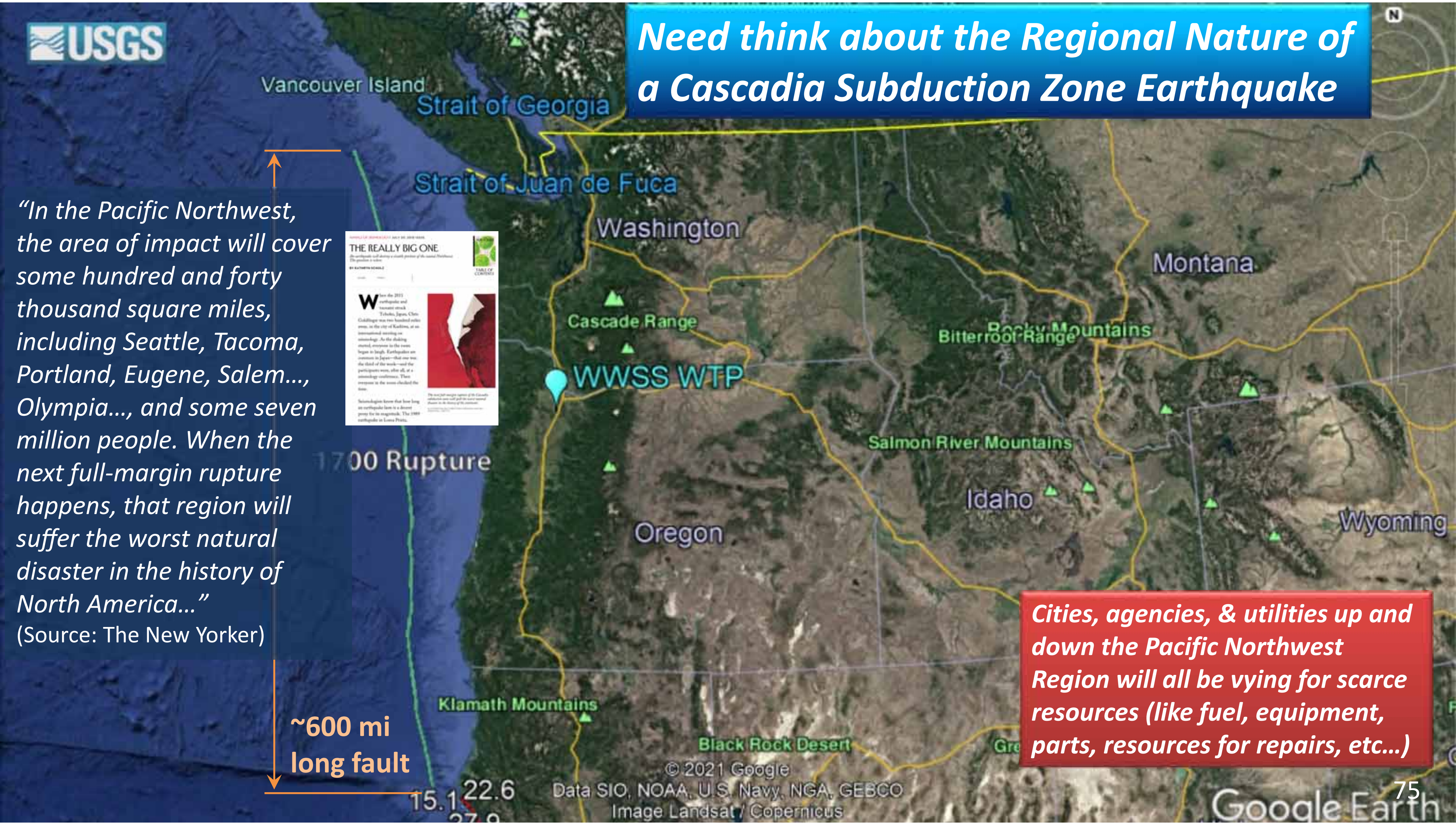
"Generator Run Times" (March 12, 2015)
Memo to Jim Doane (TVWD Commissioner)
from Mike Britch (TVWD Chief Engineer)

"Based on the Community-Specific Integrated Management Course that I attended at FEMA's National Emergency Training Facility in Emmitsburg, MD in April 2014, fuel priority in the event of a natural disaster like the CSZ earthquake would be given to critical water pump stations as well as delivered to other critical locations. As such, it is assumed that that fuel may be available at these locations within a few days. No specific fuel disbursement criteria were discussed. All fuel disbursements in this type of event would be controlled by Washington County as the lead local agency in charge of this kind of natural disaster."

