

May 7, 2014



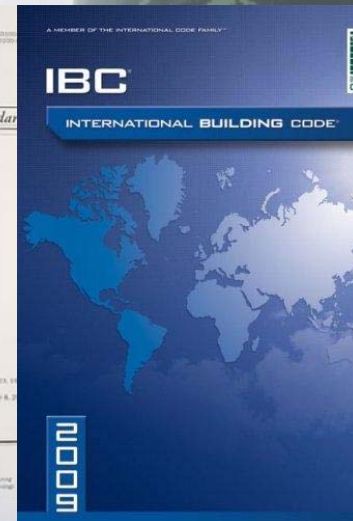
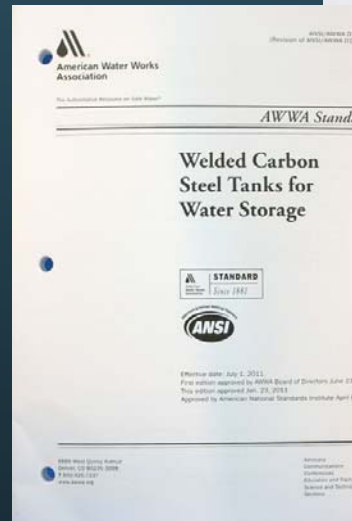
# SEISMIC RETROFIT OF STEEL RESERVOIRS

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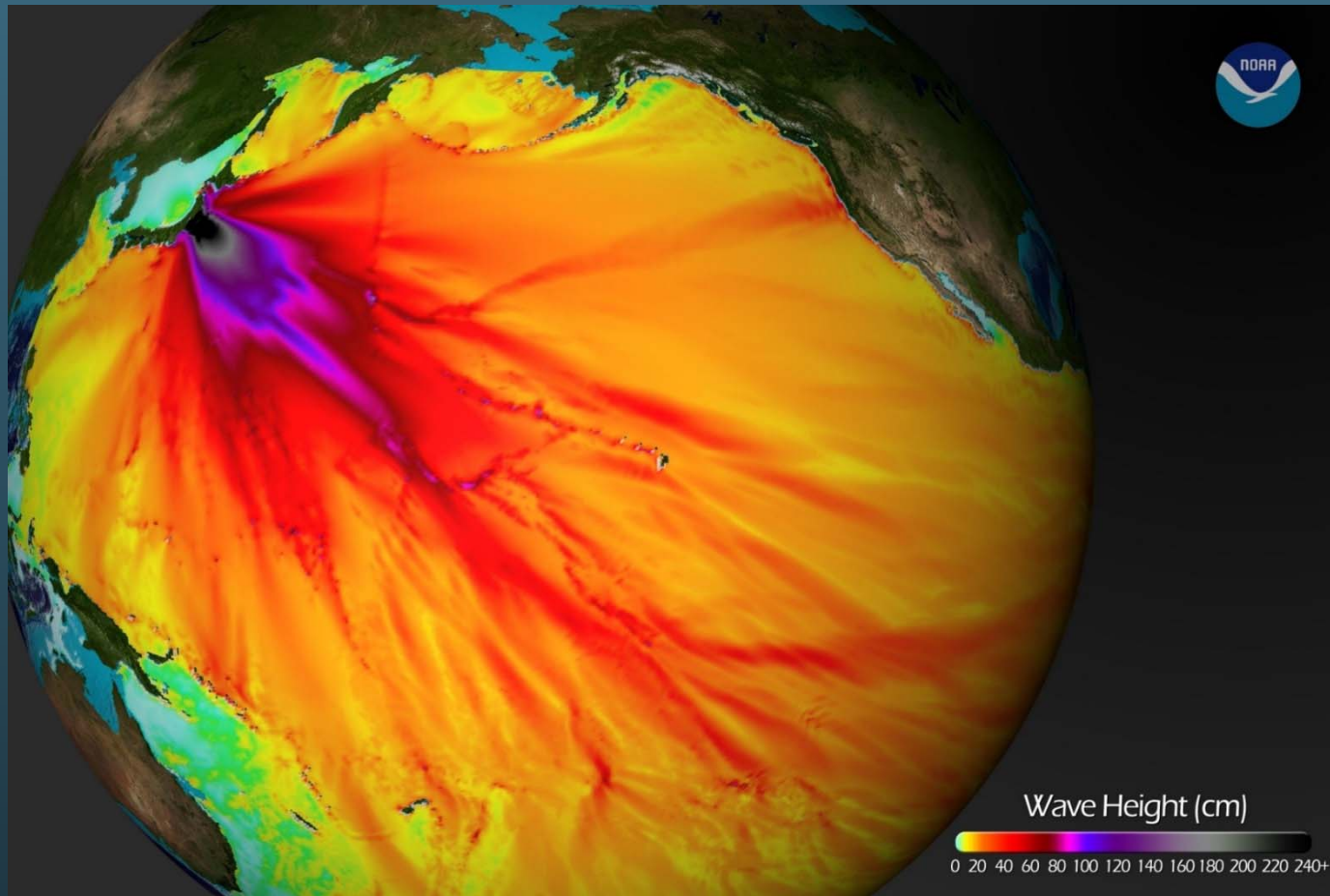
Presented by Jon Conner, P.E., S.E.  
RH2 Engineering

# SEISMIC RETROFITS

- Changes in design forces
- Ground motions
- Structural design
- Damage/failure modes
- Retrofit examples
- Detailing



