SEISMIC ANALYSIS OF VANCOUVER’S WATER TOWERS

Nick Robertson, PE, SE
OBEC Consulting Engineers
Water System Statistics

- 4th 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
Water service was never adequate. In the 20 years prior to 1933 ten complaints were lodged against the private owners and ten times the state department of public works investigated and ordered remedial action. Finally in 1933 the department itself initiated an action challenging the Oregon-Washington Water Service Company’s rates, charges, rules and regulations and proceeded to launch an investigation into the company’s rates and the adequacy of its service. Upon the findings of its engineers the department based an order placing the value of the company for rate-making purposes at $350,000 and commanding the company to adopt new, reduced rate schedules effective June 1, 1934.

Water service continued to be inadequate and on September 1, 1936 the city council notified the People’s Water and Gas Company (the then owners) of the city’s intention to purchase the system under terms of an option embodied in the franchise. The franchise provided for a board of appraisers, including two engineers hired by the city, two by the company and a fifth agreeable to all.

After an independent appraisal this board agreed upon a price of $610,000 for the system, which was accepted by the council. The city voted to issue $610,000 in water revenue bonds for purchase of the system and an additional $240,000 for improvements, replacements and extensions necessary to make the system usable.

On June 1, 1937 the purchase was consummated. Before the deal could be closed the roof on the old 1,000,000 gallon reservoir caved in. A couple of months later the old 100,000 gallon elevated wooden tank tower began to collapse.

Old wooden water tower collapses, making way for new steel tank.
Water Station 3 - 1945

115 ft  0.25 MG

Second oldest water station with three wells and an at-grade reservoir with booster station.

All facilities are being studied for replacement under planning project.

Chicago Bridge & Iron Co. Tank
Water Station 5 - 1955

129 ft  0.75 MG

Water station serves as conduit for water transfer from high yield wells to high demand pressure zones.

Tower serves the Heights High pressure zone with WSs 6&7 tanks.

On-site booster station pumps from 8MG at-grade reservoir to Pittsburgh-Des Moines Steel tank.

Site originally served ship building housing that boomed in 1940’s.
Water Station 6 - 1963
130 ft  1.0 MG

Pittsburgh-Des Moines Tower

Works with WSs 5&7 towers to serve highest demand and growing area.

Problematic exterior coatings

Tank located in close proximity to forested park area
Water Station 7 - 1968

115 ft  1.0 MG

Chicago Bridge & Iron Co. tank serves as the receiving point for most of the water produced for Heights High zone.

Operators use it to monitor storage status.

Similar site issues with large trees in close proximity to tank.
Step 1: Data Gathering

1. Material Properties
2. Member Types
3. Foundation Data
4. Original Design Criteria
Sources of Data

1. Shop Drawings
2. Soils Reports
3. Well Logs
4. Repair Drawings
5. Coatings Inspections
6. Original Design Codes/Standards
BILL OF MATERIAL

CAPACITY 250,000 GAL

STRUTS

(4") 10.2"

(1") 10.2"

(3") 15.3"

Wind 21,500" Wind 5,550"

Columns 14" W @ 103#
Area: 30.26"²; R: 3.72; ε = 92.5

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

Rods 14" Area: 1.2772#
Stress: 15,700#
Unit: 12,300%

Wind = 11,100#
Step 2: Filling in the Gaps

1. Geotechnical Investigations
2. Condition Assessment
3. Testing
Geotechnical Investigations
Condition Assessment

6 “S” Inspection

- Structural Condition
- Seismic Concerns
- Surface (Coatings)
- Safety
- Security
- Sanitation
Inspection Logistics
When all else fails…

ASS U ME
Seismic Background
CISN Rapid Instrumental Intensity Map for Loma Prieta Earthquake

Tue Oct 17, 1989 05:04:00 PM PDT  M 6.9  N37.04 W121.88  Depth: 18.0km  ID:LomaPrieta
Historic Performance

