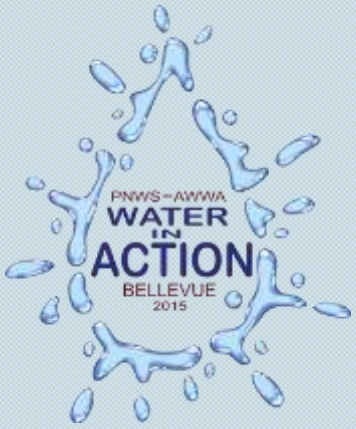
Seismic Options for New and Old Reservoirs

Lance Stevens, P.E. (WA), NACE CIP Level 3

Myron Basden, P.E., S.E. (WA)

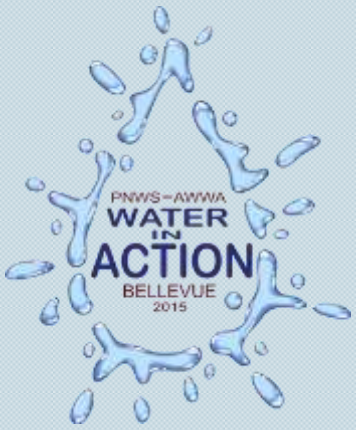
April 29, 2015

Emergency Preparedness & Disaster Response Pre-Conference Seminar



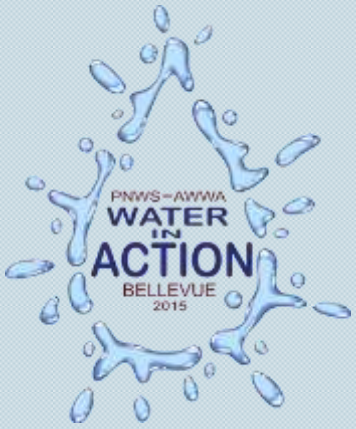
Presentation Overview

- Building Code and Notable Changes
- Seismic Options and Associated Costs for Reservoirs
  - Construction Type
  - Seismic Use Group
  - Freeboard
  - Resistance to Overturning
  - Piping Connections
  - Seismic Valves and Sensors
  - Roof Vent
  - Costs



Building Code for Structural Design

- IBC 2012 Section 1613 Earthquake Loads → ASCE 7-10 Section 15.7.7 Water Storage and Water Treatment Tanks and Vessels → applicable AWWA standard
  - ASCE 7-10 Section 15.7.7.1 Welded Steel references AWWA D100
  - ASCE 7-10 Section 15.7.7.2 Bolted Steel references AWWA D103
  - ASCE 7-10 Section 15.7.7.1 Reinforced and Prestressed Concrete references AWWA D110, AWWA D115, or ACI 350.3

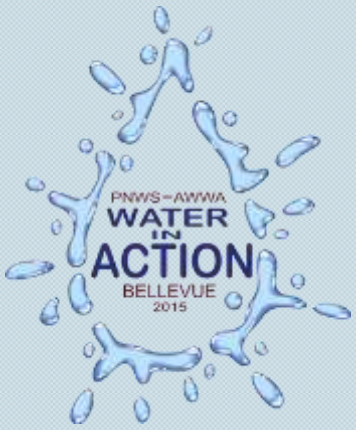


Construction Type

- Prestressed Concrete Tanks: Seismic retrofit is challenging due to prestressing strands
- Bolted Steel Tanks: Seismic retrofit is challenging due to glass-fused coating
- Fabricated Steel Tanks: Seismic retrofit is common

Notable Changes in the Building Code

- AWWA D100 last updated in 2011 – Slightly increased seismic design loads for Pacific NW.
- AWWA D100-2005: Decreased seismic design loads for Pacific NW. Transition from UBC-era seismic zones to IBC-era seismic maps with spectral acceleration contours. Vertical seismic design acceleration requirements become mandatory.
- AWWA D100-1996: Increased seismic design loads for the Pacific NW. Transition from “fixed percentage” seismic loads to UBC-era seismic zones.



Notable Changes in the Building Code

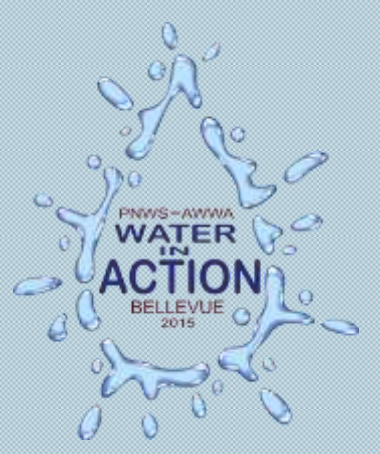
General guidelines regarding the magnitude of seismic design forces:

- 2005-2011 reservoirs may be slightly non-compliant with current code.
- 1996-2005 reservoirs may be somewhat compliant with current code.
- 1984-1996 reservoirs may be slightly non-compliant with current code.
- Pre-1984 reservoirs likely non-compliant with current code.
- In some cases a reservoir may have been designed to a more stringent standard.