"During a major catastrophic event like the Cascadia Subduction Zone (CSZ) earthquake it is assumed that water supply and distribution will be limited. Using the half-load fuel consumption rate, run times for generators at fixed sites vary from approximately one day to almost five days at our new Ridgewood View Park Pump Station." **[3 days full capacity or 5 days half-capacity]**

New kind of "thinking"

Need think about the Regional Nature of a Cascadia Subduction Zone Earthquake



"In the Pacific Northwest, the area of impact will cover some hundred and forty thousand square miles, including Seattle, Tacoma, Portland, Eugene, Salem…, Olympia…, and some seven million people. When the next full-margin rupture happens, that region will suffer the worst natural disaster in the history of North America…"
(Source: The New Yorker)

Cities, agencies, & utilities up and down the Pacific Northwest Region will all be vying for scarce resources (like fuel, equipment, parts, resources for repairs, etc…)

Where "5-Days" Came From

- Need think about Water Sector Interdependencies

We learned about supply chain vulnerabilities
from the COVID-19 pandemic

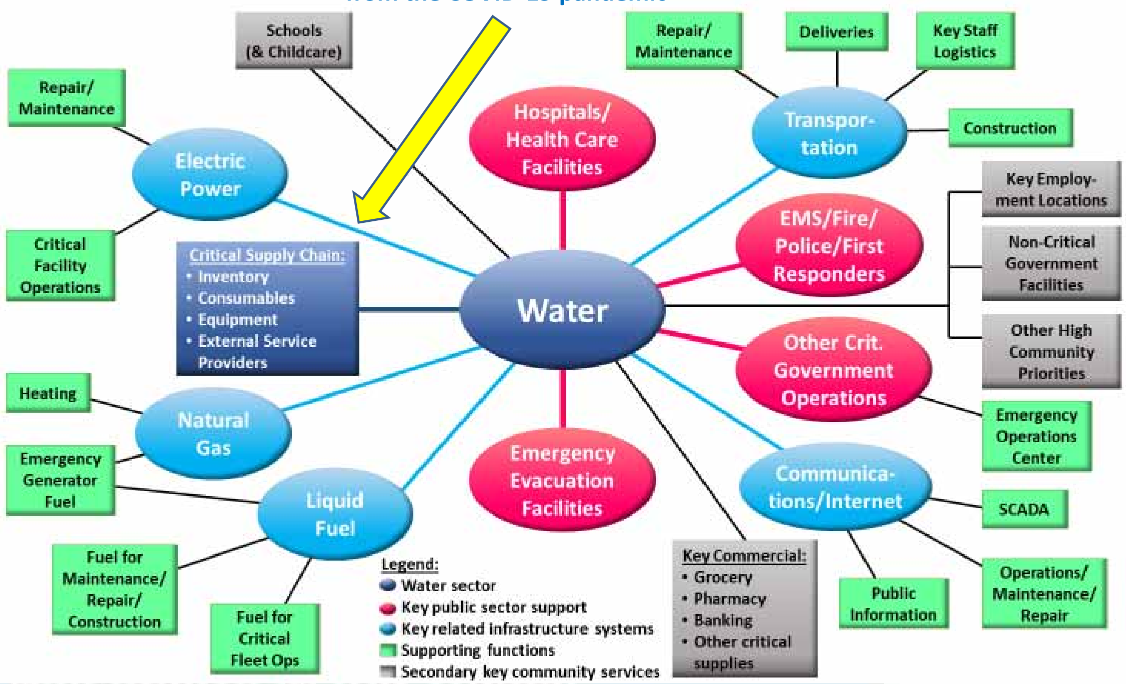


Figure 1. Water Sector Interdependencies (Source: Britch et al. (2020). Adapted from 2010 Water Sector Specific Plan [DHS, 2010])

Tualatin River Crossing Location – Roy Rogers Rd

[From RFP - WRF #5086 *"Case Studies on Water Sector Interdependencies"*]

Where "5-Days" Came From

- WRF #5014 *"Practical Framework for Water Infrastructure Resilience"* **[Content from Periodic Report 5 (Dec. 15, 2020)]**

Emergency Power for Critical Operations

Power is often a key limiting factor in the immediate aftermath of many disasters. The 2008 edition of the National Electric Code (NEC) Article 708 establishes a minimum benchmark of 72 hours for backup power for critical operations and assets. This three-day window is the expected time it may take for services to be restored and/or emergency power generators to be deployed. The greater the in-house capacity to be power-independent following an event increases a utility's resilience and minimizes the burden for like services that may be needed by other entities. This indicator considers the capacity of the utility as a whole to maintain critical operations as defined by the utility.

