

# SEISMIC ANALYSIS OF VANCOUVER'S WATER TOWERS

---

Nick Robertson, OBEC Consulting Engineers  
Patrick Craney, City of Vancouver



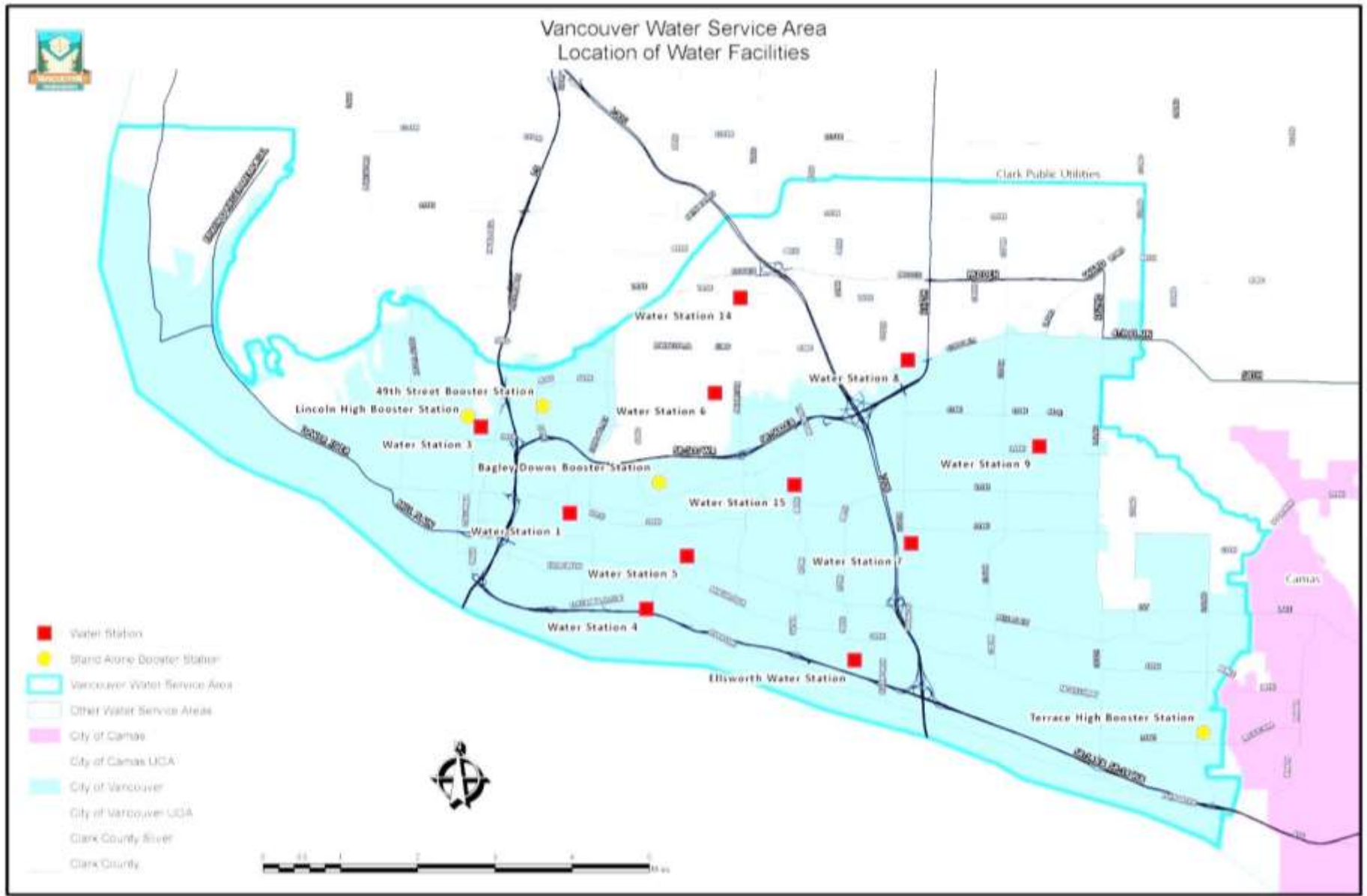


# Water System Statistics

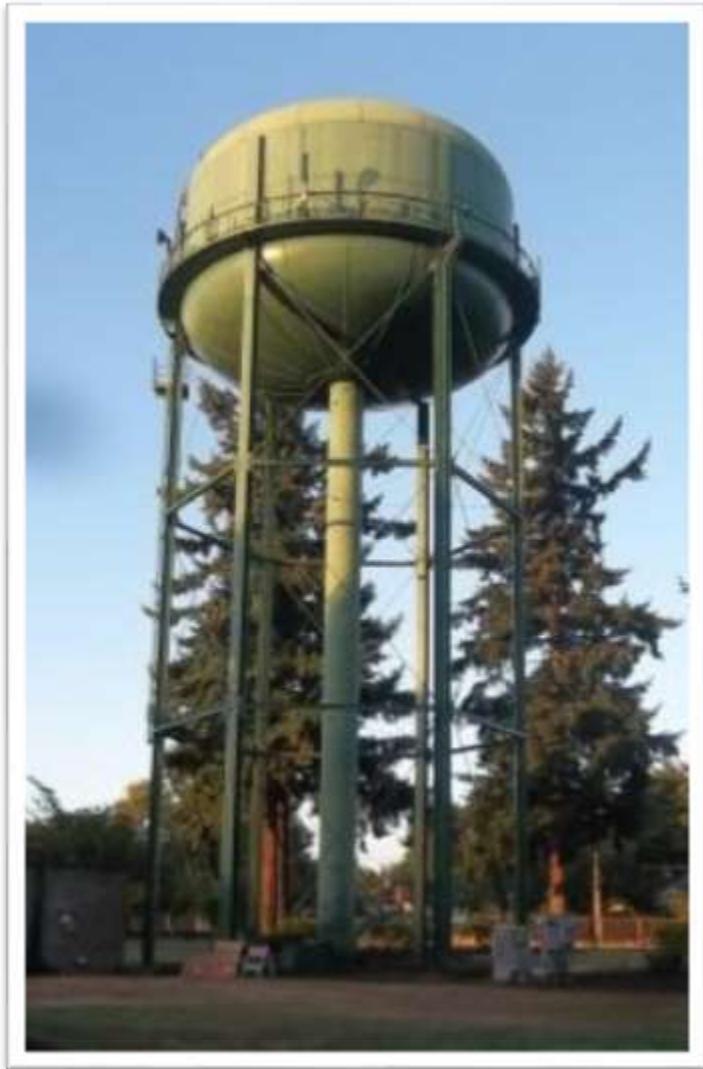
- 4<sup>th</sup> largest utility in Washington
- 72-square-mile service area with four Pressure Zones
  