# WHAT'S AT RISK?



Japan 2011: 9.0 Magnitude EQ

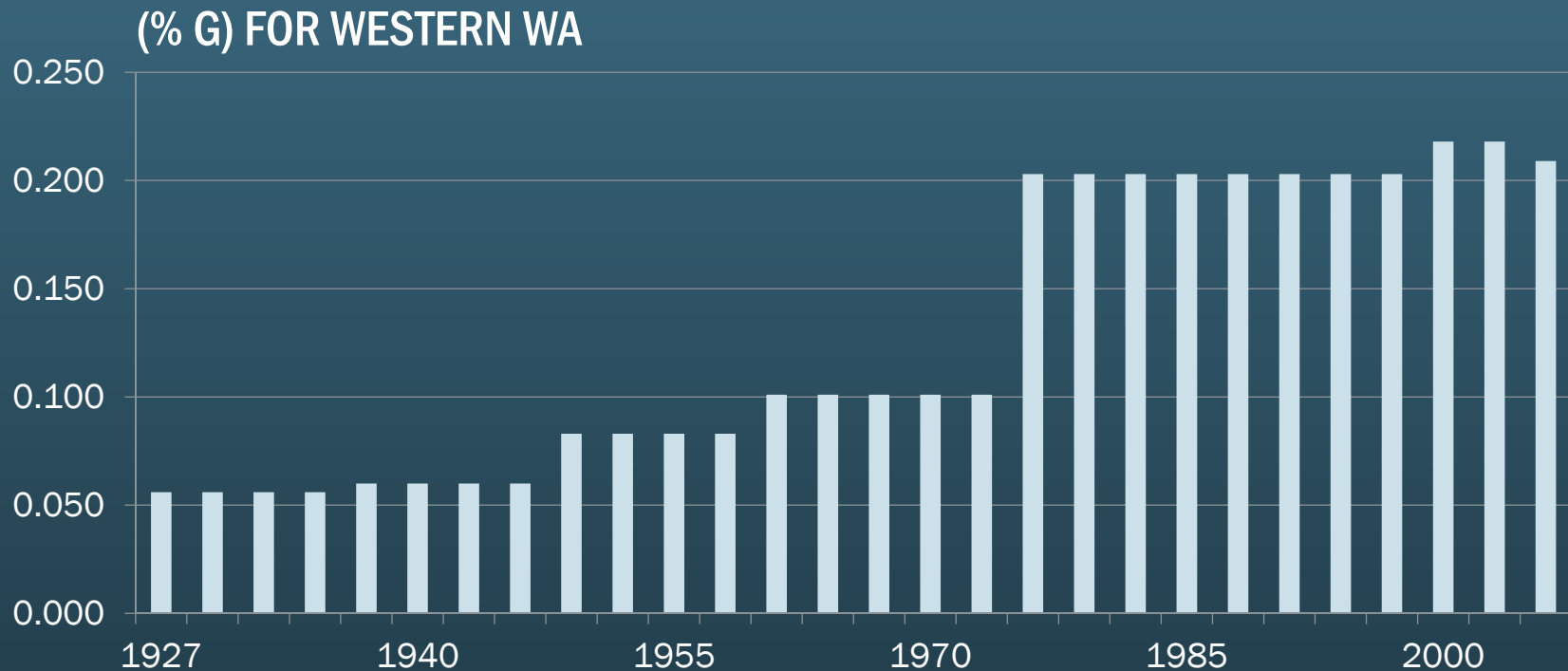
Tsunami Impact

# JAPAN 2011 EARTHQUAKE

- Subduction zone fault moved 164 ft laterally, 33 ft up
- \$309 billion in damage
- Tsunami waves up to 33 ft high reached 6 miles inland
- 18,500 killed
- Nuclear power crisis
- Damage due to water



# HISTORICAL CHANGES IN DESIGN FORCES



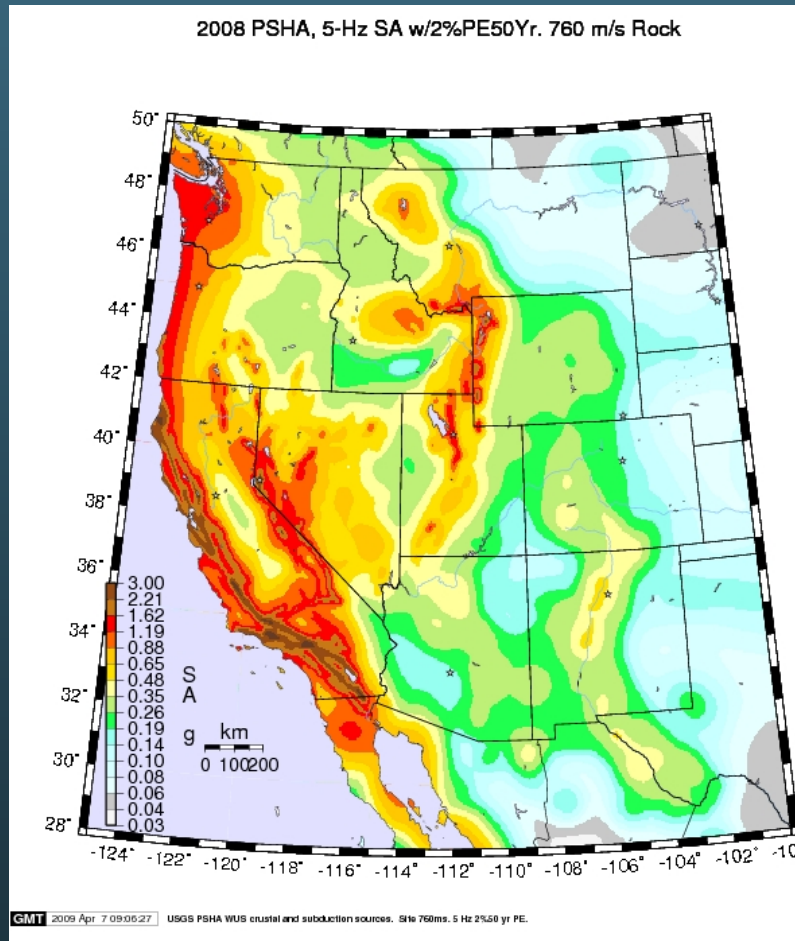
1974: UBC adopted in WA

1976: Importance Factor & Drift Limits added

2000: IBC adopted, now per USGS EQ info



# GROUND MOTION



- Based on ASCE 7 (US)
  - Site-specific based on location and soil type
  - Also used by IBC
- Max Considered EQ
  - 2% probability in 50 years
  - 2,500-year return
  - Previously 500-year return
- Developed by USGS & local professionals

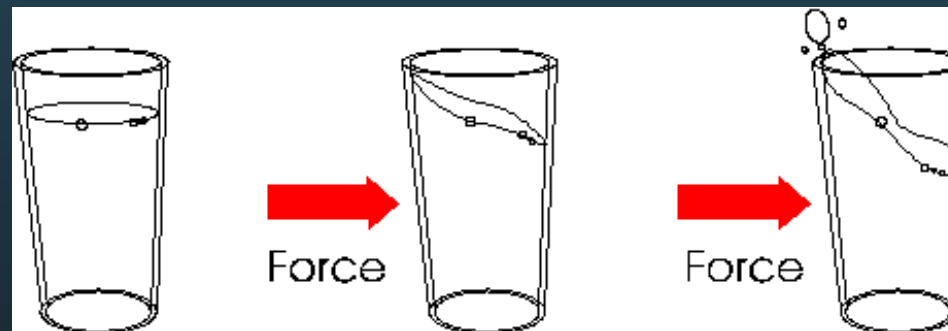
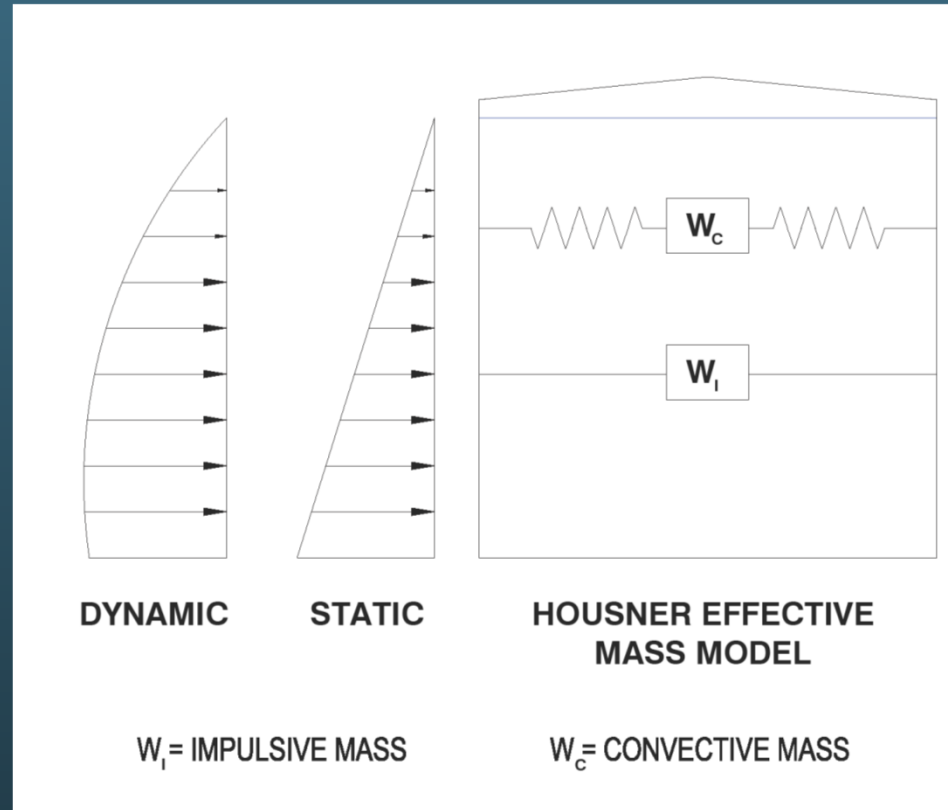
# SEISMIC DESIGN NOTES