O4: Emergency Power for Critical Operations*

Amount of Emergency Power	URI Score	WRF #5014 Case Results No.	WRF #5014 Case Results (%)
None	0.00	1	5.3%
Up to 24 hours	0.25	1	5.3%
25 - 48 hours	0.50	6	31.6%
49 - 72 hours	0.75	3	15.8%
≥ 73 hours	1.00	8	42.1%
Total No. of Utility Participants		19	

* One of the benchmarks used as part of the Utility Resilience Index (URI)

"Ensure full-load 72-hr continuous alternate power sources

According to NEC 708, the COPS alternate power source shall have the capacity and rating to run full load continuously for a minimum period of 72 hr. The alternate power source can be a generator, UPS, or a fuel cell system."

February 2021 Ice Storm Oregon Power Outage

"Worst storm they had to deal with in 40 years"

– PGE (2/16/21)

"Over 330,000 Oregonians are currently without power"

– Willamette Week (2/15/21)

Water/Power Outages, Mainbreaks, & Boil Water Notices


Technological Forecasting & Social Change

Disaster resilience as a complex problem: Why linearity is not applicable for long-term recovery

Deborah Blackman, Hitomi Nakanishi, Angela M. Benson

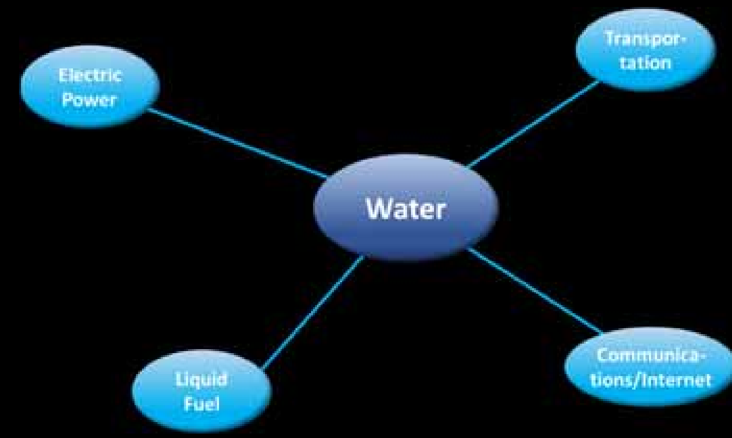
Disasters are complex multi-disciplinary problems

Blackman et. al. states that complex problems *“occur within a system, which is made up of interconnected, interdependent elements”* and that they *“cannot be addressed in a piecemeal way, it must be addressed as an entire system”* (p. 91)

Blackman, D., Nakanishi, H., & Benson, A. M. (2017). Disaster resilience as a complex problem: Why linearity is not applicable for long-term recovery. *Technological Forecasting and Social Change, 121*, *89-98.* doi: https://doi.org/10.1016/j.techfore.2016.09.018

Can Have Disasters Within Other Disasters

[further illustrates the interconnectedness and interdependencies of infrastructure systems]



Houston (2021)

- Power outages knocked out water plants - *"Water utilities are struggling to operate in light of the state power issues"*
- *"Roadways remain impassable around our area*, and we urge motorists to please avoid all unnecessary travel" – Louisiana State Police
- *"It's worse than a hurricane,"* one Houston resident told The Associated Press.
- Harris County Judge Lina Hidalgo said Tuesday that at least 300 calls regarding carbon monoxide poisoning had been received by the fire marshal, hospitals and other agencies. Hidalgo called it a *"disaster within a disaster."*

(Source: The Weather Channel 2/17/21)

Fukushima Power Plant (2011)

Learning from Japan's *"Thinking"*

- Tohoku Program (June/July 2019)
  10-day trip to Miyagi Prefecture and Tokyo
  - Sendai
  - Ishinomaki
  - Kessennma
  - Tokyo

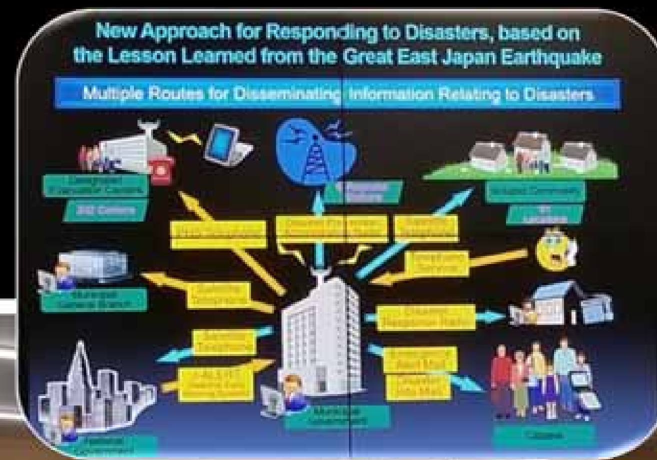
"The list of lessons to be learned from March 11 is long. At the top, however, is being prepared and taking preventative steps against natural disasters"