- 240,000 customers
- 68,000 services
  
- 1,000 miles of distribution pipe
- 40 wells at nine water stations
  
- 9.8 billion gallons pumped in 2015
- Average demand 26.8 MGD
  
- 24 MG storage in five reservoirs and five elevated towers



# >> Service Area Map



# >> Water Station 3



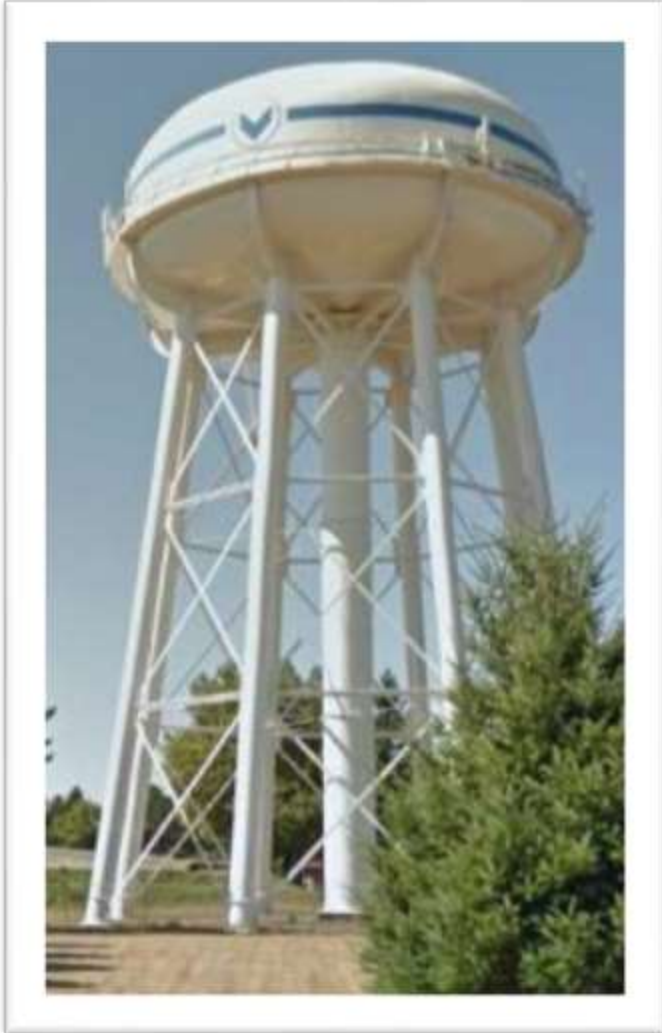
Year Built: 1945

Height: 115 FT

Volume: 0.25 MG

Chicago Bridge & Iron Co. Tank

# >> Water Station 5



Year Built: 1955

Height: 129 FT

Volume: 0.75 MG

Pittsburgh-Des Moines Steel

# >> Water Station 6



Year Built: 1963

Height: 130 FT

Volume: 1.0 MG

Pittsburgh-Des Moines Steel



# >> Water Station 7



Year Built: 1968

Height: 115 FT

Volume: 1.0 MG

Chicago Bridge and Iron

# >> Step 1: Data Gathering

1. Material Properties
2. Member Types
3. Foundation Data







# Sources of Data

1. Shop Drawings
2. Soils Reports
3. Well Logs
4. Original Design Codes/Standards



BILL OF MATERIAL

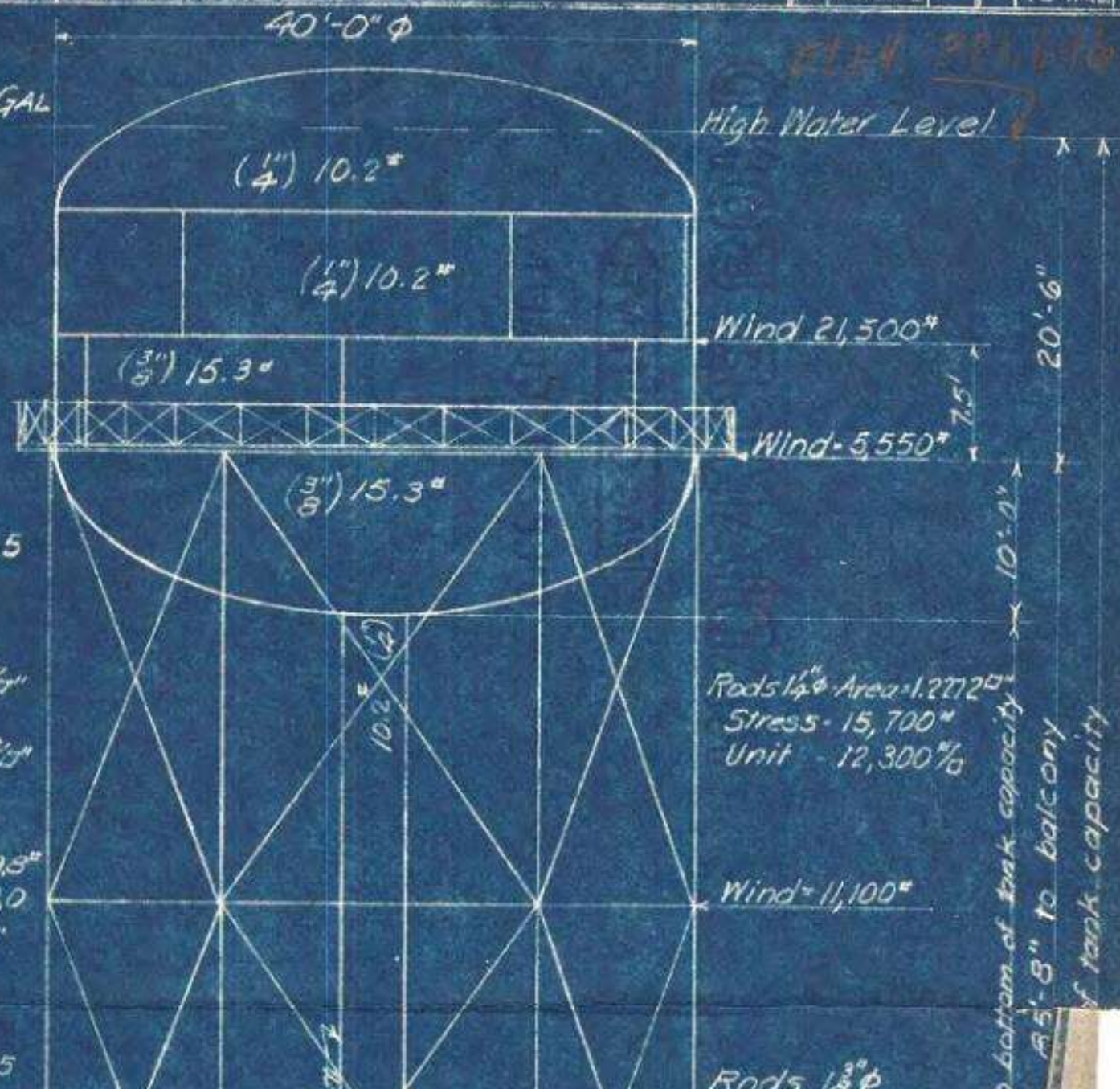
3	PLATE	9	STUCCO FIN
4	SHAPE	10	SHIPPED
5	FITTER		
6	MACH'S		TOTAL

CAPACITY 250,000 GAL

High Water Level



STRUTS



Columns - 14" WF @ 103"  
Area = 30.26"; R = 3.72"; L/R = 92.5

Water = 343,500"  
Metal = 23,300"  
Total = 366,800" = 12,100%  
Wind = 15,500"  
Total = 382,300" = 12,640%

Rods 1/4" φ Area = 1.2272"  
Stress = 15,700"  
Unit = 12,300%

Struts - 1E8" @ 11.5" & 1E7" @ 9.5"  
Area = 6.21"; R = 2.31"; L/R = 104.0  
Wind = 10,820" = 1,750%

Wind = 11,100"

Columns - 14" WF @ 103"  
Area = 30.26"; R = 3.72"; L/R = 92.5

Rods 1/8" φ

bottom of tank capacity  
10'-0"  
20'-6"  
10'-2"  
10'-0"  
of tank capacity



# Step 2: Filling in the Gaps

1. Geotechnical Investigations
2. Condition Assessment
3. Testing







1 1/4" x 1 1/2"

7/16"

5/16"