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- Structures are designed to experience some damage without collapsing
- Essential facilities are designed for 50% higher loads than ordinary facilities
- Current code uses a cost-versus-risk approach



# DESIGN MODEL





# WATER RESERVOIR CONCERNS

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Older reservoirs are most at risk

- Design loads have been increased based on new information
- Seismic-resistant details have improved
- Construction practices and materials have improved



# STEEL RESERVOIRS AT RISK

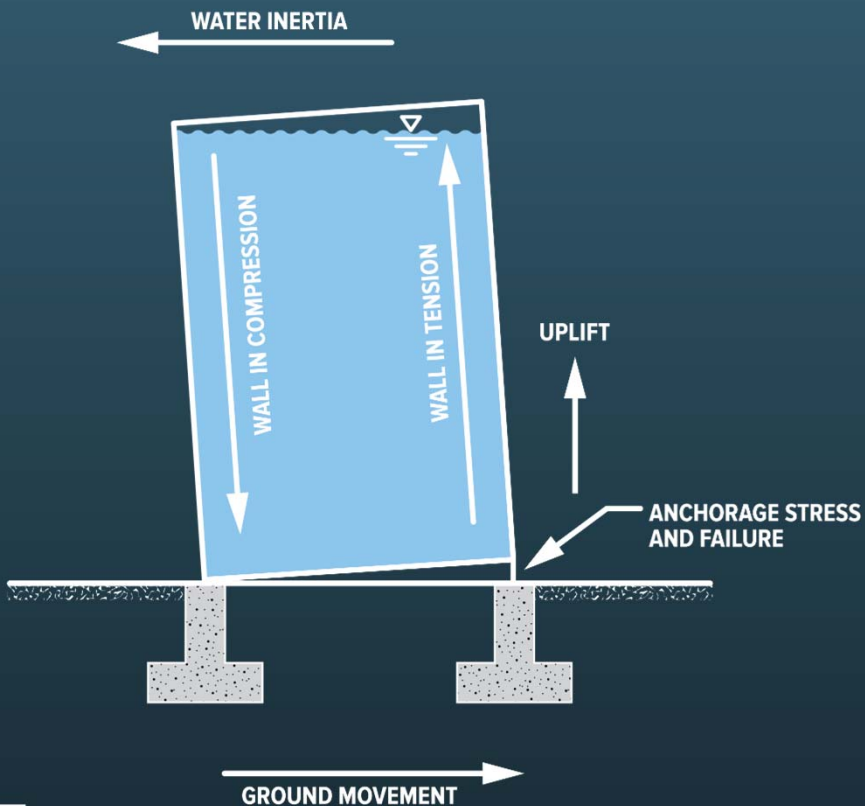


- Older reservoirs (Pre-1980s)
- Tall and slender
  - Diameter less than 1.5x height
- Inadequate foundation size
- Inadequate anchorage
  - Straps or small diameter bolts