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

• Design for 2/3 of MCE
• Low Probability of Collapse (<10% for MCE)
• Apply Importance Factor for Essential Facilities
Retrofit of Buildings

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

- Expected Damage

<table>
<thead>
<tr>
<th>Collapse Prevention</th>
<th>Life Safety</th>
<th>Immediate Occupancy</th>
<th>Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>Moderate</td>
<td>Light</td>
<td>Very Light</td>
</tr>
</tbody>
</table>

ASCE 41-13
Risk Levels
Performance Objectives

- 20% in 50
- 5% in 50
- 2% in 50
Seismic Analysis
Melding of Codes

ASCE 41-13

AWWA D100-11
Water Station 5

<table>
<thead>
<tr>
<th>Seismic analysis results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Period:</td>
<td>1.79  sec</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_1E)</td>
<td>4.7   in.</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_2E)</td>
<td>9.6   in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_1E)</td>
<td>0.11  in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_2E)</td>
<td>0.31  in.</td>
</tr>
</tbody>
</table>
Water Station 6

Seismic analysis results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Period:</td>
<td>1.96 sec</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_1E)</td>
<td>5.2 in.</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_2E)</td>
<td>10.5 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_1E)</td>
<td>0.15 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_2E)</td>
<td>0.41 in.</td>
</tr>
</tbody>
</table>
Water Station 7

Seismic analysis results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Period:</td>
<td>1.76 sec</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_1E)</td>
<td>4.6 in.</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_2E)</td>
<td>9.3 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_1E)</td>
<td>0.14 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_2E)</td>
<td>0.39 in.</td>
</tr>
</tbody>
</table>


Water Station 3

Seismic analysis results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Period:</td>
<td>3.33 sec</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_1E)</td>
<td>11.2 in.</td>
</tr>
<tr>
<td>Deflection at top of columns (BSE_2E)</td>
<td>23.7 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_1E)</td>
<td>0.27 in.</td>
</tr>
<tr>
<td>Footing settlement (BSE_2E)</td>
<td>1.97 in.</td>
</tr>
</tbody>
</table>
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
4- A36 PL 1 1/4 x 21 x 3'-0"

2'-4" typ.

0'-8"

6'-0"

0'-1"

3'-10 1/2"

4'-6"

Oversized hole w/ 1/4 PL washer and nut, typ.

0'-2 1/2" typ.

O - 2 1/2" typ.

0'-5 1/2" typ.

4- 1 1/2" dla. ASTM F1554 Gr. 105 rods with #5 clevis ea. end

ASTM A563DH sleeve nut

Roughen surfaces, typ.

CLP (4000 psl) foundation enlargement

#5 @ 6"

#5 @ 1'-0" epox. into footing, embec

2- 1 1/2" dla. F1554 Gr. 55 rods with nut and 3/4 x 6 x 0'-6" plates

PL 1 1/4 x 20 x 4'-6" with 2- 1" x 1 1/4" shear lugs and 1 1/4 x 20 x 1'-0" clevis plates (2 places)
New #4 clevis and rod

Field verify extg. plate

PLAN (12 ASSEMBLIES)

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)

Use existing hole, typ.

TANK ELEVATION

No Scale

ELEVATION

3"=1'-0"
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

Water Station 5

**Retrofit Scope**
- Add Column Anchor Bolts
- Modify Foundations

Construction Estimate = $400k
Results/Costs

Water Station 6

Retrofit Scope
- Add Column Anchor Bolts
- Add Riser Column Anchor Bolts
- Modify Foundations
- Replace Spider Rods

Construction Estimate = $660k
(Last Coated in 1993)
Results/Costs

Water Station 7

**Retrofit Scope**
- Add Column Anchor Bolts
- Add Riser Column Anchor Bolts
- Modify Foundations
- Replace Spider Rods

Construction Estimate = $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.