09/02/2014



09/03/2014



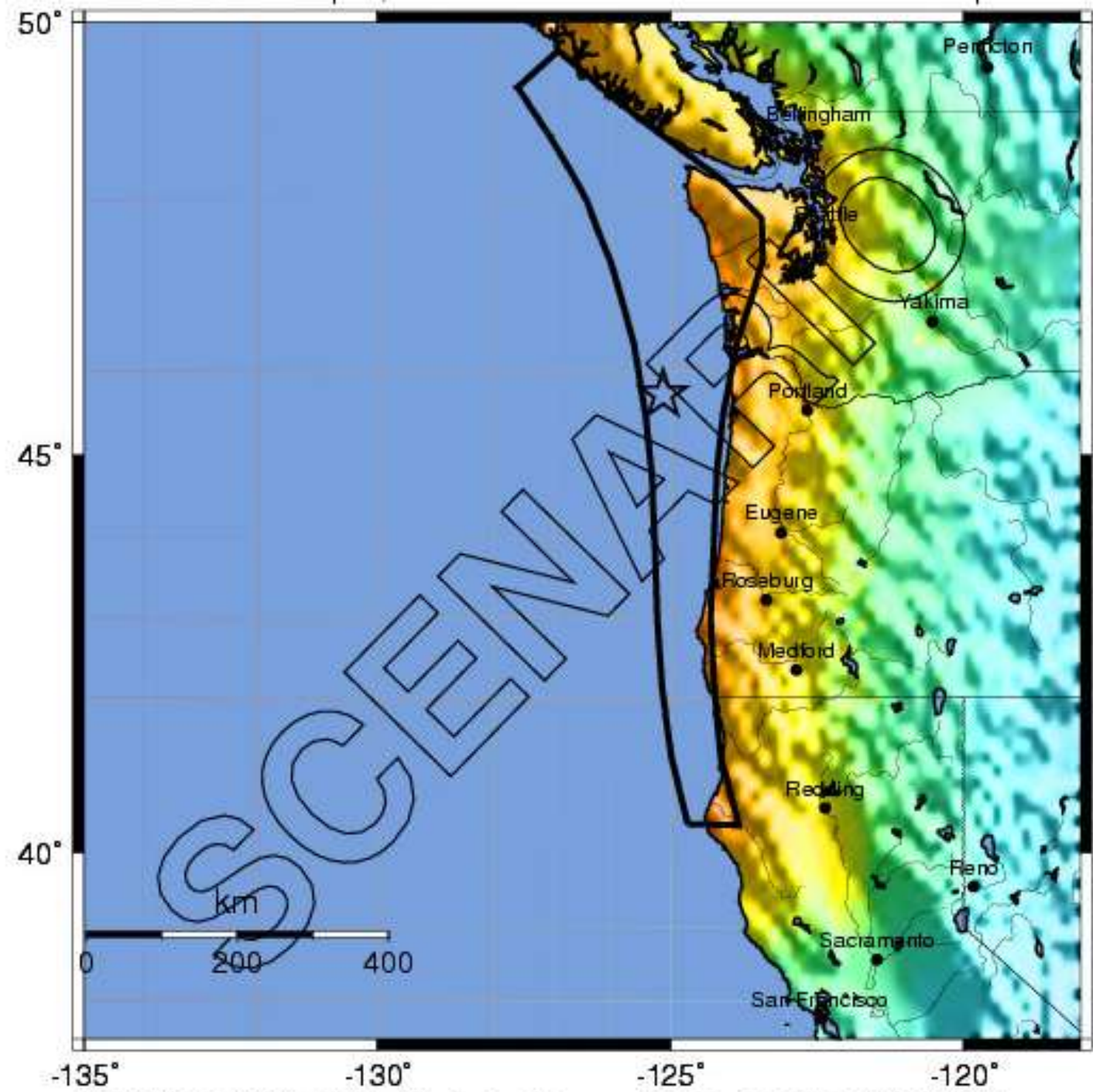


09/03/2014



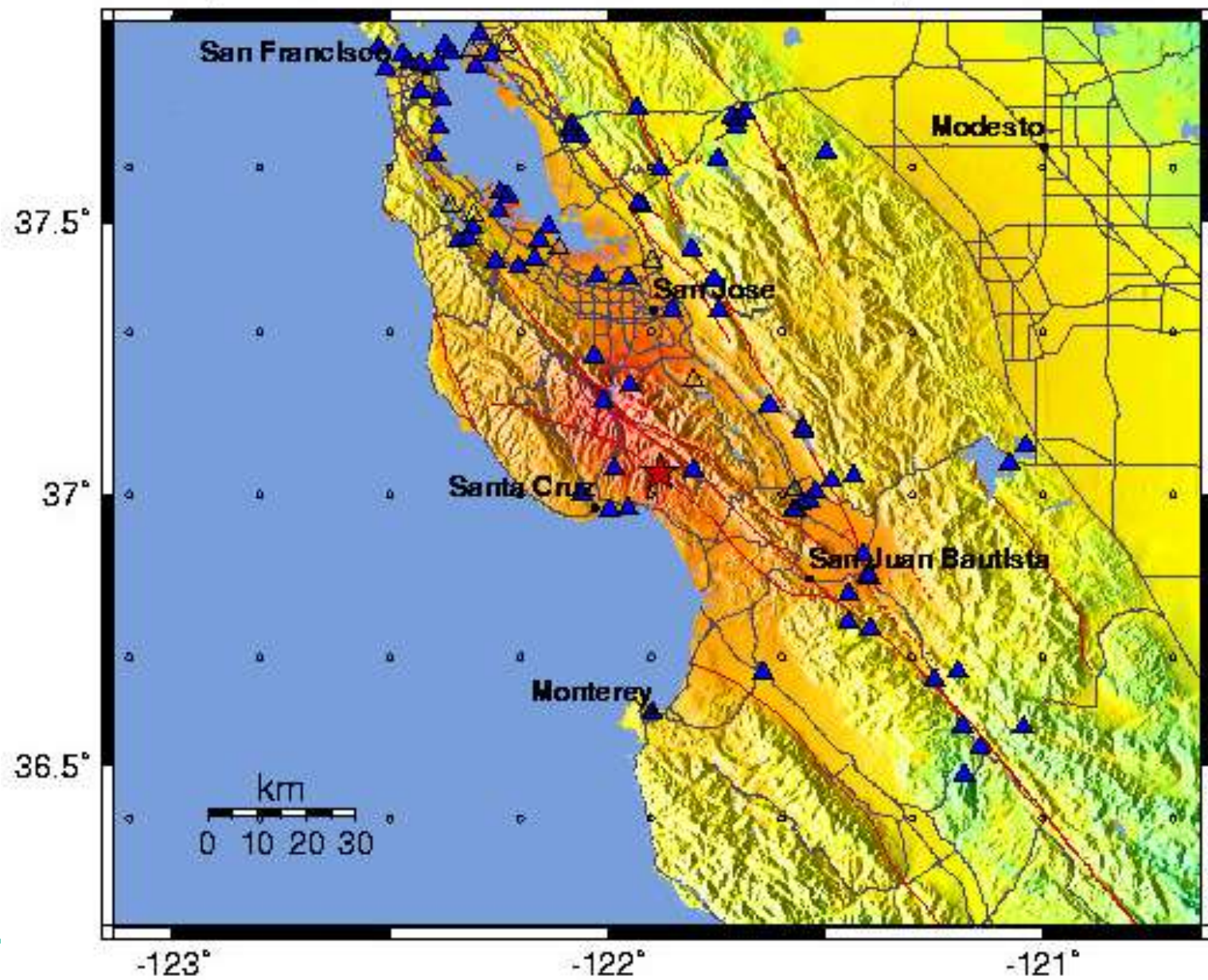


09/03/2014





CISN Rapid Instrumental Intensity Map for LomaPrieta Earthquake  
Tue Oct 17, 1989 05:04:00 PM PDT M 6.9 N37.04 W121.88 Depth: 18.0km ID:LomaPrieta



PROCESSED: Wed Jun 18, 2003 11:12:02 AM PDT,



# Historic Performance

- Whittier (1987)
  - Loma Prieta (1989)
  - Northridge (1994)
  - Nisqually (2001)
  - Napa (2014)
-



# Retrofit of Buildings

- ASCE 41-13
  - Performance Objectives
  - Building Lifespan
  - Risk Levels
-



# >> Performance Objectives

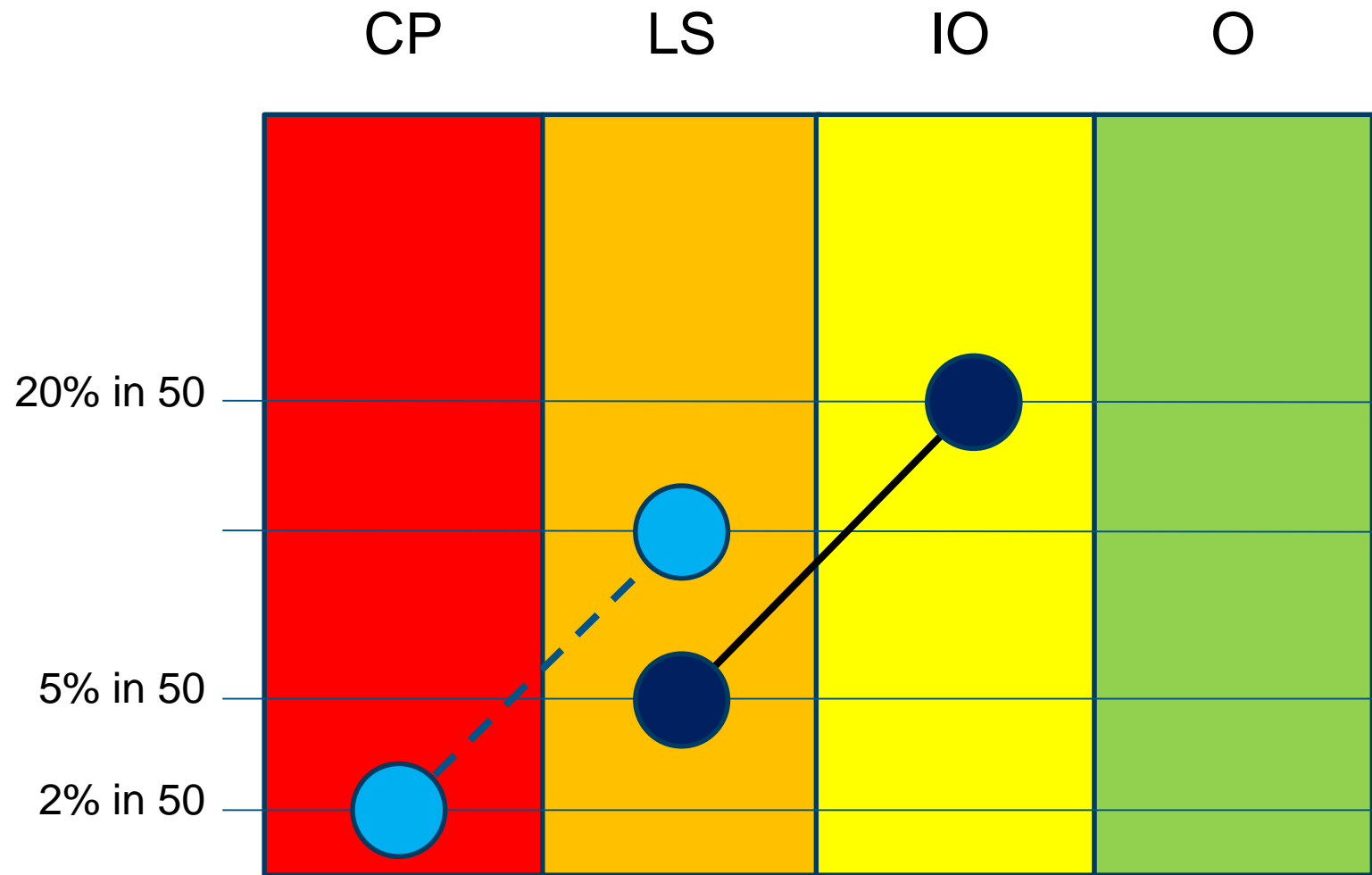
- Expected Damage

Collapse Prevention	Life Safety	Immediate Occupancy	Operational
Severe	Moderate	Light	Very Light