Notable Changes in the Building Code

- What if no drawings or other information are available for an existing tank? Make site visit with a steel thickness gauge, record geometry. For anchored tanks, measure size & quantity of foundation straps or anchor bolts. Pothole for depth and size of ringwall/footing. Perform a seismic analysis back at the office.

- Seismic Forces required by AWWA-D100-11 are based on maximum considered ground motion for an event with a 2% probability of exceedance within a 50-year period (recurrence interval of approximately 2,500 years).



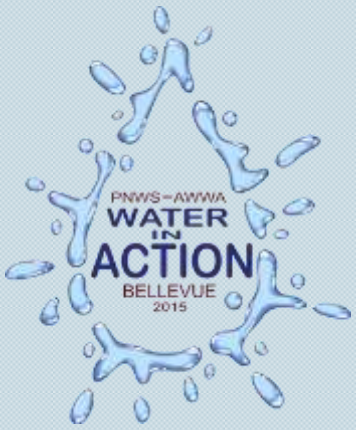
Seismic Use Group

- AWWA-D100 Section 13.2: Seismic Use Group is a classification assigned to the tank based on its intended use and expected performance. Seismic Use Group III shall be used unless otherwise specified.

- Seismic Use Group III: Serves facilities that are deemed essential for post-earthquake recovery and essential to the life, health, and safety of the public, including post-earthquake fire suppression (I_E = 1.50).

- Seismic Use Group II: Serves facilities that are deemed important to the welfare of the public (I_E = 1.25).

- Seismic Use Group I: All other tanks. (I_E = 1.00).



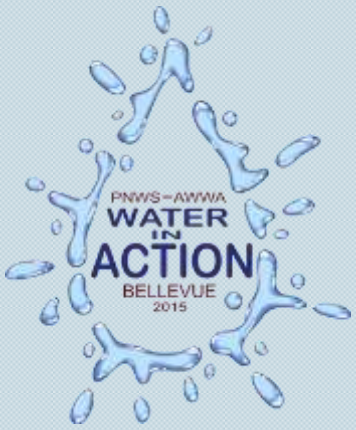
Old Reservoirs – Seismic Use Group

- Reservoir contents essential for post-earthquake recovery? If yes, design to Seismic Use Group III → increased design forces → increased size of structural members → increased construction cost

- If there are multiple reservoirs within a system, reservoirs could be strategically prioritized according to which are essential/non-essential for post-earthquake recovery

Freeboard

- Often the freeboard of an existing reservoir is less than that required by current code. Options to address this include:
  - Raise Roof (costly)
  - Lower the maximum operating level
  - Design and retrofit roof connections for forces applied to roof by sloshing wave in the case of insufficient freeboard
  - Accept risk of insufficient freeboard – not likely to cause catastrophic failure of the reservoir – more likely to cause only local roof damage

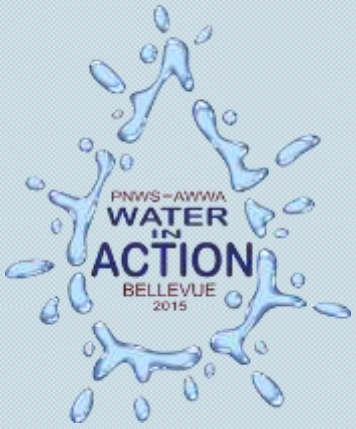


Freeboard

- The recurrence period can be estimated for the size of earthquake for which existing freeboard is adequate. For example, an existing freeboard may not meet AWWA-D100, which is based on a recurrence period of 2,500 years, but may be found to be adequate for the size of earthquake that has a recurrence period of 1,000 years.

- Note that the cost to repair freeboard damage due to an earthquake would likely be less than the cost to raise the roof.

- Note that insufficient freeboard which constrains the sloshing wave can also increase the net horizontal seismic force on the reservoir – the reservoir anchorage/foundation should be evaluated for this behavior.



Seismic Retrofit

- Type of Failure: Anchorage to Foundation

(photo: damage from Nisqually Earthquake of 2001)

Seismic Retrofit

- Type of Failure: Anchorage to Foundation
- Anchorage achieved ductile behavior – bend but not break.

