Raising The Roof

An Unconventional Approach to Reducing Seismic Demand

Covington Water District Tank 2B

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We Are Going to Talk About…

- Seismic overload caused by insufficient freeboard* and how it impacted a 4.0 MG welded steel tank constructed in 1980

- Evaluation of alternative solutions

- Construction – raising the roof!

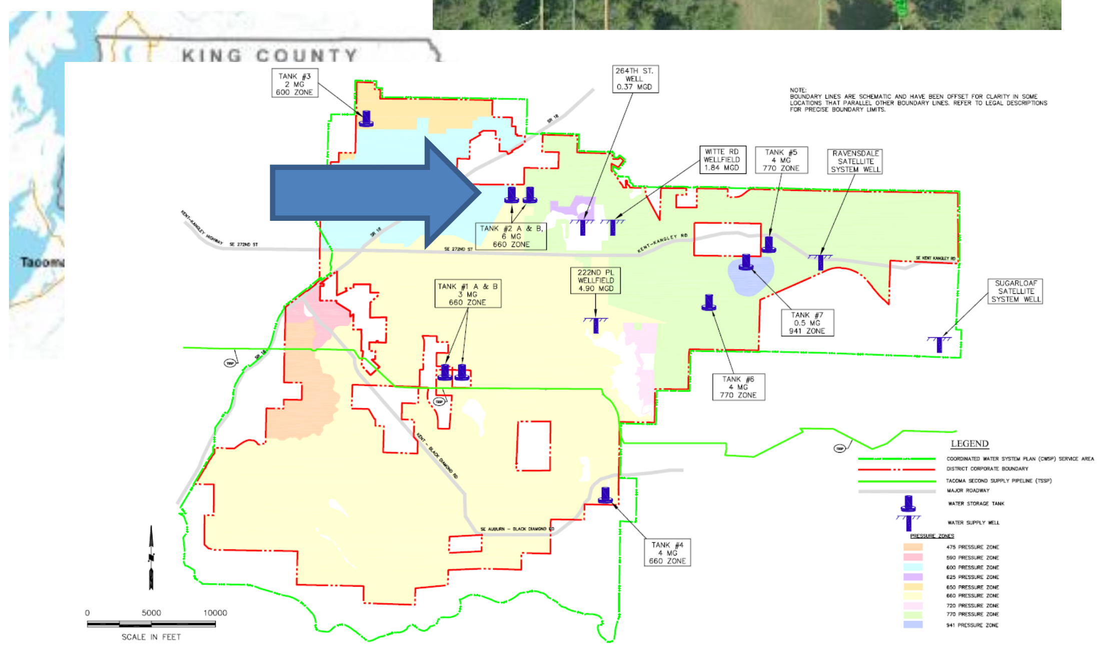
*(Freeboard is the minimum distance between the top of the water surface and the top of the tank shell)

Seismic Overload Issues

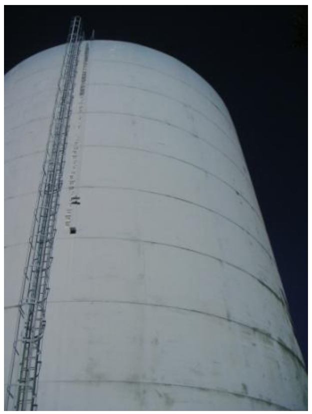
- Details of original 1980 construction
- Changes in design codes and assumptions since 1980
- Analysis results and issues identified