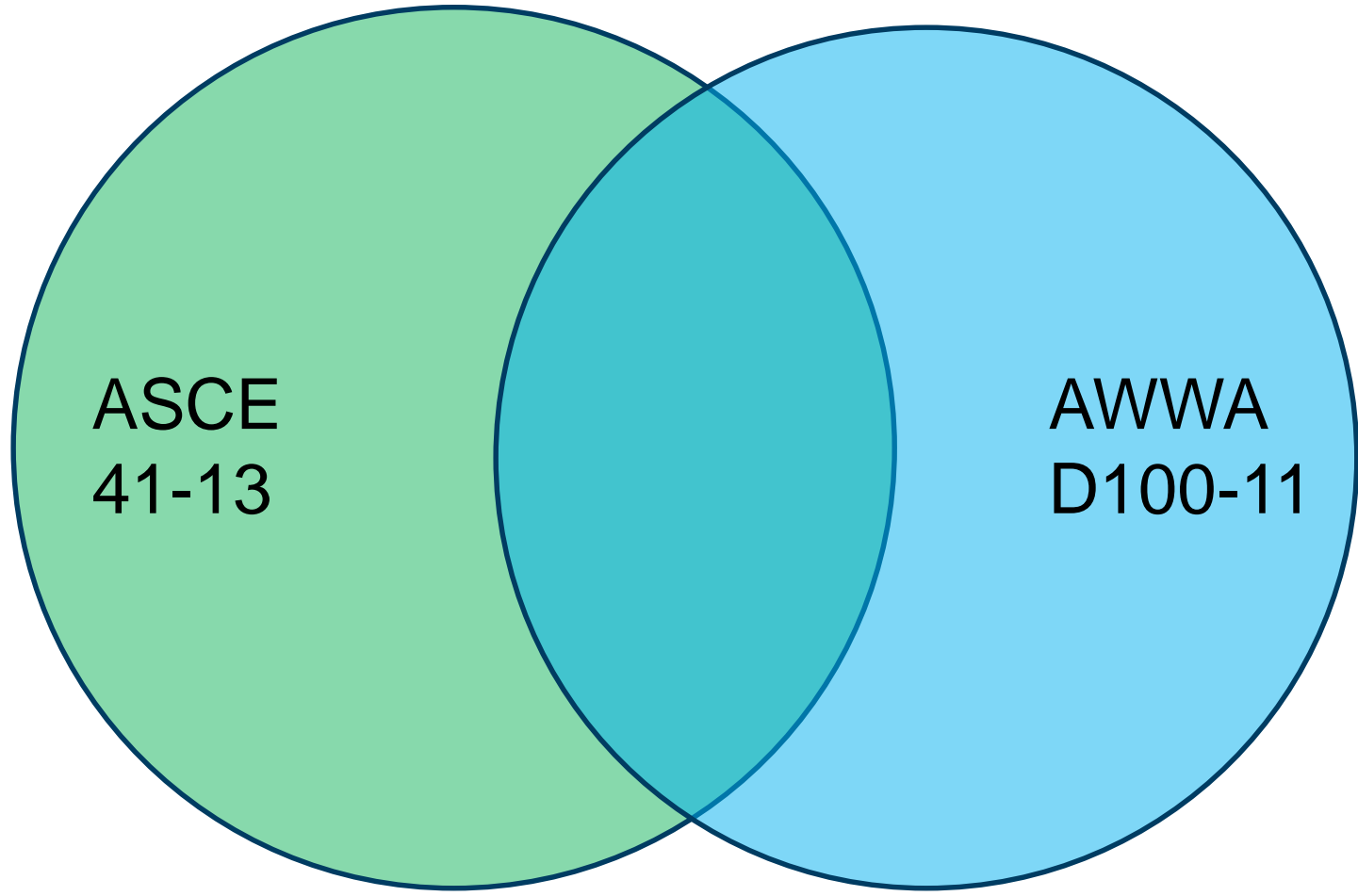
ASCE 41-13



# Performance Objectives



# >> Melding of Codes



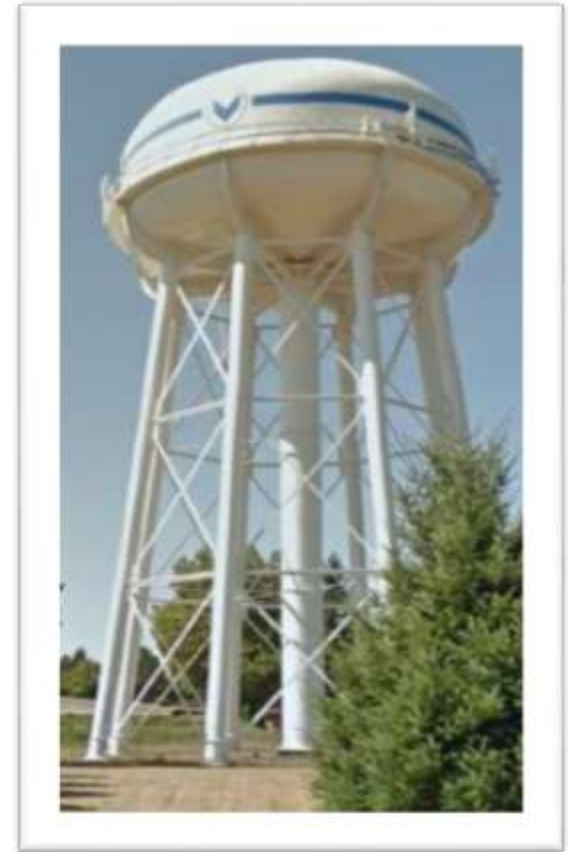
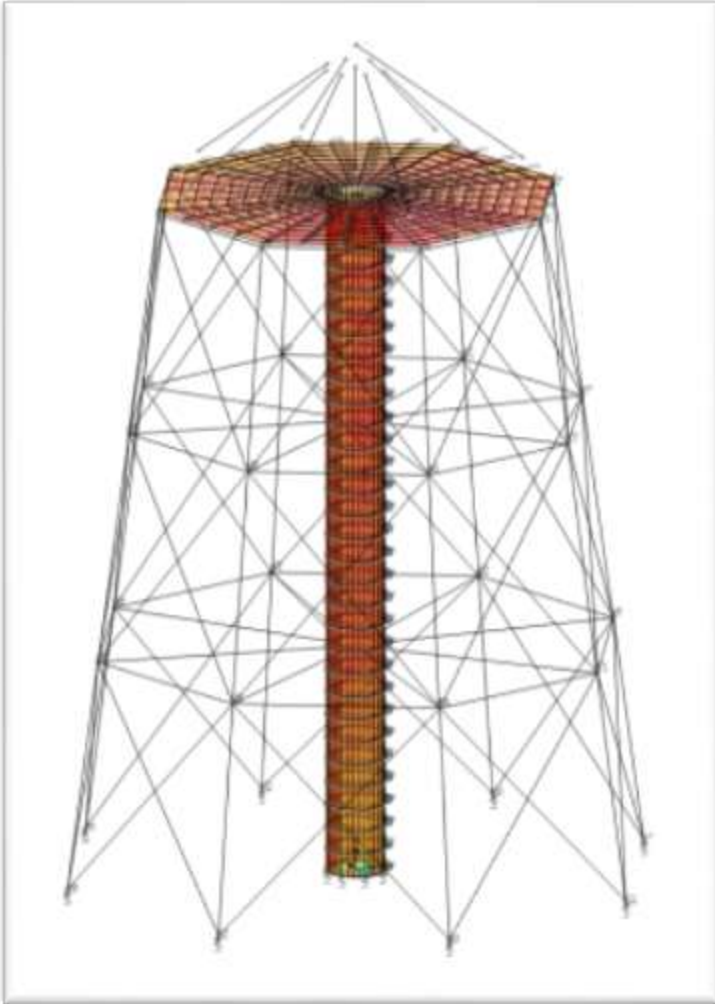
# >> Seismic Analysis



VS



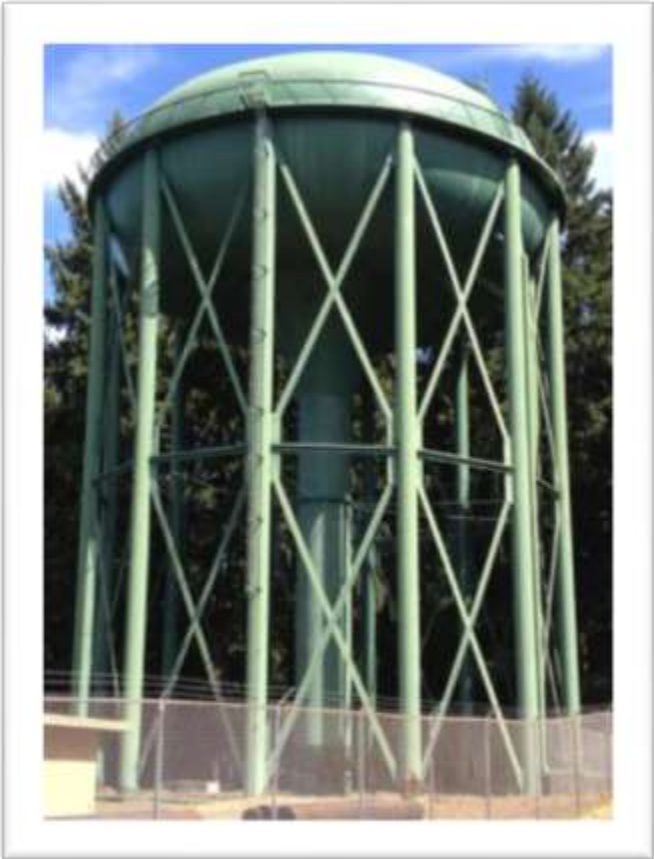
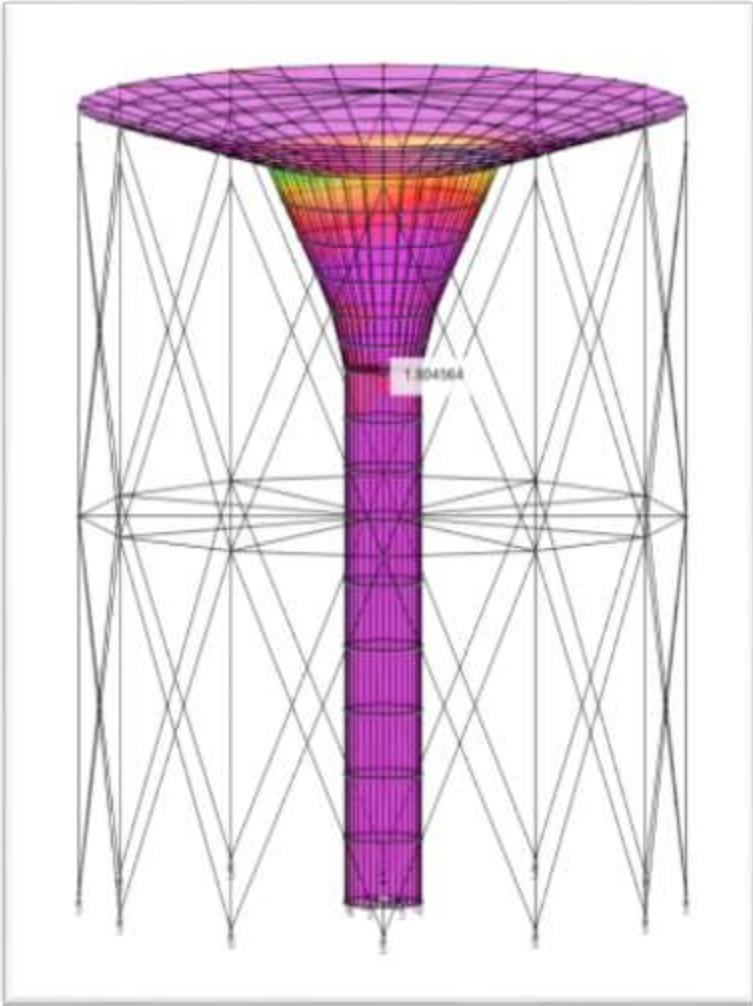
# >> Water Station 5