# POSSIBLE FAILURE MODES

## Anchorage failure

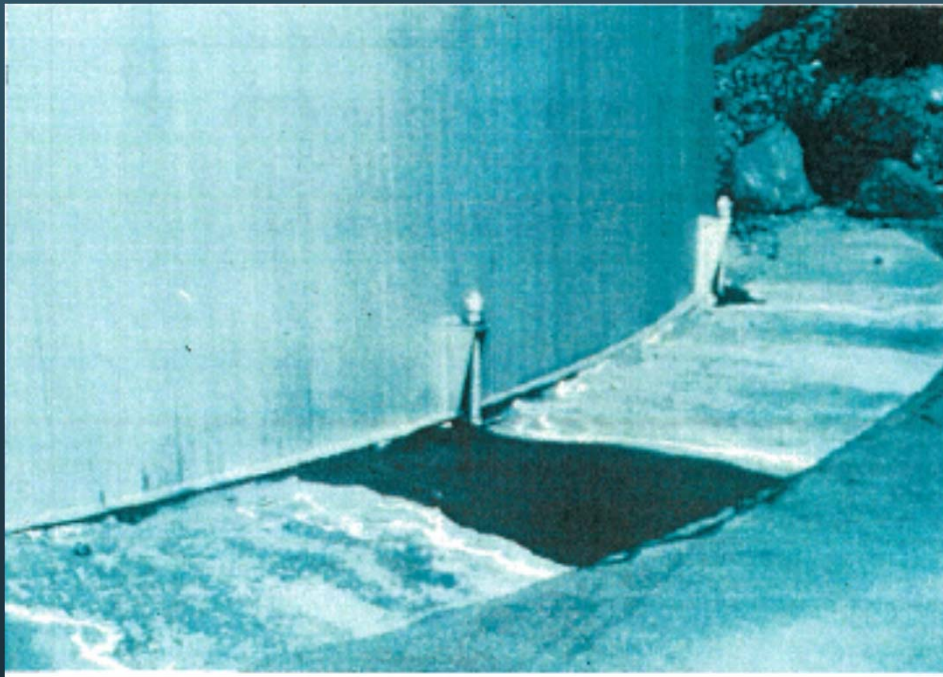
- Primary: Anchorage stress



# POSSIBLE FAILURE MODES

## Anchorage failure

- Secondary: Floor cracking



# POSSIBLE FAILURE MODES

**SMALL DIAMETER BOLTS**



**LARGE DIAMETER BOLTS WITH ANCHOR CHAIRS**

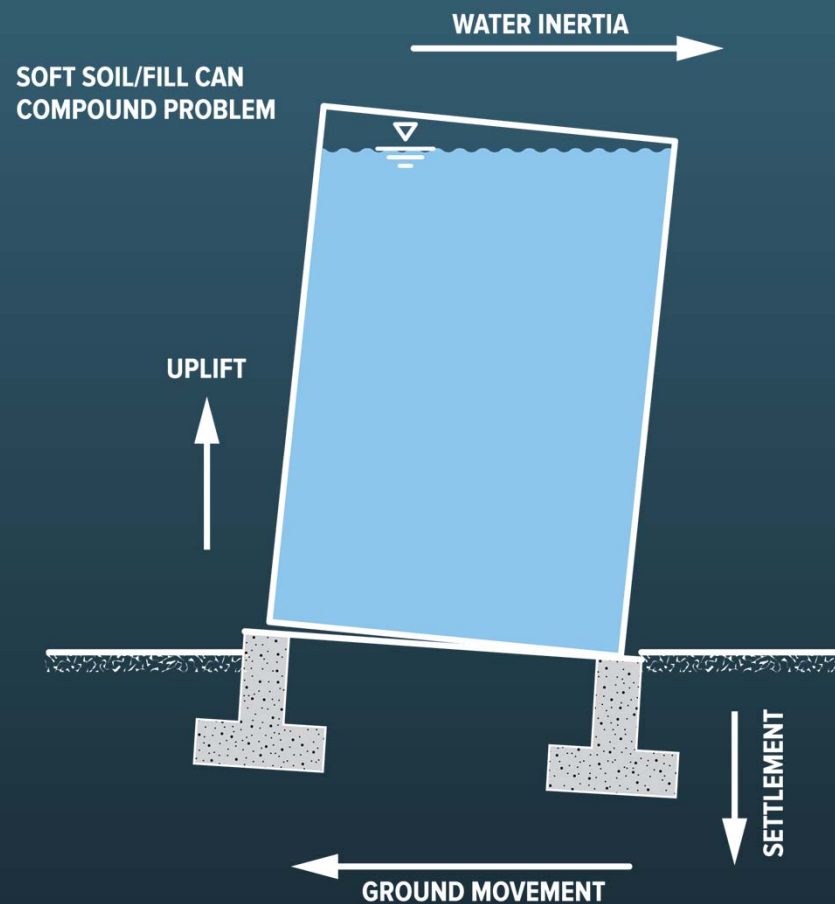
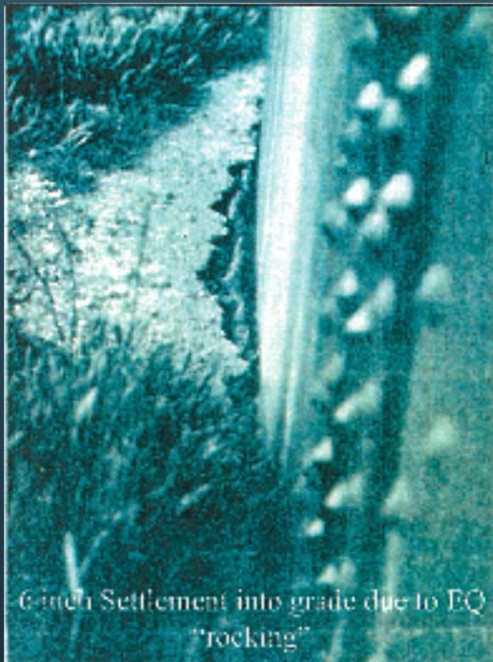