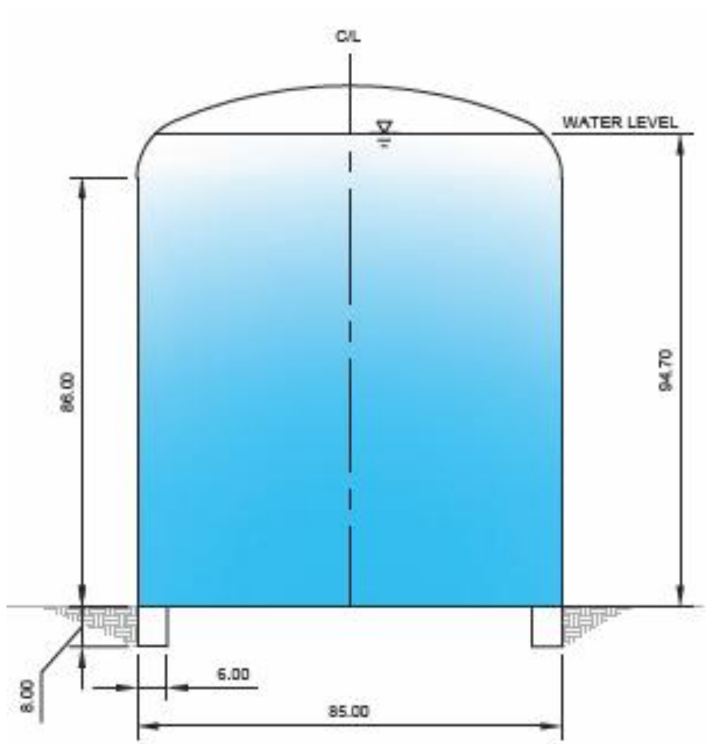
Location And Site

Tank 2B – 4.0 MG



Tank 2B Prior to Retrofit





Tank Data	
Capacity	4.0 MG
Diameter	84'-9"
Sidewall Height	86 ft
Total Height	104.38 ft
Water Depth	94.37 ft
Structure Weight	696 kips (roof 82 kips)
Water Weight	33,215 kip
Anchors	90 each @ 3 inch dia.

I kip = 1000 lbs

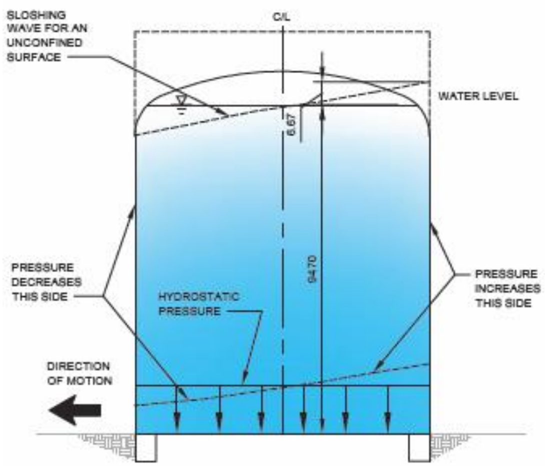
Design Codes Then and Now

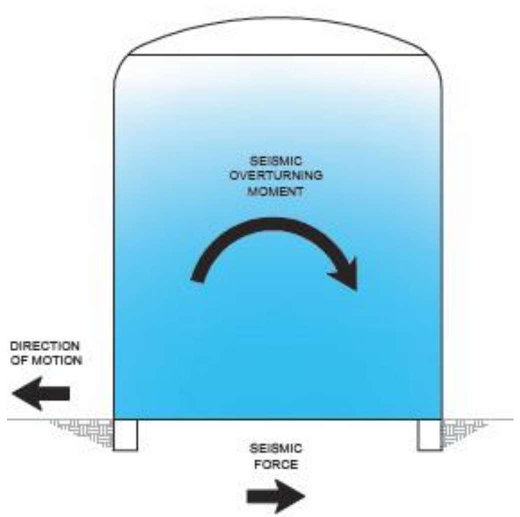
	1980	2010
Building Code	1979 UBC	2009 IBC
AWWA D100 Standard	1979	2005
Basic ground motion assumptions	Seismic Zone 3 Z = .75	Spectral accelerations. S_S = 1.212g, S_1 = .407g
Adjustment for soil type	1.2	1.0 for S_S, 1.37 for S_1
Importance factor	1.0 or 1.5 optional with purchaser	1.5
Required freeboard	Specified by purchaser	Mandated by code*

*Added to AWWA D100 in 1996

The methodology for computing seismic design loads for tanks changed significantly in the 1997 UBC after this tank was built, including formulas not mentioned above

General Seismic Behavior of Tanks





- Lateral motion of the ground induces pressure increases and decreases on a tank that result in unbalanced loads that have to be resisted
- Vertical motion of the ground increases or decreases water pressure on the tank walls and floors, and in this case the roof
- Standard design methodology assumes no contact of the water surface with the roof