Seismic analysis results	
Fundamental Period:	1.79 sec
Deflection at top of columns (BSE_2E)	9.6 in.



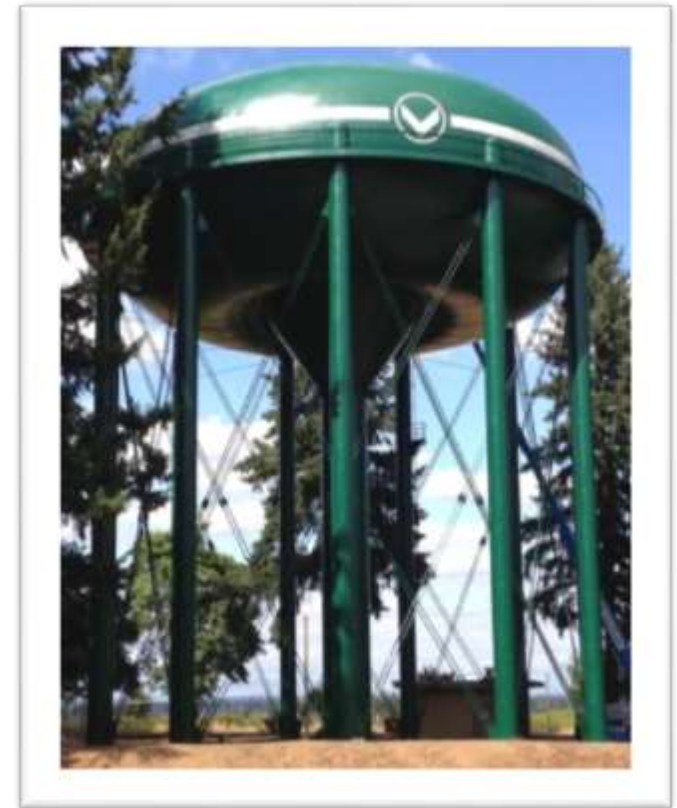
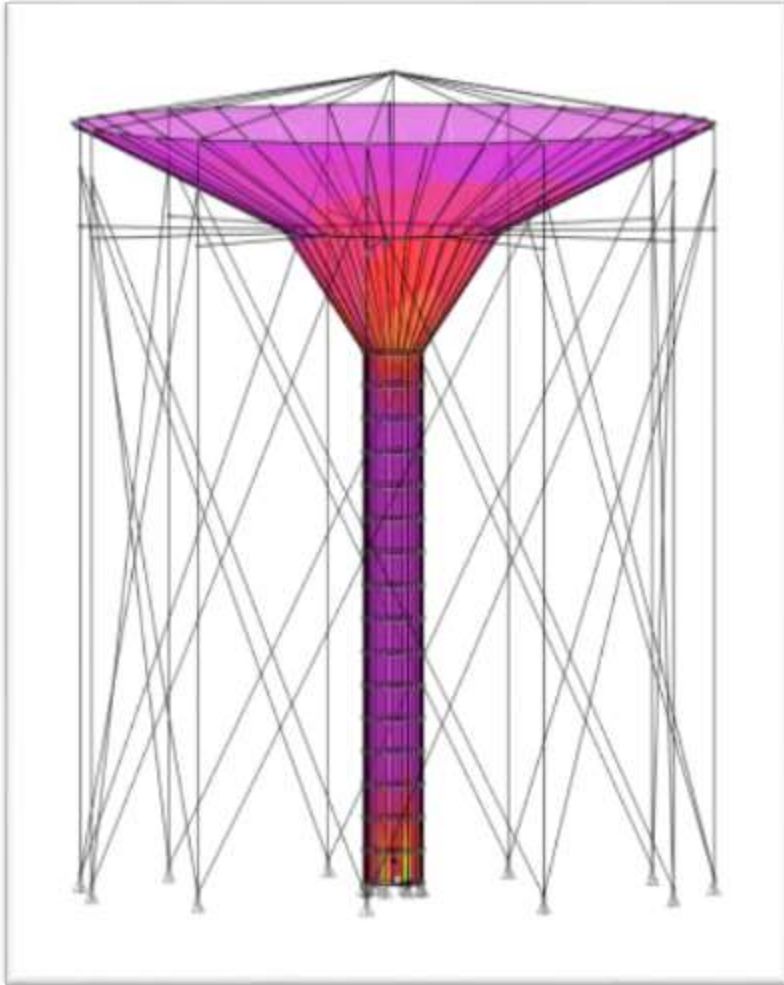
# Water Station 6



Seismic analysis results	
Fundamental Period:	1.96 sec
Deflection at top of columns (BSE_2E)	10.5 in.

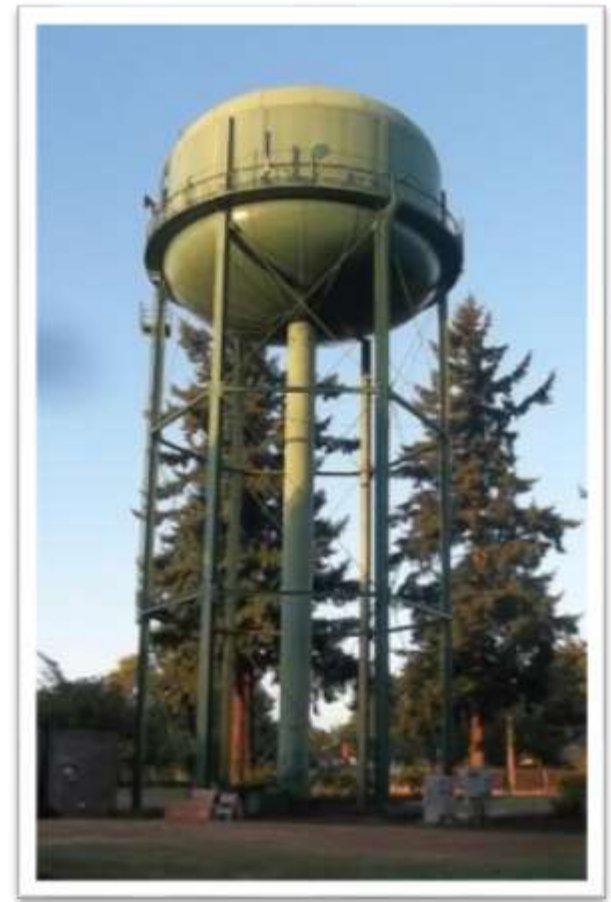
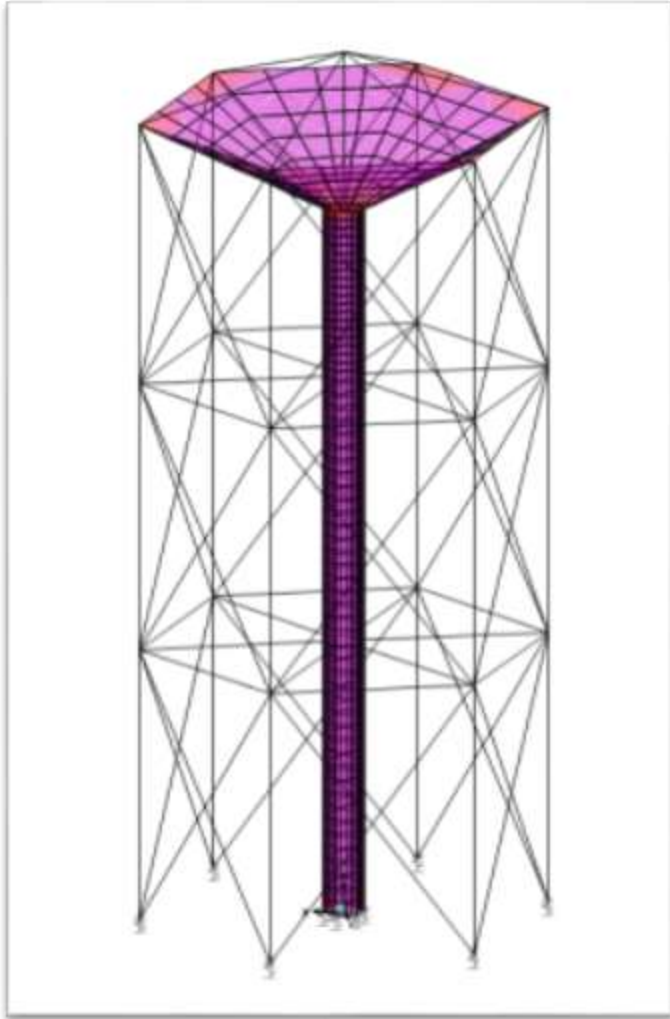


# >> Water Station 7



Seismic analysis results	
Fundamental Period:	1.76 sec
Deflection at top of columns (BSE_2E)	9.3 in.