**ANCHOR STRAPS**

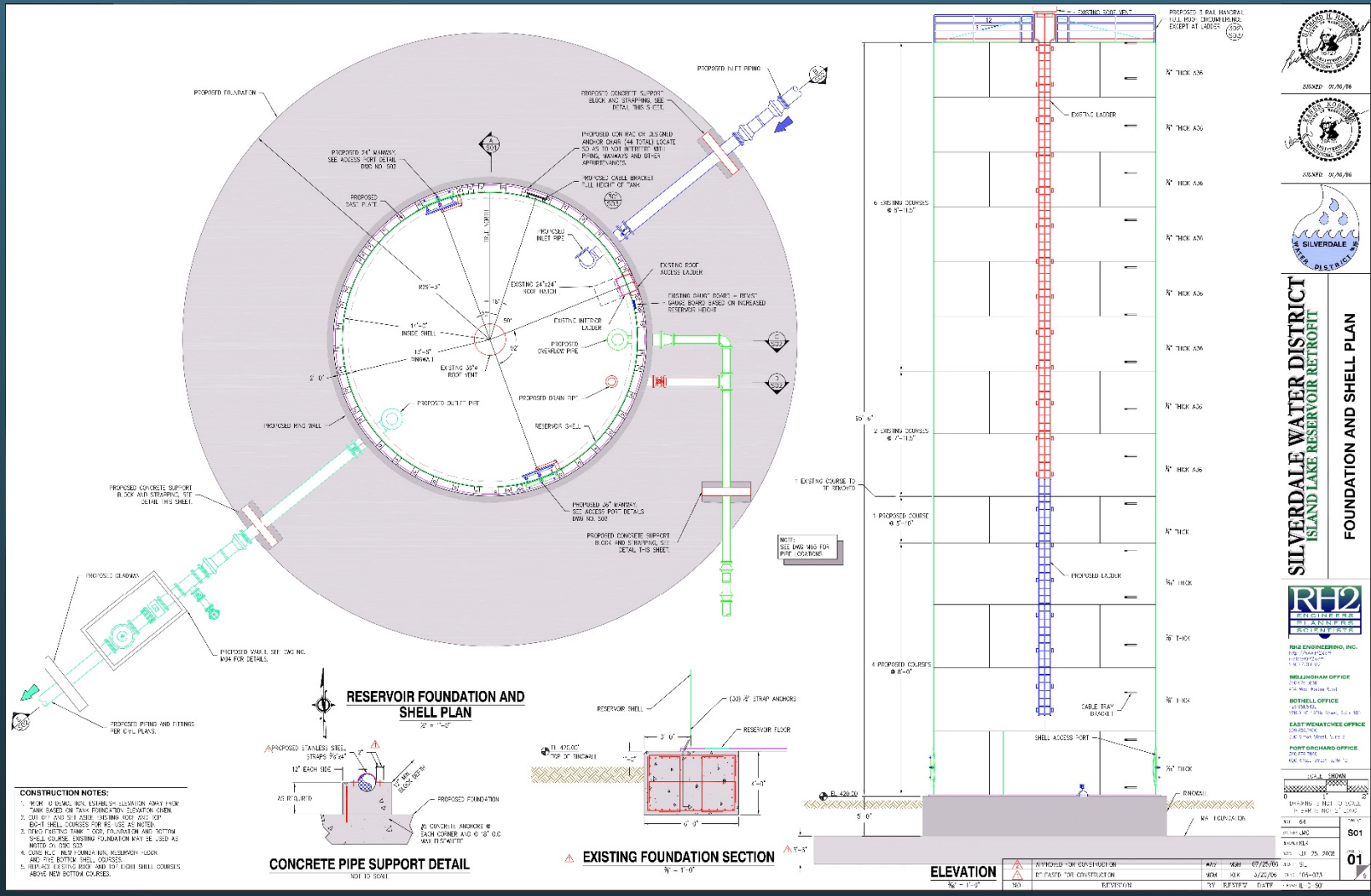


# POSSIBLE FAILURE MODES

## Soil failure (Inadequate Foundation)

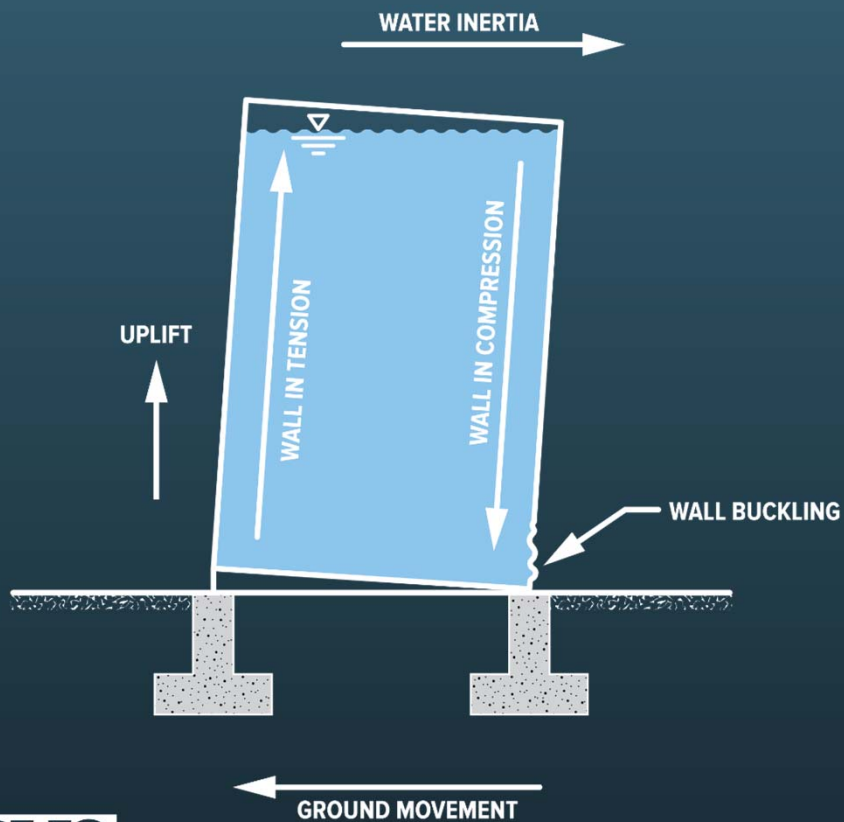


# STEEL RESERVOIRS: INADEQUATE FOUNDATIONS



# POSSIBLE FAILURE MODES

## Shell buckling (Elephant Foot)





# POTENTIAL BUCKLING SOLUTIONS

- Stiffen shell
- Add interior ballast ring
- Lower water level



# POSSIBLE DAMAGE MODES

- Sloshing damage
- Soil stability



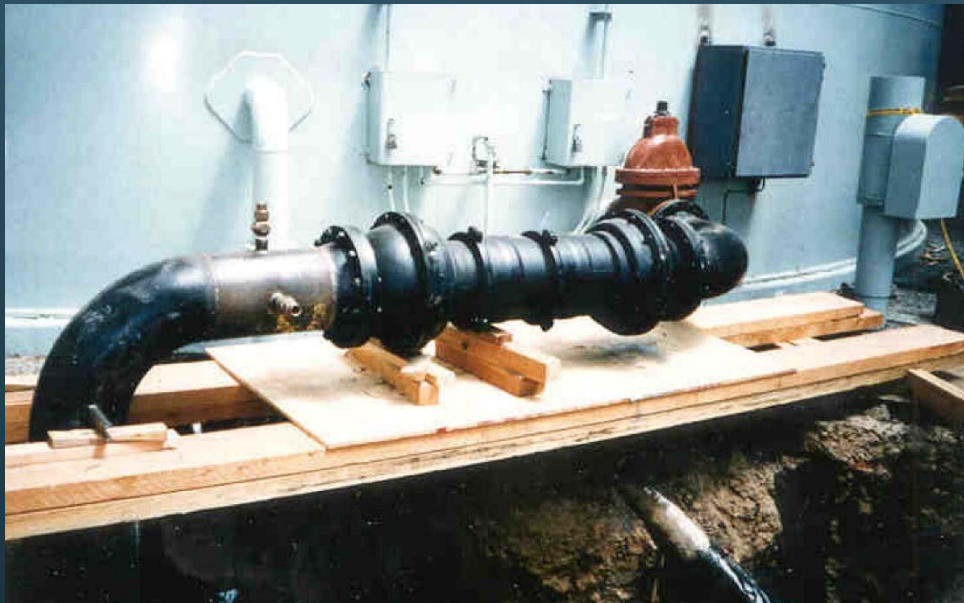
# DETAILING

- Freeboard
- Ventilation
- Piping



# PIPING CONNECTIONS

- Allow for relative displacements
- Prepare for emergency shut down
- Isolate damaged sections



# RETROFIT EXAMPLES

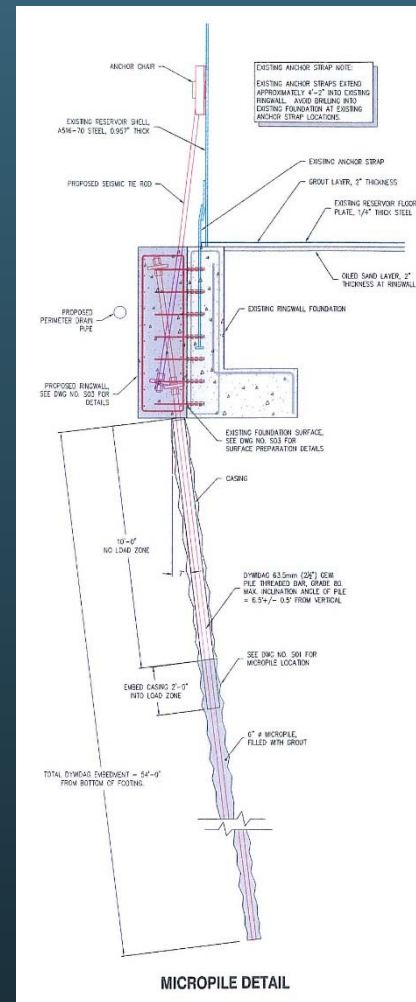
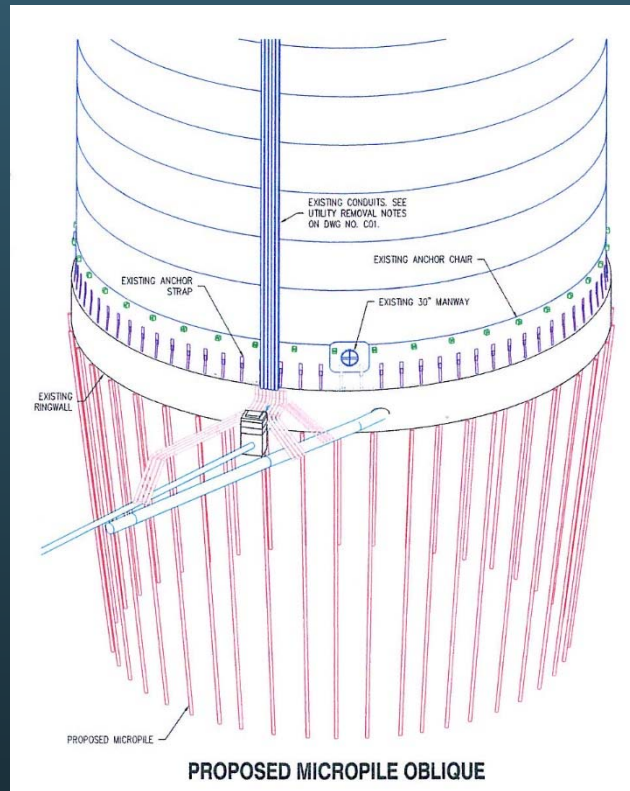
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## Micropiles

- Useful where site constraints make it difficult to expand the existing foundation
- Expensive – can be up to \$10,000 per pile depending on depth
- Piles provide both uplift resistance and bearing capacity