(photo: damage from Nisqually Earthquake of 2001)

Seismic Retrofit Options

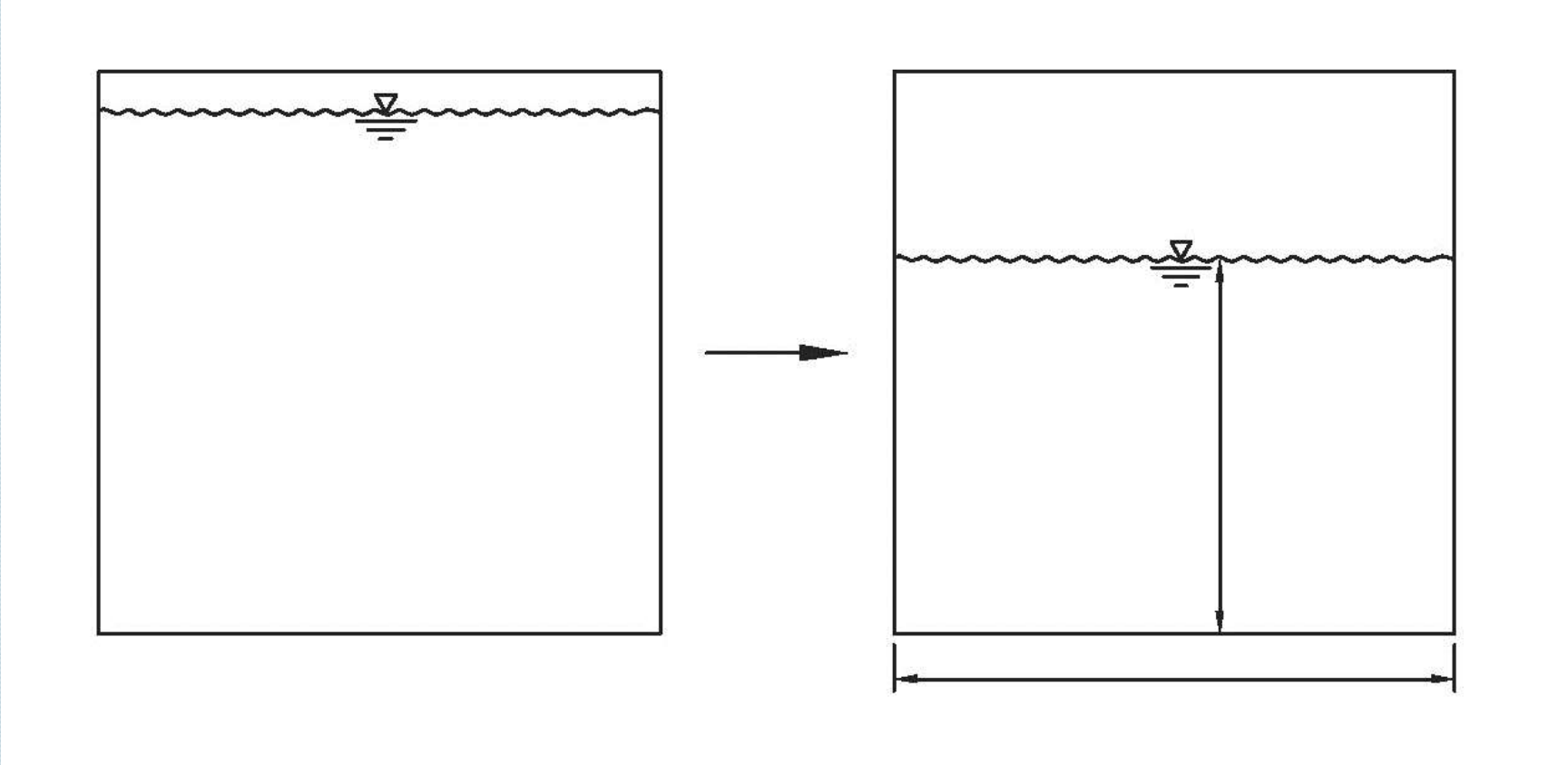
- Reservoir geometry affects which retrofit options are available
- Rule of Thumb: Anchorage is typically not required for ground supported steel tanks with up to 1.0D : 0.7H

PNWS–AWWA WATER IN ACTION BELLEVUE 2015

Seismic Retrofit Options

- For purpose of analysis, the tank height can be roughly considered to be top of water level

- Consequently, one option for seismic retrofit is to reduce the water level to achieve 1.0D : 0.7H