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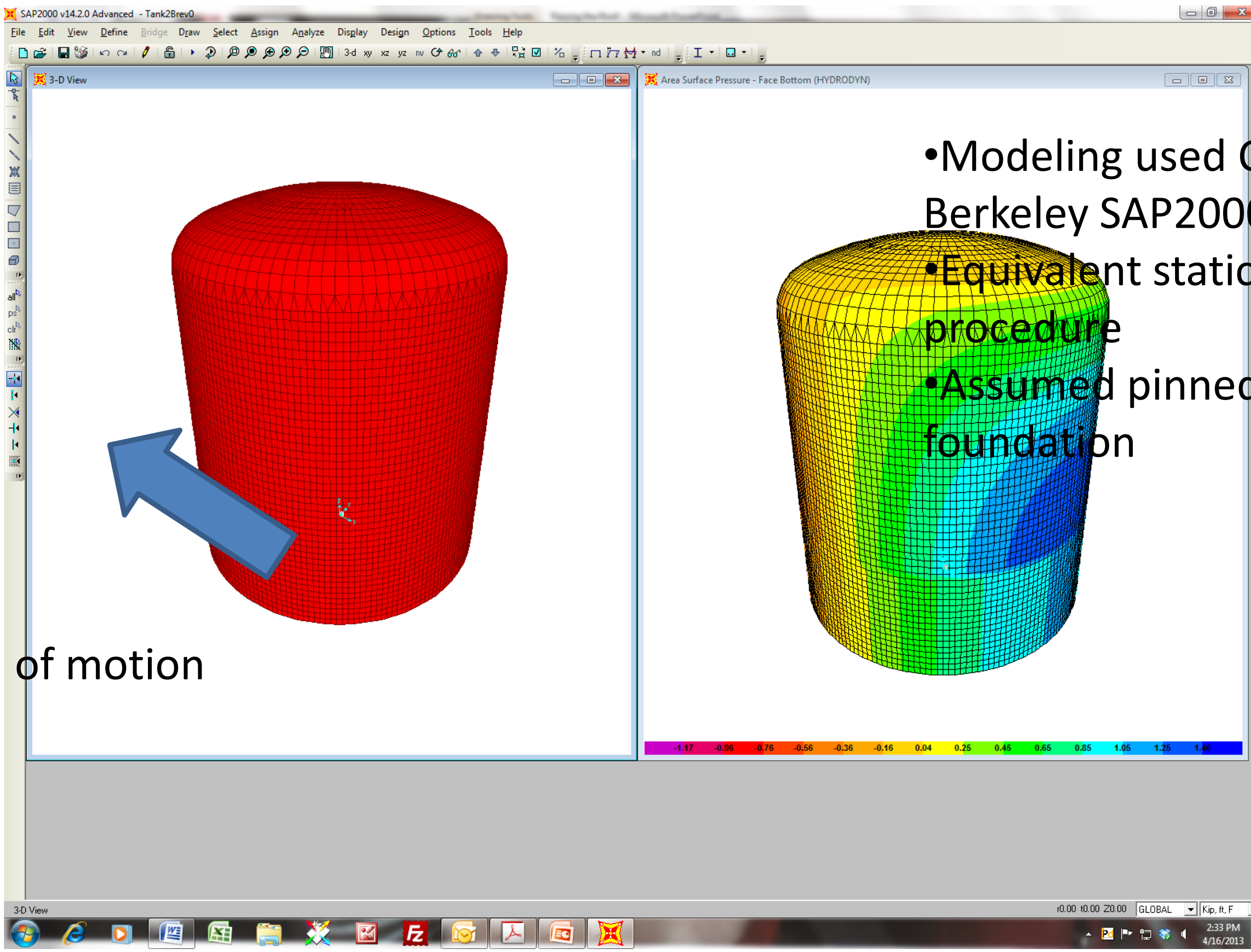
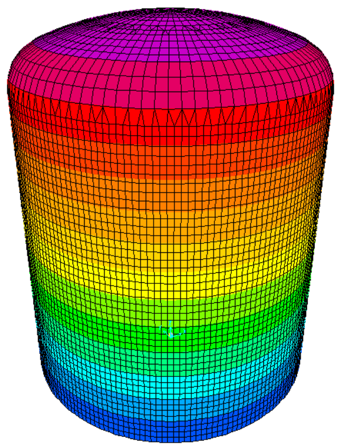
Finite Element Model