# MICROPILE RETROFIT

Anchors and piles embedded in small ringwall expansion



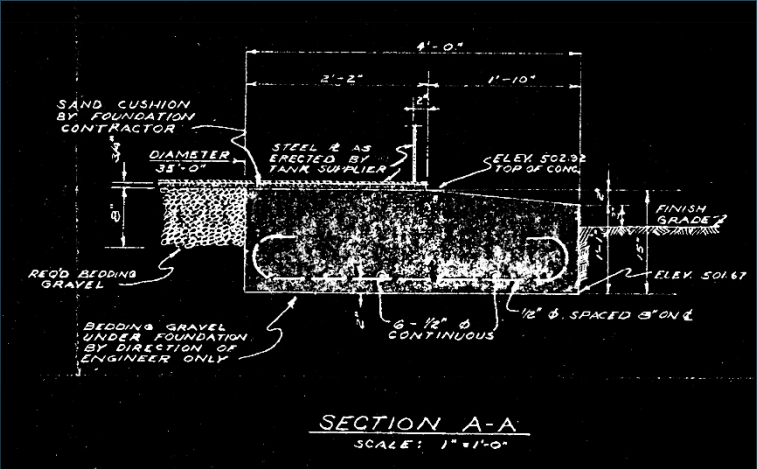


# MT. VIEW-EDGEWOOD WATER CO. SOUTH RESERVOIRS



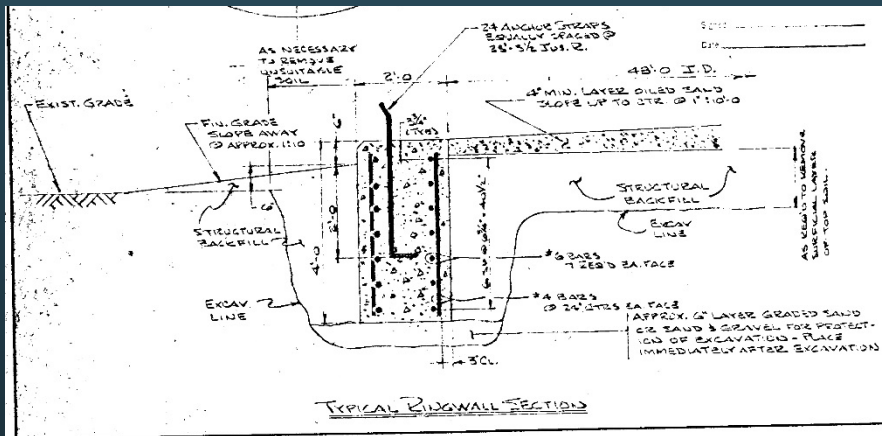


# EAST RESERVOIR



# WEST RESERVOIR

- Small Foundation = high bearing pressure
- Anchor Straps

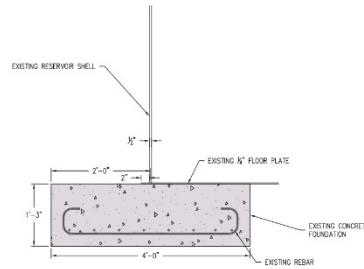


# RETROFIT SOLUTIONS

Mt View Edgewood Water Company  
Reservoir Seismic Vulnerability

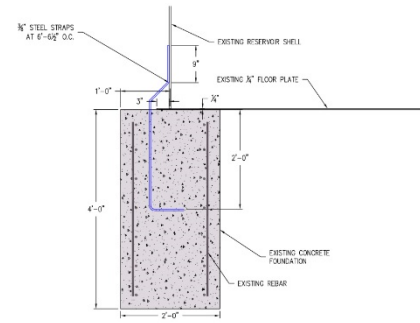
FIGURE A

## EAST TANK



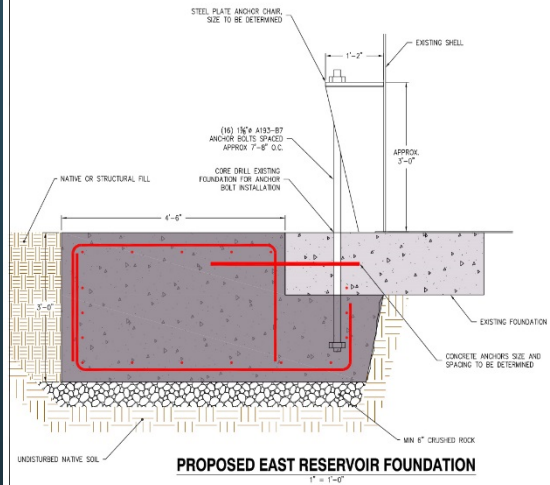
EXISTING EAST RESERVOIR SECTION  
1" = 1'-0"

## WEST TANK



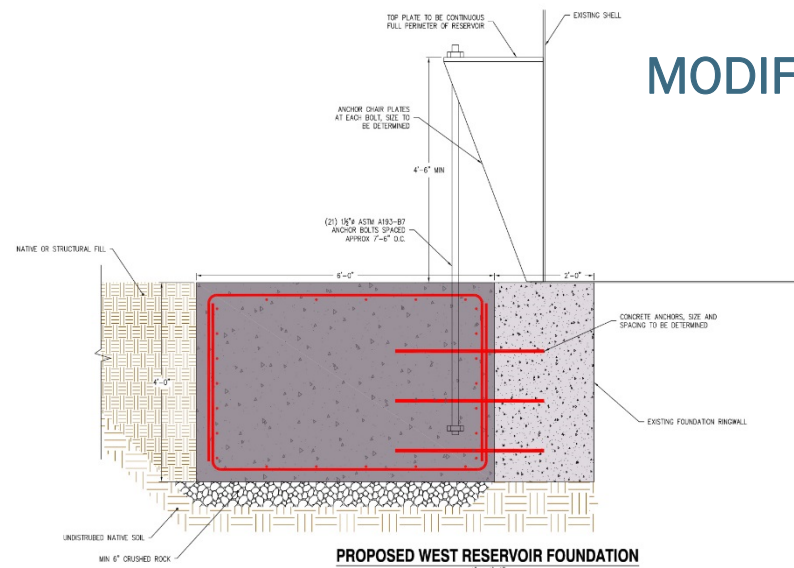
EXISTING WEST RESERVOIR SECTION  
1" = 1'-0"

## EAST MODIFICATIONS



PROPOSED EAST RESERVOIR FOUNDATION  
1" = 1'-0"

## WEST MODIFICATIONS



PROPOSED WEST RESERVOIR FOUNDATION  
1" = 1'-0"

DRAWING IS NOT TO SCALE  
IF DIM IS NOT ST. LONG.