Source: Mr. Morimoto, former University of Tokyo professor (The Japan Times, 2011)

Learning from Japan's *"Thinking"*

Ishinomaki City – Day 3 **Tuesday June 25, 2019**

Disaster Control Center



Q: Outside aid – 3 days of fuel, solar panel, stay as much as a week, food supplies

Q: How long with out power? Depends on neighborhood – earliest 1 wk recovery / 1 month maximum

Learning from Japan's *"Thinking"*

Tokyo – Day 6 **Friday June 28, 2019**

Mitsubishi Estate Group – Ohtemachi Park Building & Grand Cube

100 buildings, 4300 companies

Marunouchi Area - Approximately 200-acre commercial district that is home to Tokyo's financial district and the headquarters for countries three largest banks

Q: Building Evacuation Site Supplies? Water, protein bars… follow guidelines by Tokyo area (City recommendations). 3 days of water and food for expected number of people.

Mitsubishi Estate Group CEO

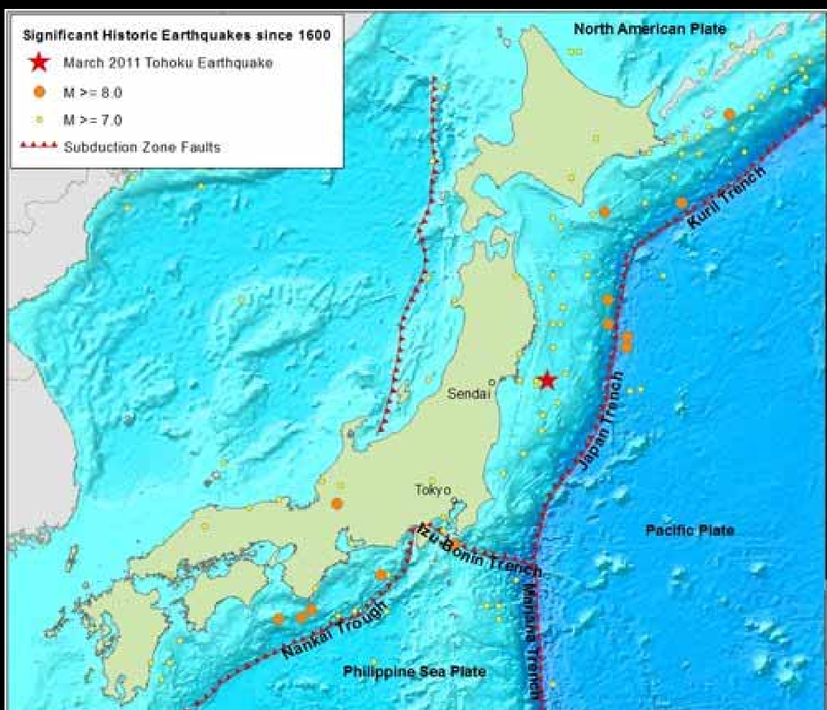
Emergency Power Generators

"The buildings store… fuel… for running emergency power generators, ensuring that power supply would not be interrupted for 72 hrs"

Photo source: https://commons.wikimedia.org/wiki/File:Imperial_Palace_Pano_Some_CROPPED_RESIZED.png

Learning from Japan's "Thinking"