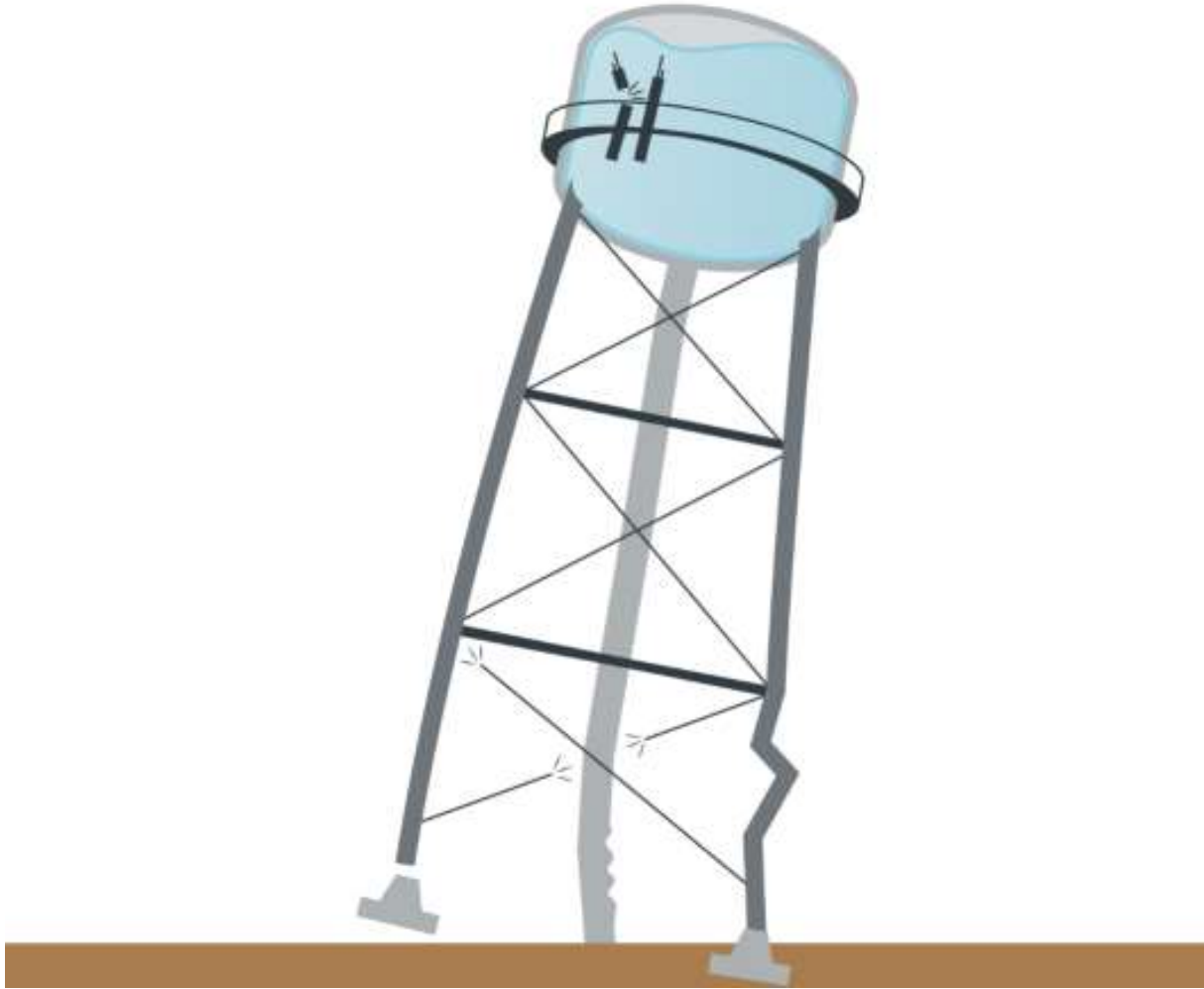
# >> Water Station 3



## Seismic analysis results

Fundamental Period:	3.33 sec
Deflection at top of columns (BSE_2E)	23.7 in.

# >> Preliminary Results



# >> Preliminary Results

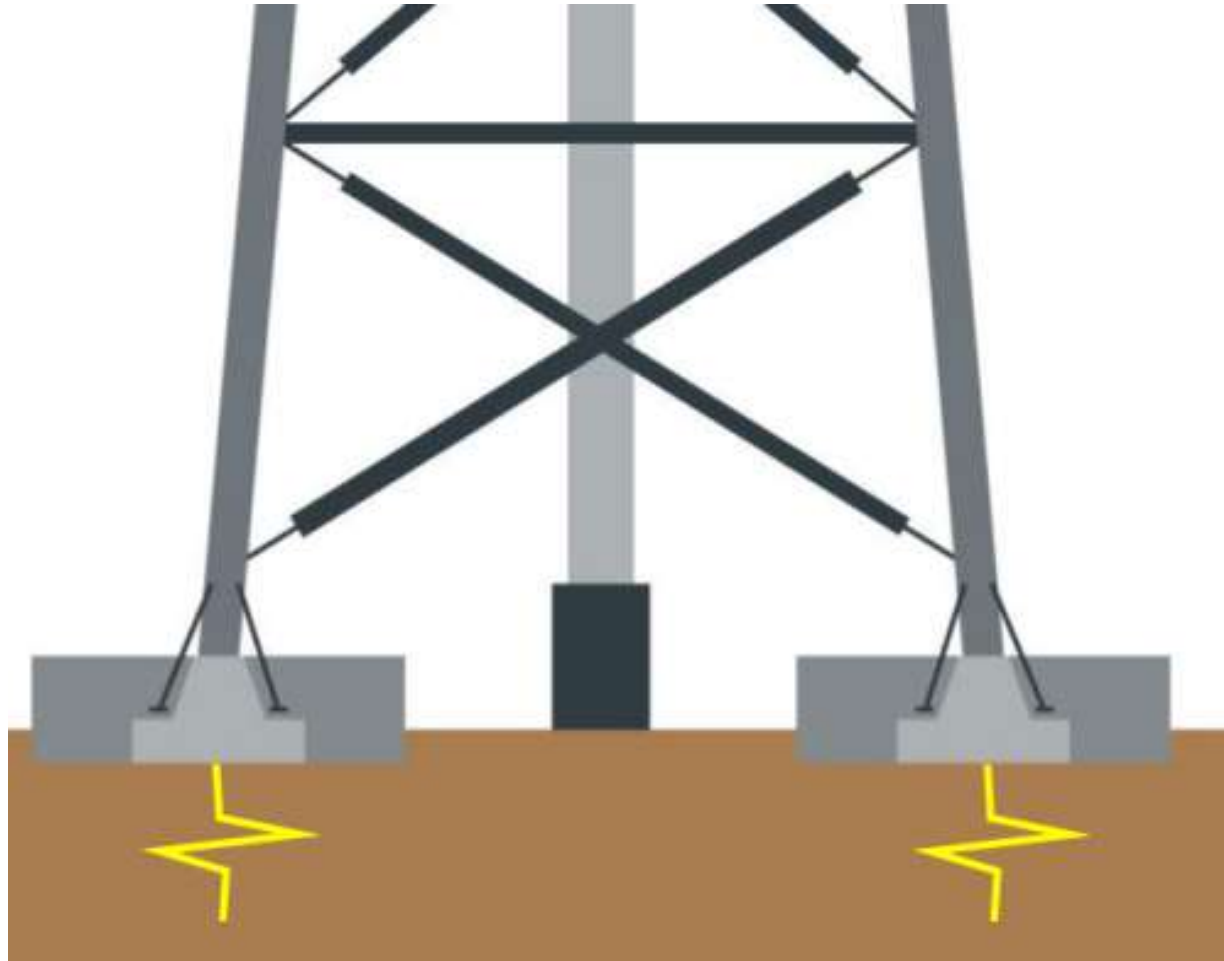
Initially high Demand/Capacity for many elements

Ways to Reduce Retrofit Costs:

- Change Performance Goals (+Risk)
  - Refine Assumptions (+Risk)
  - Refined Analysis (\$\$)
-