AUG. 14, 2009

# EAST RESERVOIR ANCHORS



# EAST RESERVOIR FOUNDATION



# FOUNDATION CONSTRUCTION



# WEST RESERVOIR ANCHORS

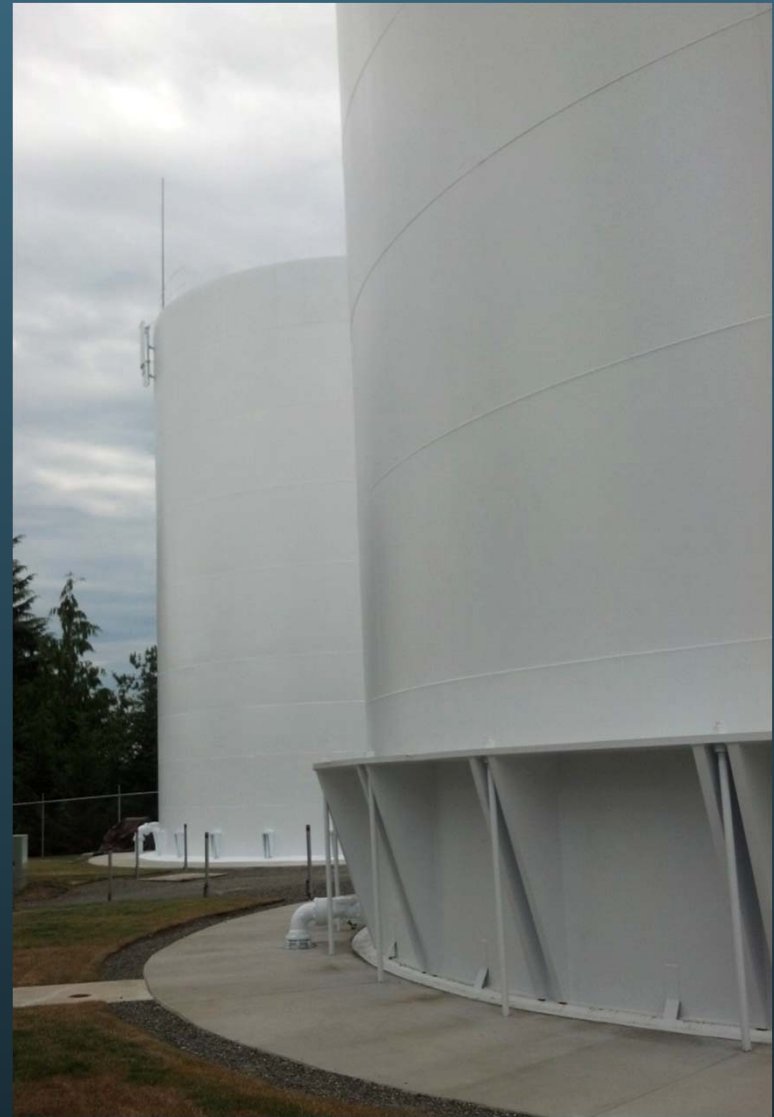


# WEST RESERVOIR FOUNDATION





# COMPLETED TANKS



# PIPING MODIFICATIONS

- Expansion joints on inlet, outlet, and drain
- New valves



# SEISMIC VALVE



# PROJECT COSTS

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- Total \$800,000
  - Foundations: \$100,000
  - Anchors: \$202,000
  - Mechanical: \$97,000
  - Site Work: \$57,000
- Owner's direct costs:
  - Coatings, electrical, non-structural improvements:
    - \$300,000
- FEMA grant: \$1,000,000