Earthquake resiliency has been part of the Japanese culture for 100s of years

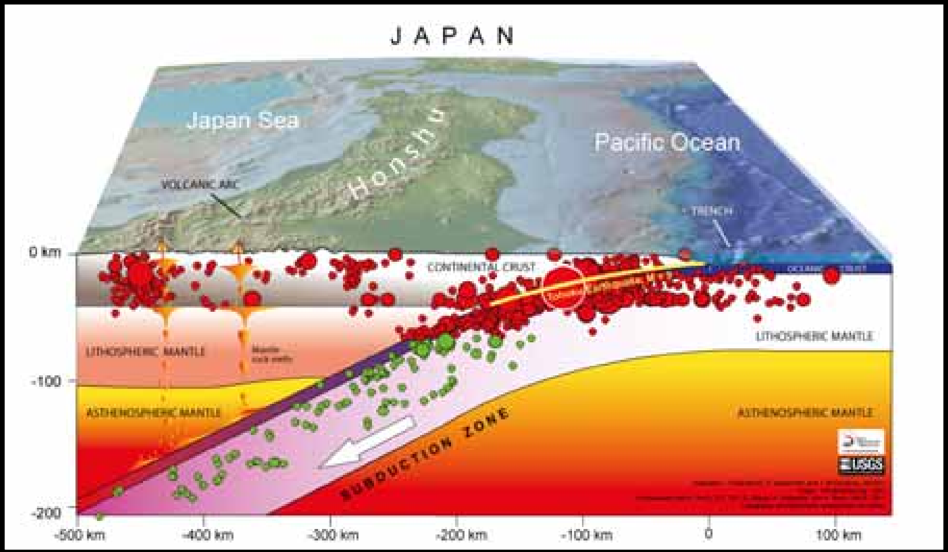


Marunouchi in flames following the 1923 M 7.9 Kanto Earthquake. Estimated 142,800 deaths, many due to fire.

1995 M 6.9 Kobe Earthquake. Estimated about 6,434 deaths. Hanshin Expressway collapsed.

Learning from Japan's "Thinking"

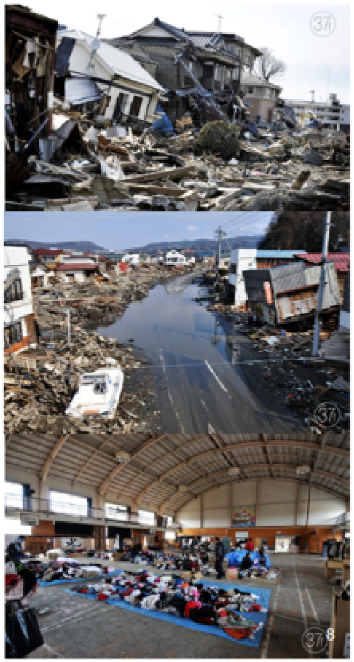
Earthquake resiliency has been part of the Japanese culture for 100s of years



Tohoku Japan

M9.0 Earthquake (March 11, 2011)

- 16,447 Deaths
- 4,787 Missing
- 5,888 Injured
- 430,000 Homeless
- 111,944 Buildings destroyed
- 637,277 Buildings damaged
- Honshu Island moved 7.8 feet West
- Nuclear power meltdown
- Cost could exceed $300 billion



PART III – BATTERY BACKUP AT FACILITIES

Turnouts

- Vital Part of Overall System Operation
  - Throttle flow
  - Maintain pressurized system
  - Preserve system storage
  - Continuity of system communications & control through SCADA

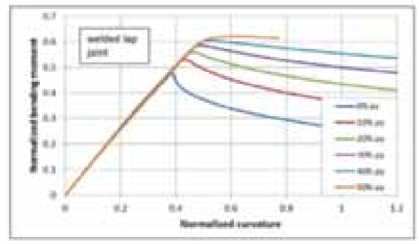
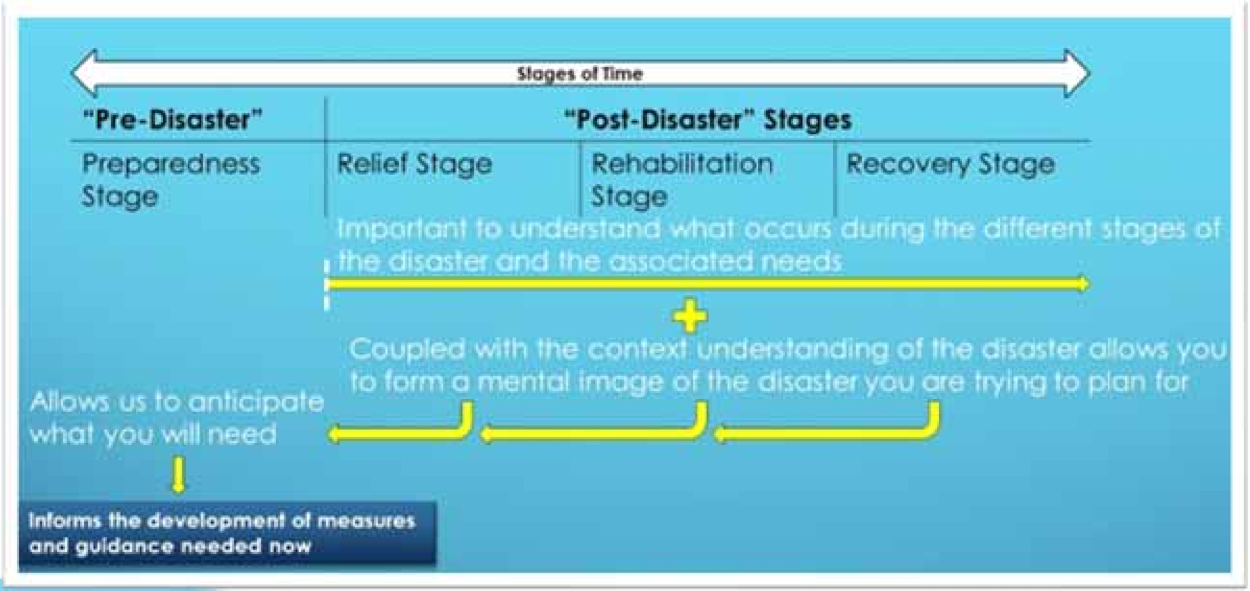