PNWS-AWWA WATER IN ACTION BELLEVUE 2015

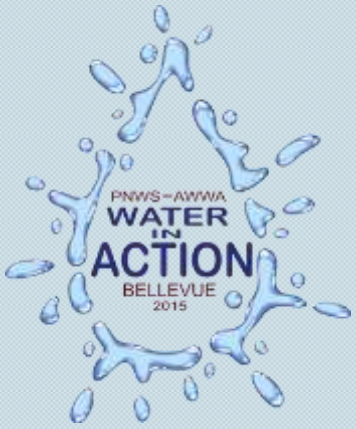
Seismic Retrofit Options

- **For insufficient anchorage to foundation and/or insufficient foundation:**
- Retrofit Option 1 - Strengthen the anchorage. Add anchorage and foundation elements as required to resist overturning forces.
- Careful coordination required to install around existing pipes, vaults, and other utilities.
- If foundation work is required, cost can increase due to volume of concrete needed to resist overturning, excavation and coordination around existing utilities.
- Modifications to improve ductility – e.g. strap anchors.

Seismic Retrofit Options

Seismic Retrofit Options

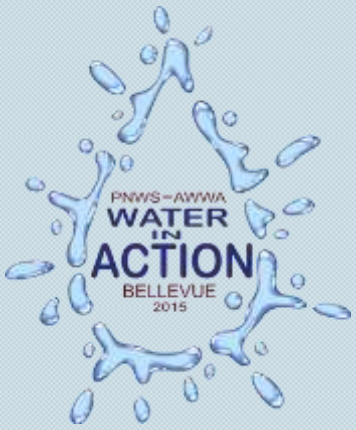
- **For insufficient anchorage to foundation and/or insufficient foundation:**
- Retrofit Option 2: Add concrete ballast slab on existing steel floor of reservoir. Install new steel floor over the top of the new ballast slab.
- Retrofit design utilizes weight of water in reservoir to resist overturning – no additional foundation anchorage or foundation enlargement required. This option is feasible for ground-supported tanks up to 1.0D : 1.5H, depending on bearing pressure capacity of supporting soils.
- Cost savings over Option 1
- Reduced water storage
- Can also be used to address non-compliant seismic soil bearing pressure



Seismic Retrofit Options

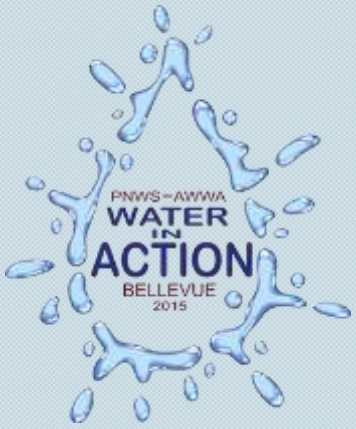
Seismic Retrofit Options

- **For insufficient bracing rods and/or foundation anchorage in steel <u>elevated tanks</u>:**
- Retrofit Option 1: Increase size of bracing rods, foundation anchorage, and foundation as required to resist current code-level seismic forces.
- Careful coordination required to install around existing pipes, vaults, and other utilities.
- If foundation work is required, cost can increase due to volume of concrete needed to resist overturning, excavation and coordination around existing utilities.



Seismic Retrofit Options

- **For insufficient bracing rods and/or foundation anchorage in steel <u>elevated tanks</u>:**
- Retrofit Option 2: Performance-based analysis and design utilizing friction dampers. Friction dampers reduce the internal stresses in structural members by allowing controlled ductility of the structure.
- Cost savings over option 1 because existing members and foundation do not require strengthening.
- Piping connections may need to be revised to accommodate the seismic movement of the structure.



Piping Connections

- Use HDPE between the inlet/outlet and the system.
- Use force-balanced Flex Tend Couplings.
- Important that all components are detailed to work together to provide flexibility – avoid locating rigid points next to flexible points.
- AWWA D100 provides table of minimum design displacements for connections of piping to steel tank.

Piping Connections

Seismic Valves and Sensors

- System is used to detect a seismic event of a certain magnitude and then monitor for conditions indicating a main break.
- Flow can be monitored either by a flow meter or a pressure transducer.
- Requires a PLC and is best integrated with SCADA so that OPS has direct control over flow out of the tank.
- System can also be used to remotely close the reservoir outlet in the event of a security breach.

Roof Vent

- Verify roof vent is adequately sized for the case of reservoir contents emptying through a pipe break.

Other Considerations

- Steel tanks built in the 1980's and 1990's are due for recoating – a good time to evaluate the seismic adequacy of the tank and install retrofits.
- Nisqually earthquake of 2001 – the level of ground shaking in the Seattle area roughly corresponds to a recurrence period of 100 years.

Costs

- Costs vary significantly depending upon what is needed for the update and size of the reservoir.
- The best approach to get planning level costs for seismic upgrades is to have an evaluation performed.
- For only a little additional effort, you can have the coatings, safety features, and appurtenances evaluated as well.

Questions?