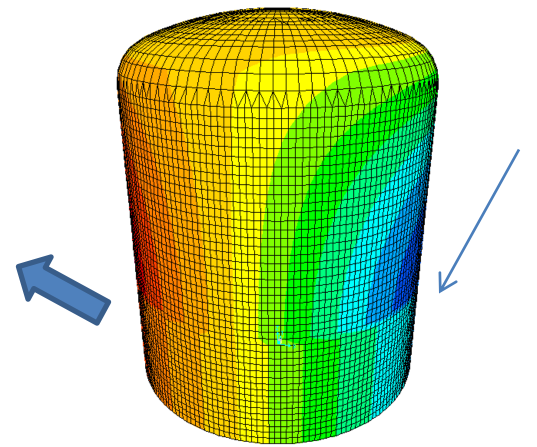
- Modeling used CSI Berkeley SAP2000 software
- Equivalent static force procedure
- Assumed pinned at foundation

Direction of motion

Static and Dynamic Pressure



Static Water Pressure



Pressure increases this side (toe), decreases opposite side (heel)

Hydrodynamic Pressure Increment

Results of Analysis of Existing Tank

	Allowable Limit	Results if no roof contact assumed	Results including roof contact effects
Dynamic longitudinal stress ratio	≤ 1.33	**1.24**	**1.47**
Base shear		7,894 kips	10,482 kips (+32.8%)
Overturning moment		311,030 ft-kips	389,132 ft-kips (+25.1%)
Safety Factor Against Ringwall Uplift	≥ 1.23	**.76**	**.61**
Safety Factor Against Foundation Tipping	≥ 1.23	**1.49**	**1.19**
Maximum anchor bolt stress	≤ 28.8 ksi	**26.94 ksi**	**33.7 ksi**

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Conclusions

- Bolts overstressed
- Shell subject to buckling
- Foundation hold-down capacity too low (overturning risk)

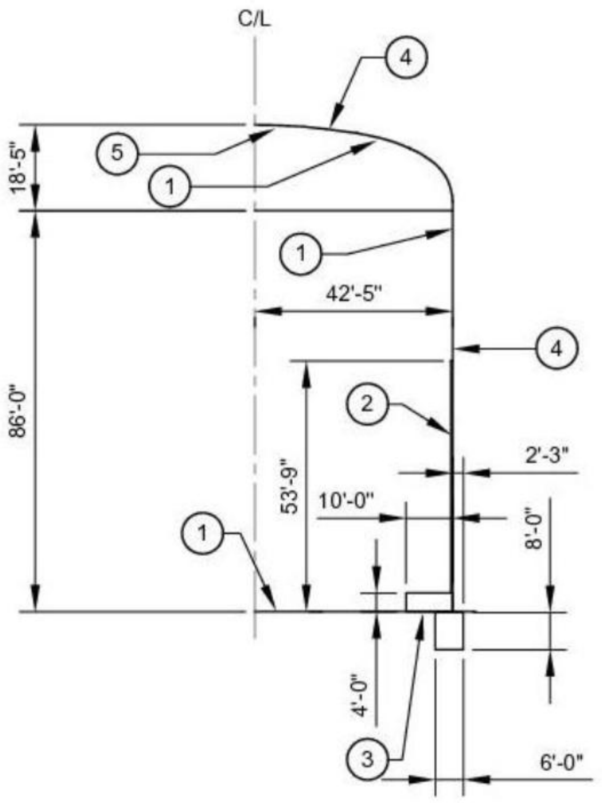
Alternative Solutions

- Alternative 1 - Strengthen the tank to resist the predicted seismic loads
- Alternative 2 - Raise the roof to reduce the seismic loads and reduce the strengthening cost

Note:
Reducing the water level to decrease seismic loading was considered but rejected as an option due to system hydraulic requirements

Note: Improvements to appurtenances, access, yard piping and grading and other items common to Concepts #1 and #2 are not shown.