Figure 9. Effect of internal pressure on the bending response of double-welded lap joints (D/t = 191).

Requires 5 days of battery backup (or alternate power supply) as part of overall "System Operations"

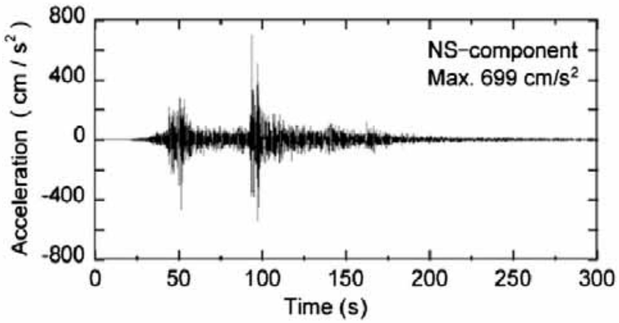
WTP, RWF, RES Battery Backup

- 8 – 12 hours of battery backup for critical systems
  - Allows for critical functions prior to generator startup



Timeline of Events & Sequence of Activities

Earthquake occurs



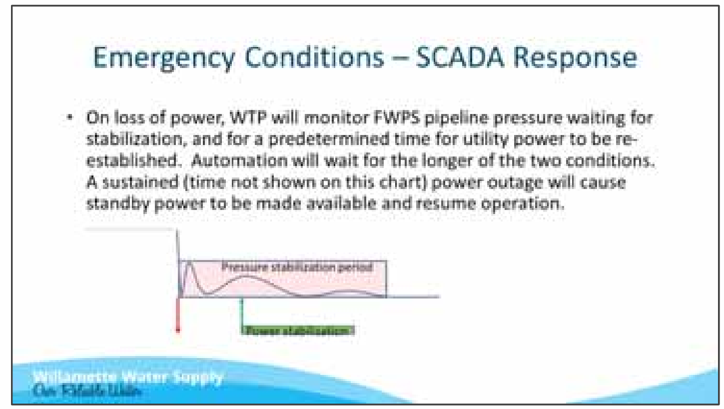
Observed seismic acceleration record in Sendai city (Nankodai Higashi elementary school) during the 2011 earthquake.

Mori, Tomohiro & Tobita, Yoshio & Okimura, Takashi. (2012). The damage to hillside embankments in Sendai city during The 2011 off the Pacific Coast of Tohoku Earthquake. Soils and Foundations. 52. 910–928. 10.1016/j.sandf.2012.11.011.