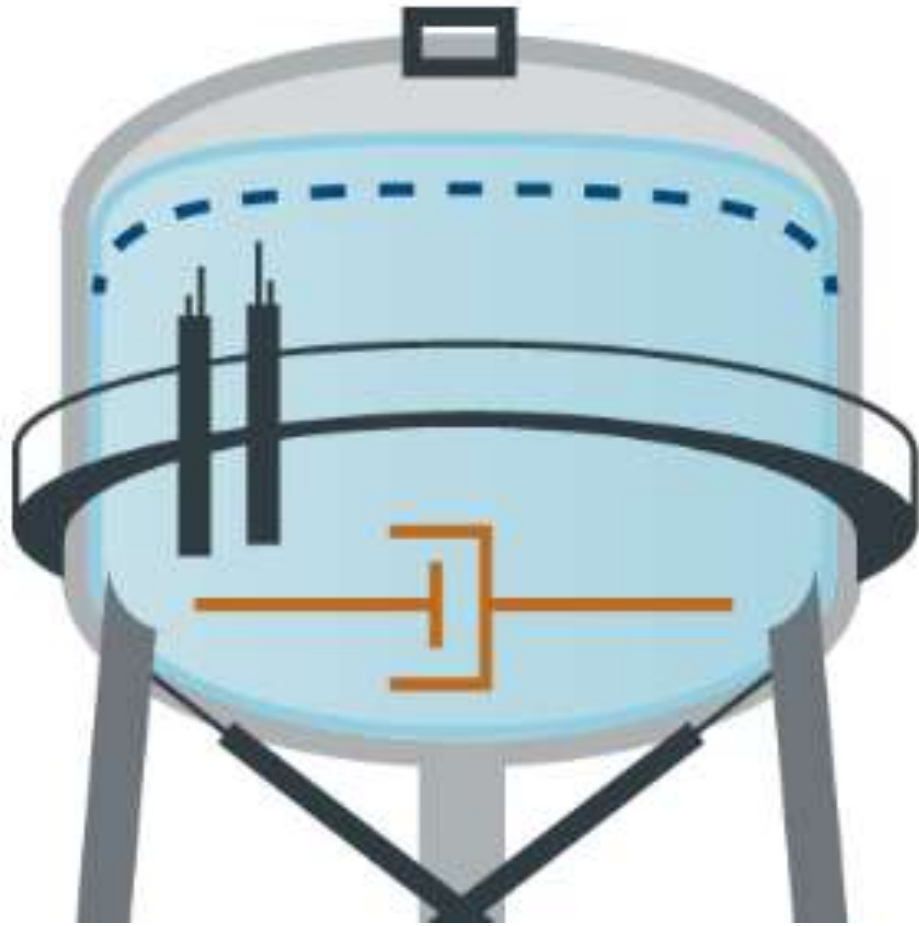


# Soil-Structure Interaction





# Structure-Fluid Interaction



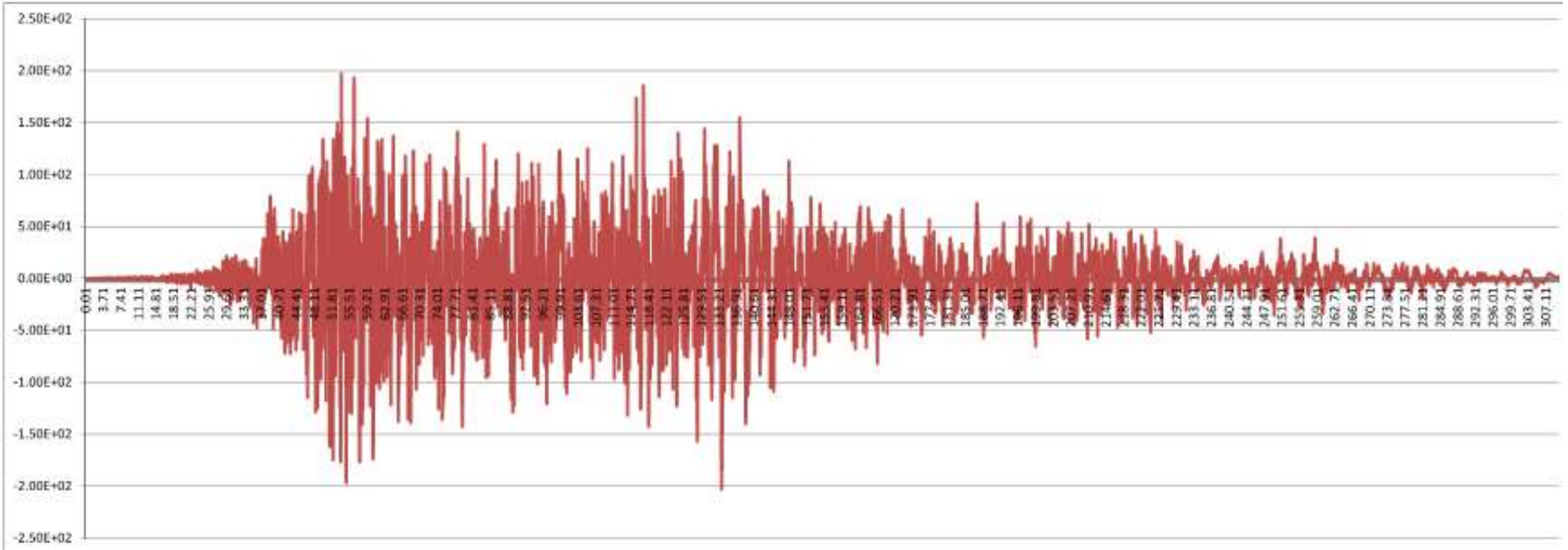
# >> Friction Dampers







# Time History Analysis



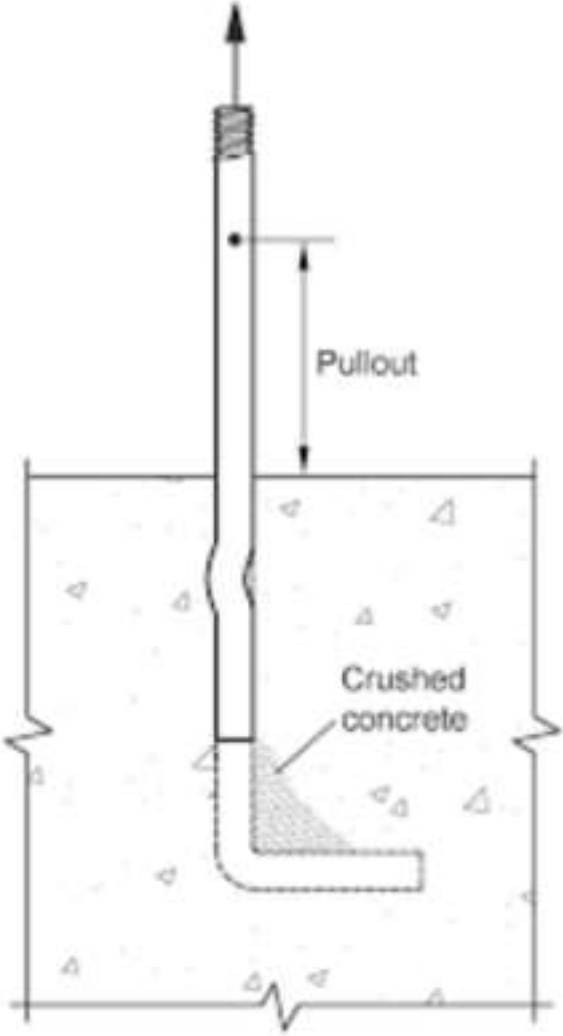
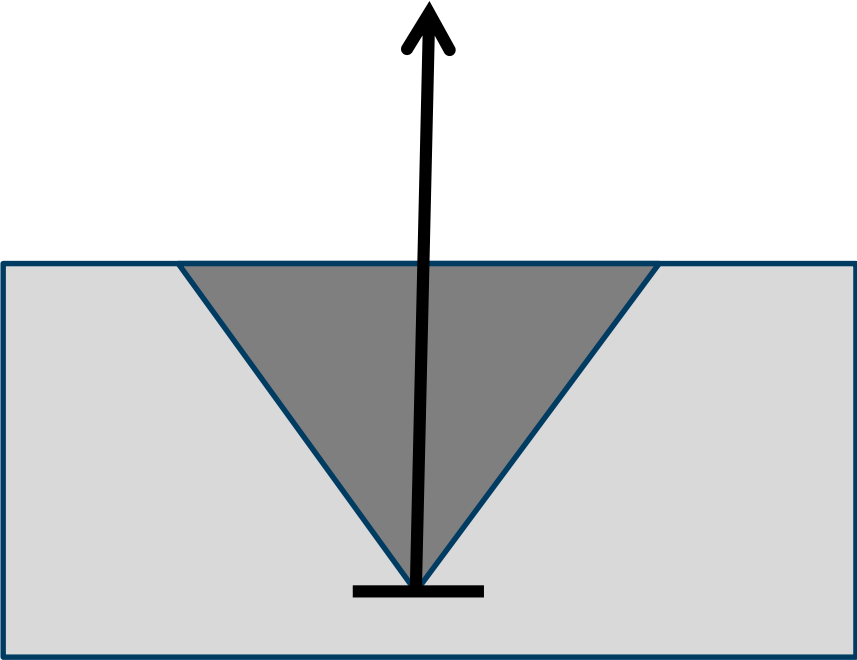