Alternative 1 - No Load Reduction



Item	Description
1	Completely remove and dispose of all interior coatings inside tank by abrasive blasting to white metal finish, followed by two coats of NSF-61 approved 2-component epoxy to a total dry film thickness (DFT) of 8-14 mils. Selective patching of corroded floor plate areas. Removal and recoat not required where surface will be covered by new interior footing.
2	Install 62 each WT x 6" vertical stiffeners, equally spaced, web double fillet welded.
3	Construct an interior concrete footing, 4 feet high x 10 ft radial distance. Assume .75" x 4" Nelson studs at shell, say 356 total. Provide .25" liner plate on top and exposed face. Assume 4000 psi concrete, 435 CY. Assume rebar at 146 lbs CY, including lap.
4	Recoat existing exterior surfaces. Grind down all weld damaged surfaces and prep to near white metal surface followed by inorganic zinc primer. If selective prep is more expensive than tenting the tank and taking the entire tank down to bare metal, then use cheaper option. Provide epoxy tiecoat and polyurethane topcoat to approx 10 mils total DFT.
5	Seal weld existing roof stiffeners and painters rails. Estimate total length of weld at 2424 feet (double sided welds counted as 2ft/lf of joint).

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Alternative 1 - Pros and Cons

<u>Pros</u>

- Minimum construction laydown area required
- No height change required, fewer permit considerations
- Less construction risk

<u>Cons</u>

- Most Expensive Option
- Larger foundation ring addition required
- Shell stiffeners required
- No improvement in roof survivability

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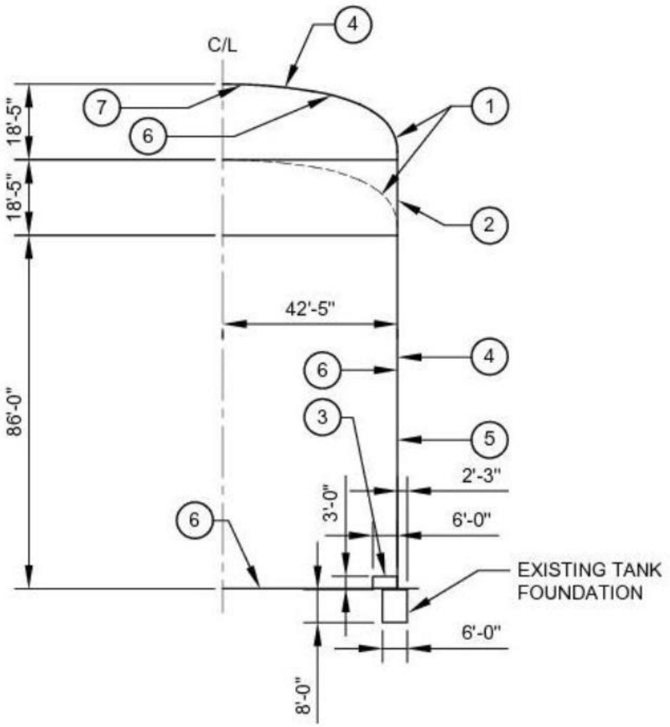
Alternative 2 – Raise The Roof