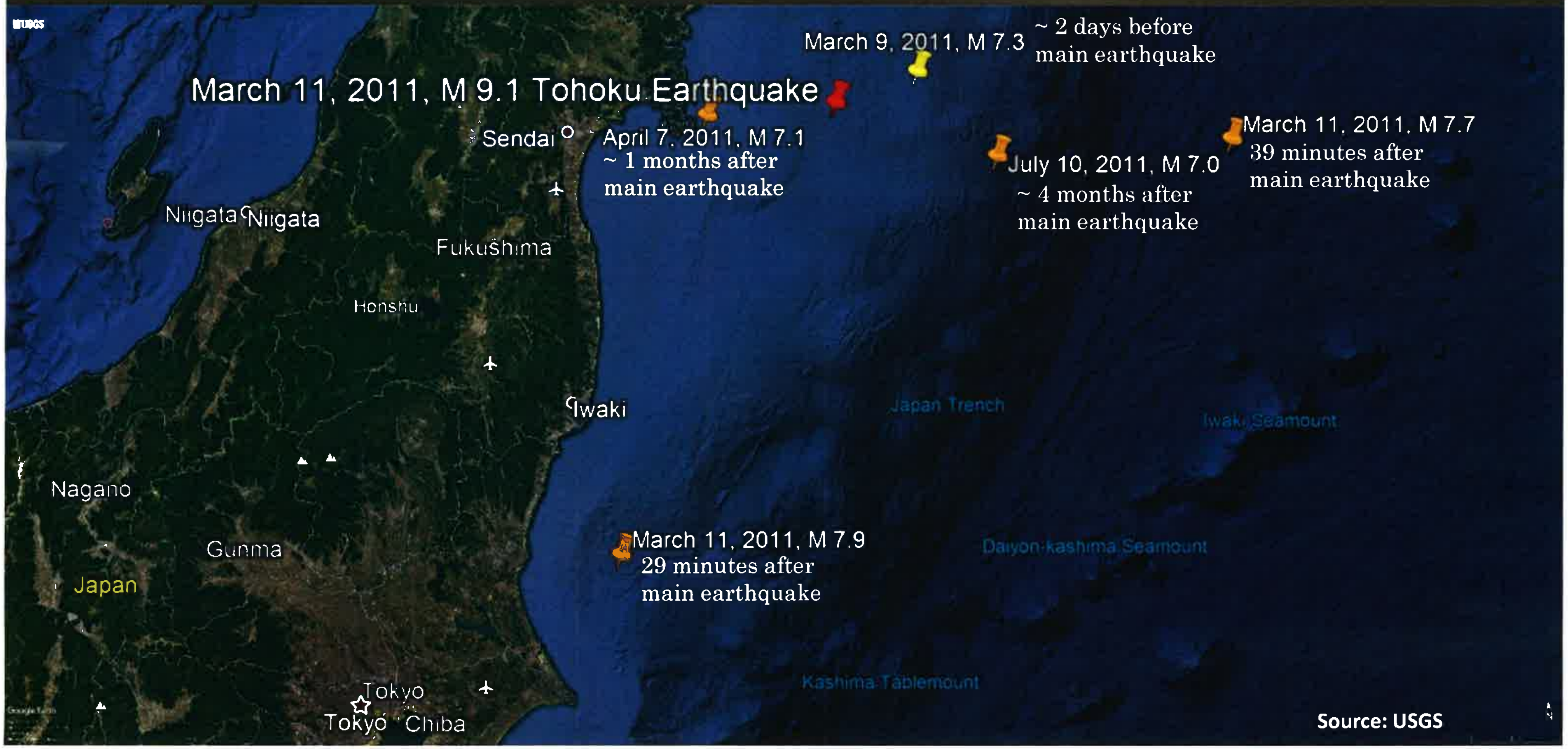
- Earthquake Response:
  - Local accelerometer or "early warning system" provide signal
    - WWSS System Controls are initiated
      - Goal to get equipment to most stable state:
        - » Stop all mechanical systems
        - » De-energize all equipment
      - When external power supply stops, battery systems provide power to critical systems
      - Remain in stable state until post-earthquake critical activities complete

Timeline of Events & Sequence of Activities

- Post-Earthquake Activities (prior to energizing generators):
  - Life safety/staff activities:
    - Individual safety
    - Staff safety check
    - Off-duty staff report in (as available)
  - System hydraulic transients dissipate
  - Aftershocks



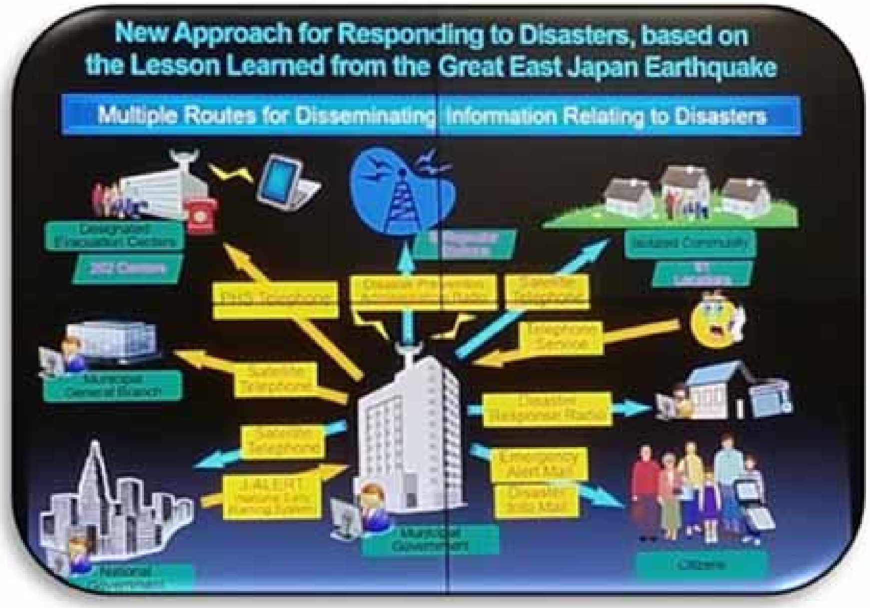
Magnitude 7+ Earthquakes Related to Tohoku Earthquake