# Common Deficiencies

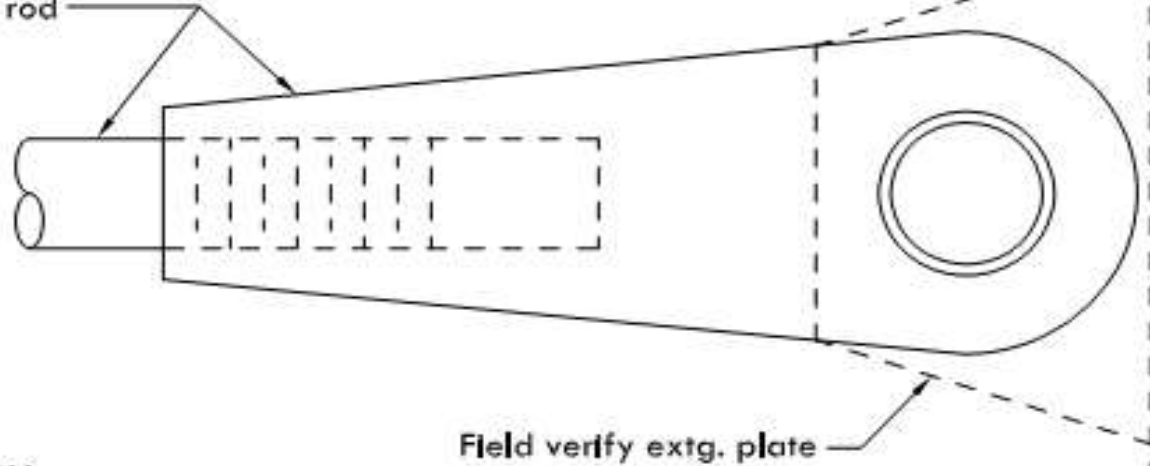
- Anchor Bolts
  - Bracing
  - Spider Rods
-



# Anchor Bolt Bearing



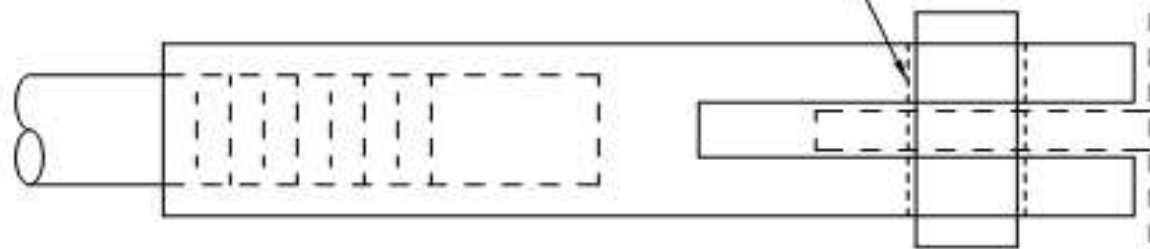
New #4 deivs  
and rod



**PLAN (12 ASSEMBLIES)**

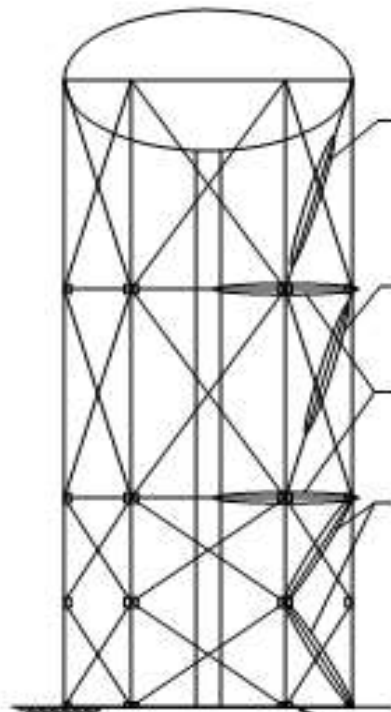
3"=1'-0"

Use existing hole, typ.



**ELEVATION**

3"=1'-0"



New 1.75" braces  
(12 places, this level)

New 1 5/8" braces  
(12 places, this level)

Spider Rods  
(12 places)

New 1 5/8" dia.  
braces and  
brackets  
(24 places, this  
level)

New conn. PLs, typ.

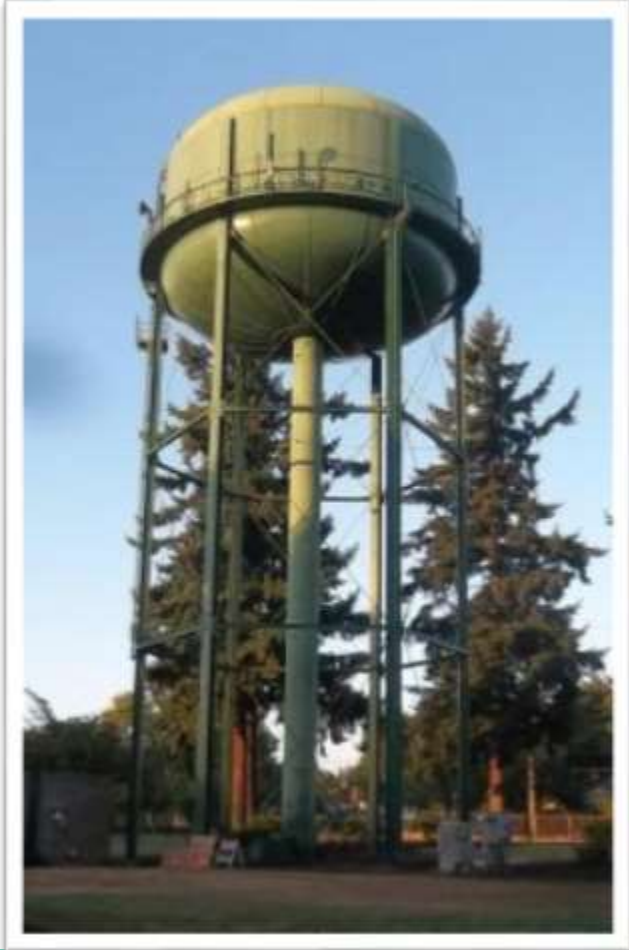
**TANK ELEVATION**

No Scale



# >> Results/Costs

## Water Station 3



### Retrofit Scope

- Replace Lower Bracing
- Replace Middle Bracing
- Replace Upper Bracing
- Replacing Spider Rods
- Add Column Anchor Bolts
- Increase Foundation Footing Size

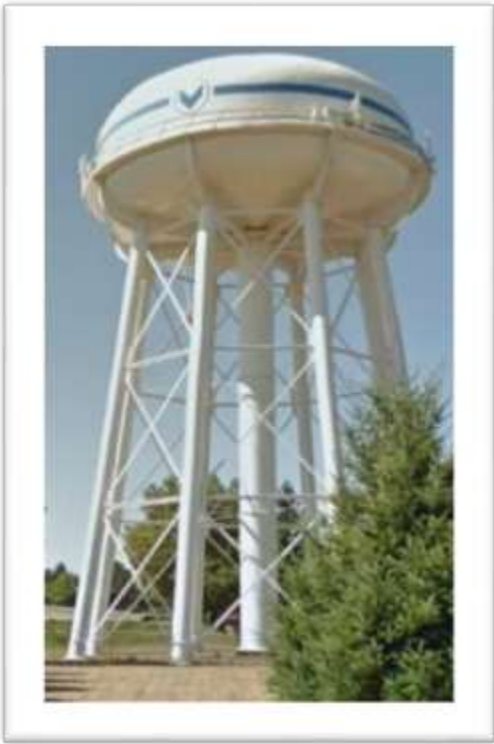
Construction Estimate = \$475k  
(Last Coated in 1990)



# Results/Costs

## Retrofit Scope

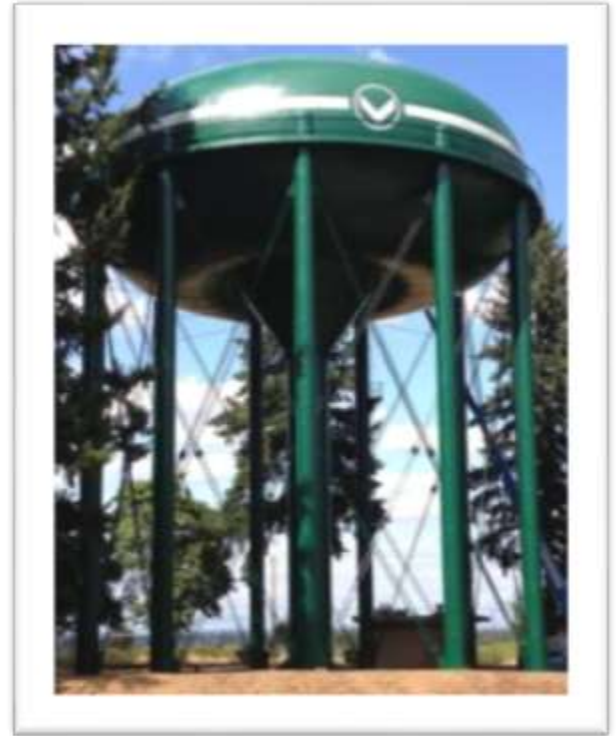
- Add Anchor Bolts
- Modify Foundations
- Replace Spider Rods



Cost Est: \$400k



\$660k



\$640k



## Q: What Does the Future Hold? A: Water

- Storage compromises largest budgeted item except piping with \$40 million.
- Deliver seismic upgrades for similar tower retrofits at Water Stations 5, 6, and 7.
- WS3 Tower & Reservoir will have demolition date defined with station planning process.
- Provide new “wheel” storage replacing seismically deficient 8MG at-grade reservoir at WS5.