Item	Description
1	Add rigging elements as required, prepare laydown area, cut off and remove existing dome. Reinstall dome after shell height has been increased. If laydown and salvage are more expensive than dome demolition and reconstruction, then use the cheaper option.
2	Add 15 feet of new .325” steel shell at top of existing shell. ASTM A131/A or other AWWA Class 1 material. Interior side, prep metal by abrasive blasting to white metal finish, followed by two coats of NSF-61 approved 2-componenet epoxy to a total dry finish thickness (DTF) of 8-14 mils. Exterior side prep metal by abrasive sand blasting to near white metal finish, followed by a three coat coating system. Prime coat inorganic Zinc; intermediate coat 2-components epoxy; top coat polyurethane. Total 10-16 mils DFT.
3	Construct an interior concrete footing, 3 ft high x 6 ft radial distance. Assume .75” x 4” Nelson studs at shell, say 356 total. Provide .25” liner plate on top and exposed face. Assume 4,000 psi concrete, 165 CY. Assume rebar at 185 lbs/CY, including lap. Coat exposed surfaces on liner plate as described in Item 2 above for interior shell plate.
4	Recoat existing exterior surfaces. Grind down all weld damaged surfaces and prep to near white metal surface. If selective prep is more expensive than tenting the tank and taking the entire tank down to bare metal, then use the cheaper option. Prep existing coatings to remain per tiecoat manufacturer’s specifications. Provide epoxy tiecoat and polyurethane topcoat to approx 10 mils total DFT.
5	Add 15 ft of exterior painted steel caged ladder. Install 15 feet on interior stainless steel caged ladder. Add 15 feet on 8” vertical drop pipe for overflow.
6	Completely remove and dispose of all interior coatings inside tank to white metal finish. Selective patching of corroded floor plate areas. Interior coating system same as described in Item 2 above. Removal and recoat not required in areas that will be covered by new concrete inside footing.
7	Seal weld existing roof stiffeners and painters rails. Estimate total length of weld at 2424 feet (double sided welds counted as 2 ft/lf of joint).

Alternative 2 – Pros and Cons

Pros

- Estimated construction cost saving $552,000. Faster schedule
- Roof seal welds, painting and appurtenances can be done on the ground
- Roof survability improved, no superstructure strengthening required

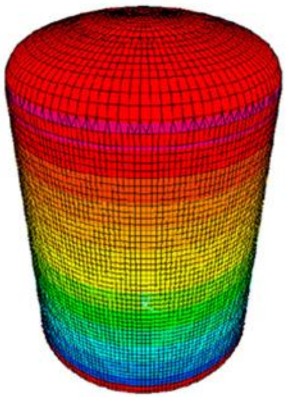
Cons

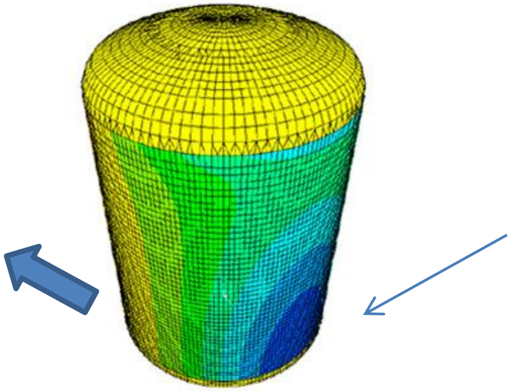
- Construction riskier – more weather dependent
- More laydown area required, more site congestion
- Possible objections to increased height

Final Project Scope

- Alternative 2 – roof raising – foundation changes
- Complete coating removal and replacement, inside and out
- New roof improvements, railing, stairs, access, vents
- Site grading, drainage and electrical improvements
- Yard piping improvements
- New controls and telemetyry
- Security improvements
- Tank 2A demolition

Static and Dynamic Pressure
"Final Raised Roof Analysis"





Localized pressure increase

Static Water Pressure

Hydrodynamic Pressure Increment

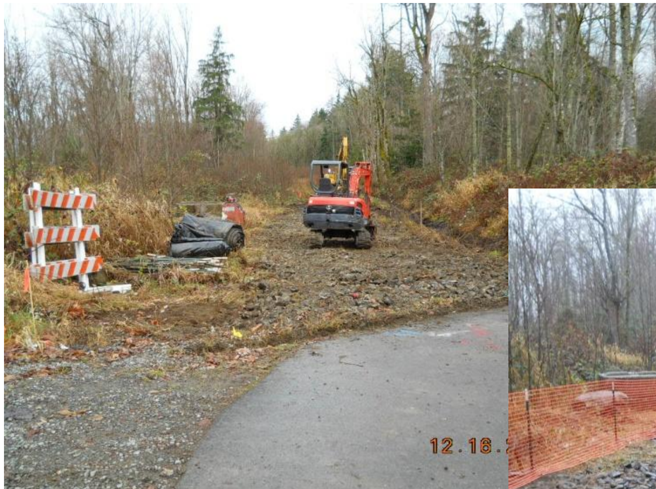
Construction

Contract Information

- Contractor: T. Bailey, Inc., Anacortes
- Bids Received: 3
- Contract Amount: $2.79 Million
- Engineers Est.: $2.55 Million
- Original Completion Date: Sep 12, 2012
- Change Orders: $102,150 (4.0%)