Timeline of Events & Sequence of Activities

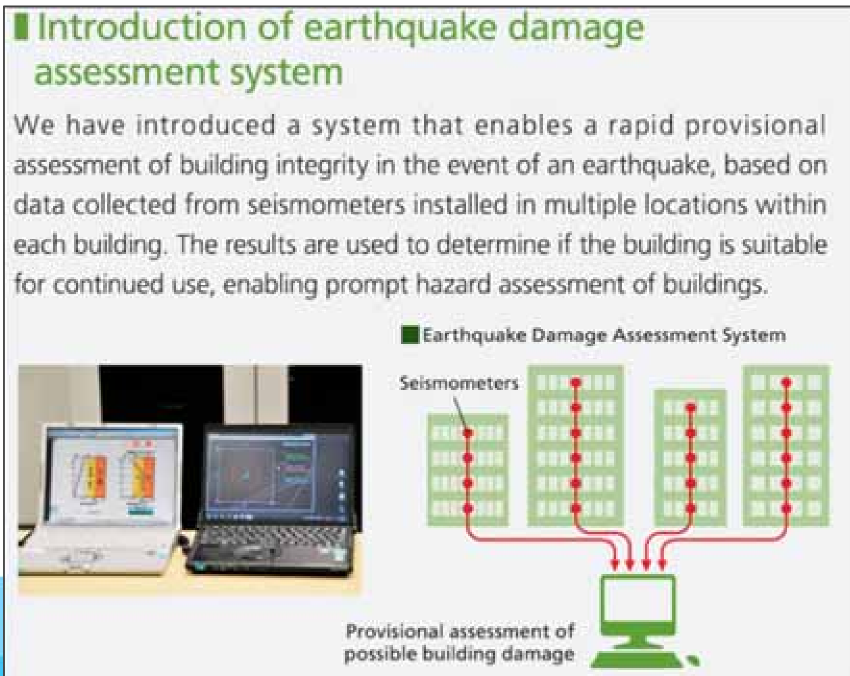
- Post-Earthquake Activities (prior to energizing generators):
  - System checks through SCADA

"Communications is one of the most common types of failures during disasters" (FEMA, 2014)



Timeline of Events & Sequence of Activities

- Post-Earthquake Activities (prior to energizing generators):
  - System checks through instrumentation



Mitsubishi Estate Group buildings have sensors every seventh floor to provide feedback on building performance

Raw Water Facilities will have an instrument to assess tilt in the caisson

Timeline of Events & Sequence of Activities

- Post-Earthquake Activities (prior to energizing generators):
  - Visual inspections
    - In person (preferred)
    - Through video (if can't have staff conduct in person inspections (e.g., RWF)

Building a cooperative system with general contractors and utility service companies

The Group has built a collaborative system with 22 general contractors and utility service companies to carry out hazard assessments on buildings and emergency repairs to ensure safety, as well as provide emergency response materials.

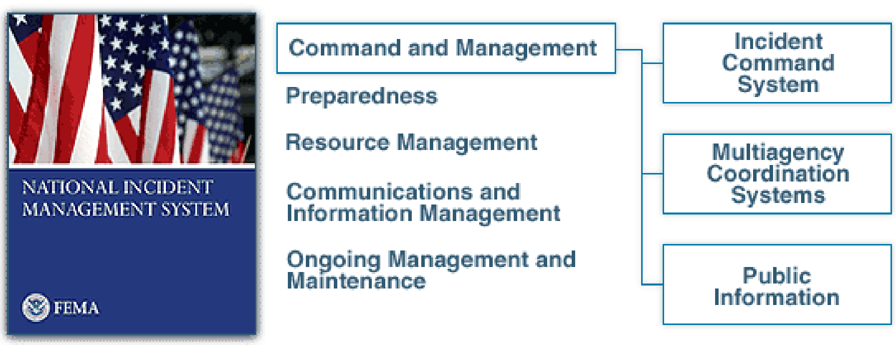
Procedures in place with the Mitsubishi Estate Group to conduct inspections following an earthquake

Hazard assessment for building damage (image)

RWF will have cameras for video inspection

Timeline of Events & Sequence of Activities

- Post-Earthquake Activities (prior to energizing generators):
  - Coordination and reporting out to Partner Agencies and other emergency response activities



Timeline of Events & Sequence of Activities

- Once all these *"Post-Earthquake Activities"* have been completed, then the generators will be powered up
  - Allows operators time to complete checks without having to ***"rush"*** to turn the system on
  - System can be brought online earlier if desired

Questions

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