# OAK LODGE WATER DISTRICT VIEW ACRES RESERVOIRS



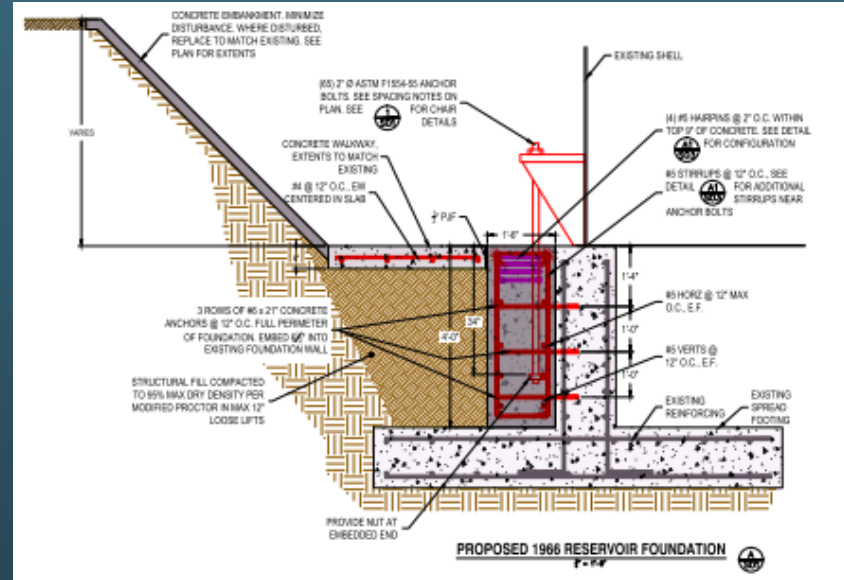
# 1966 RESERVOIR



# DATA ACQUISITION

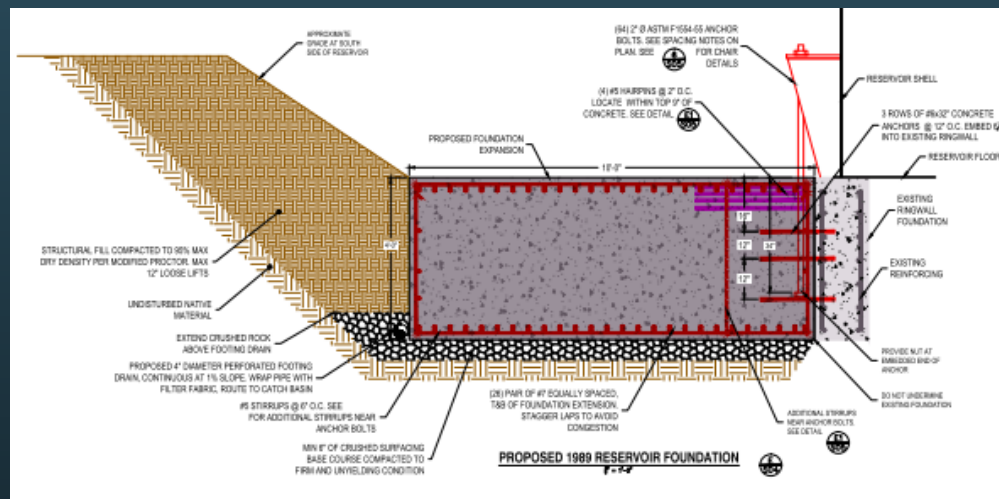


# 1966 RESERVOIR

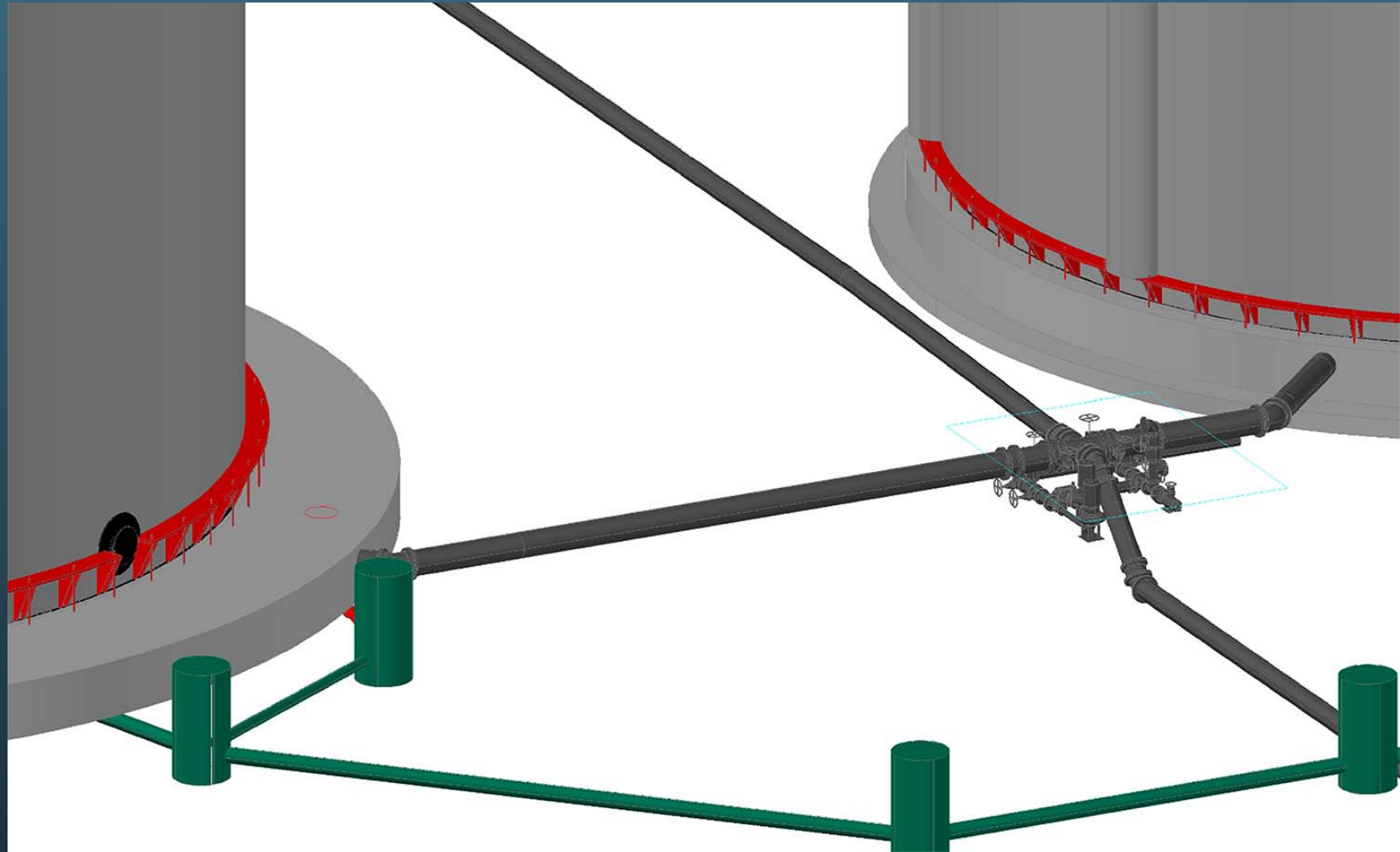




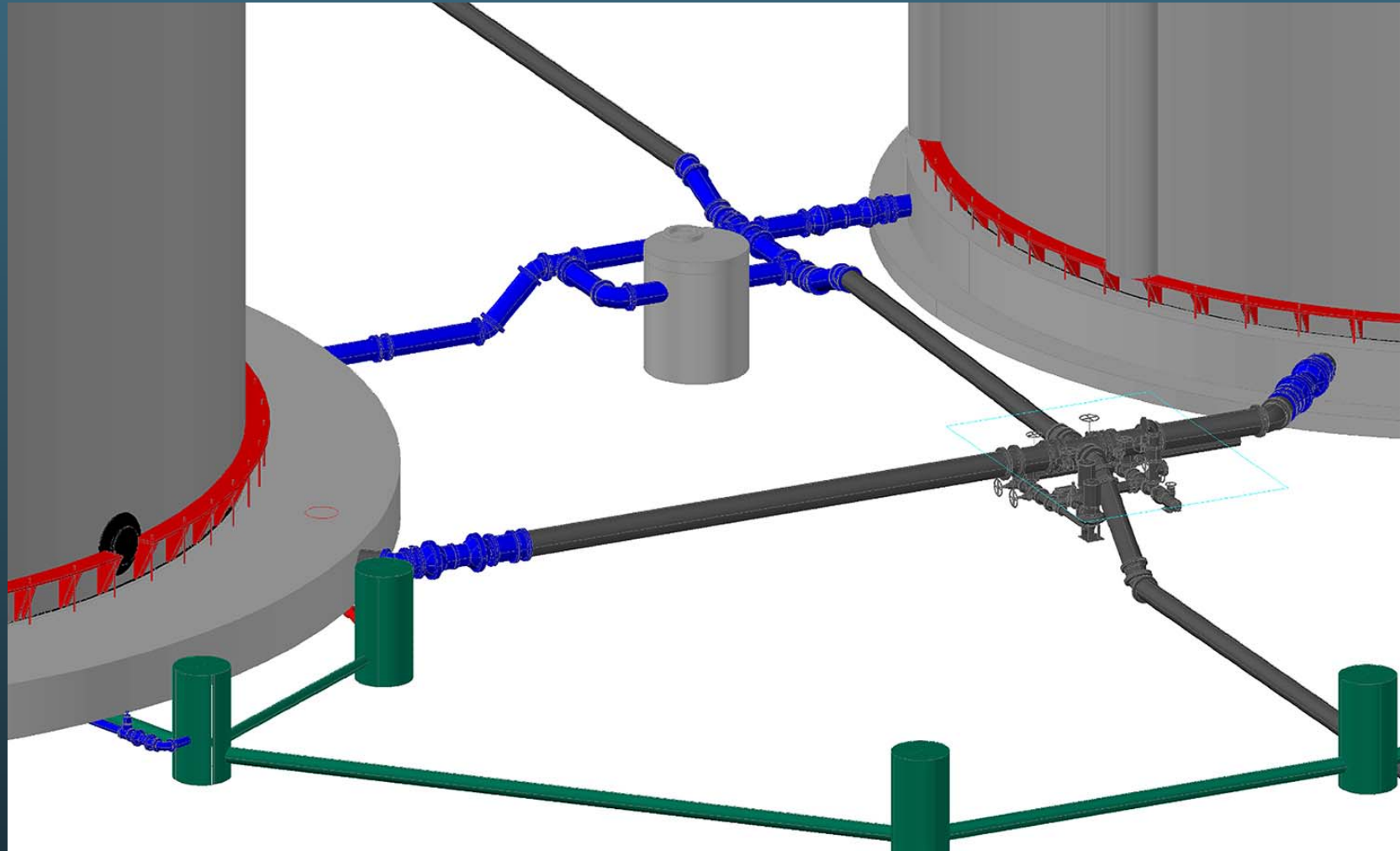
# 1989 RESERVOIR



# EXISTING PIPING



# PROPOSED PIPING



# 1966 TANK CONSTRUCTION



New Inlet



Drilling for Epoxy Anchors



Construction Access Door

# 1966 TANK CONSTRUCTION



# WATER MAIN TIE IN



# 1989 TANK CONSTRUCTION



# 1989 TANK CONSTRUCTION





# PIPING MODIFICATIONS



# PROJECT COSTS

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- Total \$1,754,000
  - Foundations: \$240,000
  - Anchors: \$400,000
  - Mechanical: \$537,000
  - Site Work: \$170,000
  - Coatings: \$380,000
  - CP: \$25,000



# RETROFIT SUMMARY

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- Foundation modifications used to reduce soil bearing pressures and provide an area to embed new anchors.
- Uplift problems require anchors. May require additional foundation weight.
- Buckling issues require stiffening the shell.
- Sloshing/freeboard issues are typically not cost effective to address

# QUESTIONS?