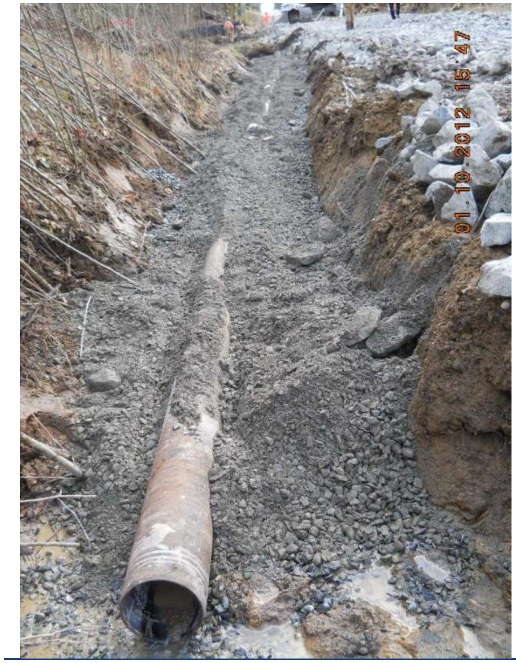
Move In – Access Construction

Temporary Road Access Construction, Clearing and Erosion & Sediment Control



Preliminaries

Drain Tank 2B and
Insert Bypass Spool in
12 Inch Supply Line



Construct Temporary Drainage

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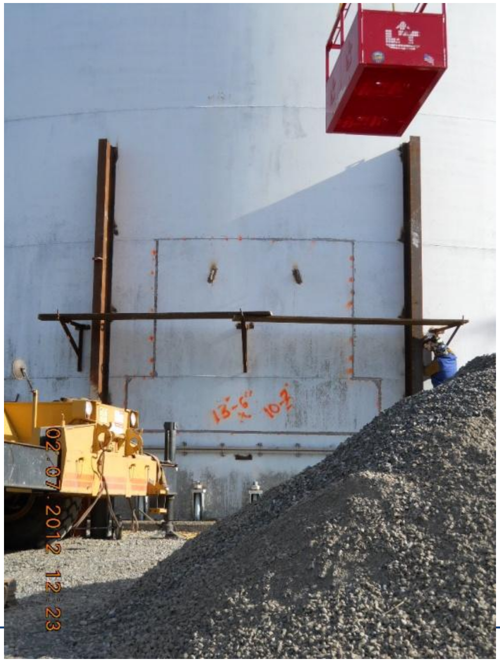
Remove Door Sheet



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Drain Interior – Roof Scaffolding

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Getting Ready to Raise the Roof

Stage 100 Ton Crane

Cut Roof Dome
Free of Shell

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Lift Off

Setting the Dome Down

Structural Work

Weld headed studs to shell

Mark new openings. Drill holes for dowels into existing ringwall

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Foundation Ring

Shell Extension – First Course

Under The Dome – Seal Welding and Painting

Dome Retrofit & Ready To Rig

Lifting lugs and cable slings

Preparing For the Lift

Two shell courses and scaffolding in place for lift

Attaching rigging slings to crane

Beginning of the Pick

Positioning the Roof

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Finishing the Job

Roof in Place – Ready to Weld

Tank Painted – Back in Service

Key Milestones

Jan 2010	Condition Assessment NTP
Aug 2010	Design NTP
Aug 2011	Advertise for Bids
Sep 2011	Bids Opened
Oct 2011	Construction NTP
Nov 2011	Start Construction
Jan 2012	Tank 2B Taken Offline and Drained
Feb 2012	Tank 2B Roof Removed
May 2012	Tank Shell Raised, Dome Painting
Jan 2013	Tank Refilled & Returned to Service