Seismic Retrofit of Existing Reservoirs

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"We learn geology the morning after the earthquake."

Ralph Waldo Emerson

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Why Reservoir Seismic Upgrades?

- Older Reservoir Designs Didn't Adequately Address Seismic Issues.
- Seismic Code Changes
  - Spectral Map Replaced Zones
  - IBC and AWWA Upgrades
- Seismic Events
  - 2001 Nisqually Quake
  - California Quakes

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Presentation Outline

Overview of Seismic Stresses

Failure Examples

Retrofit Necessity

Retrofit Strategies

Other Seismic Retrofit Issues

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Overview of Seismic Stresses

What happens to a water reservoir during an earthquake?

Ground movement and water inertia combine to put stresses on the tank shell, the tank foundation, and the anchorage of the tank to the foundation.

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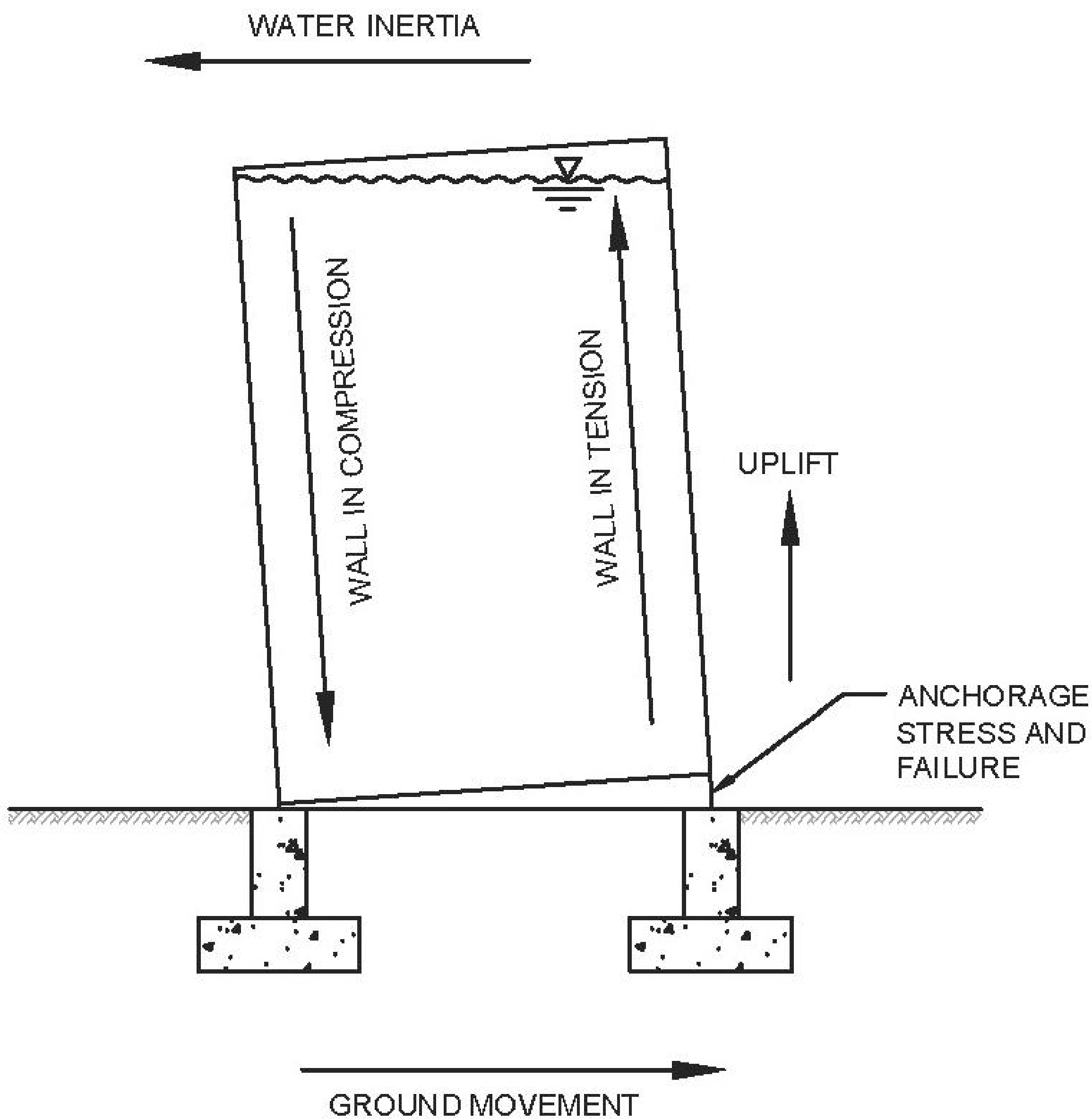
Simple Example

Beer can

The inertia of the water and the ground movement create uplift on one side of the tank creating anchorage stress and possible failure.



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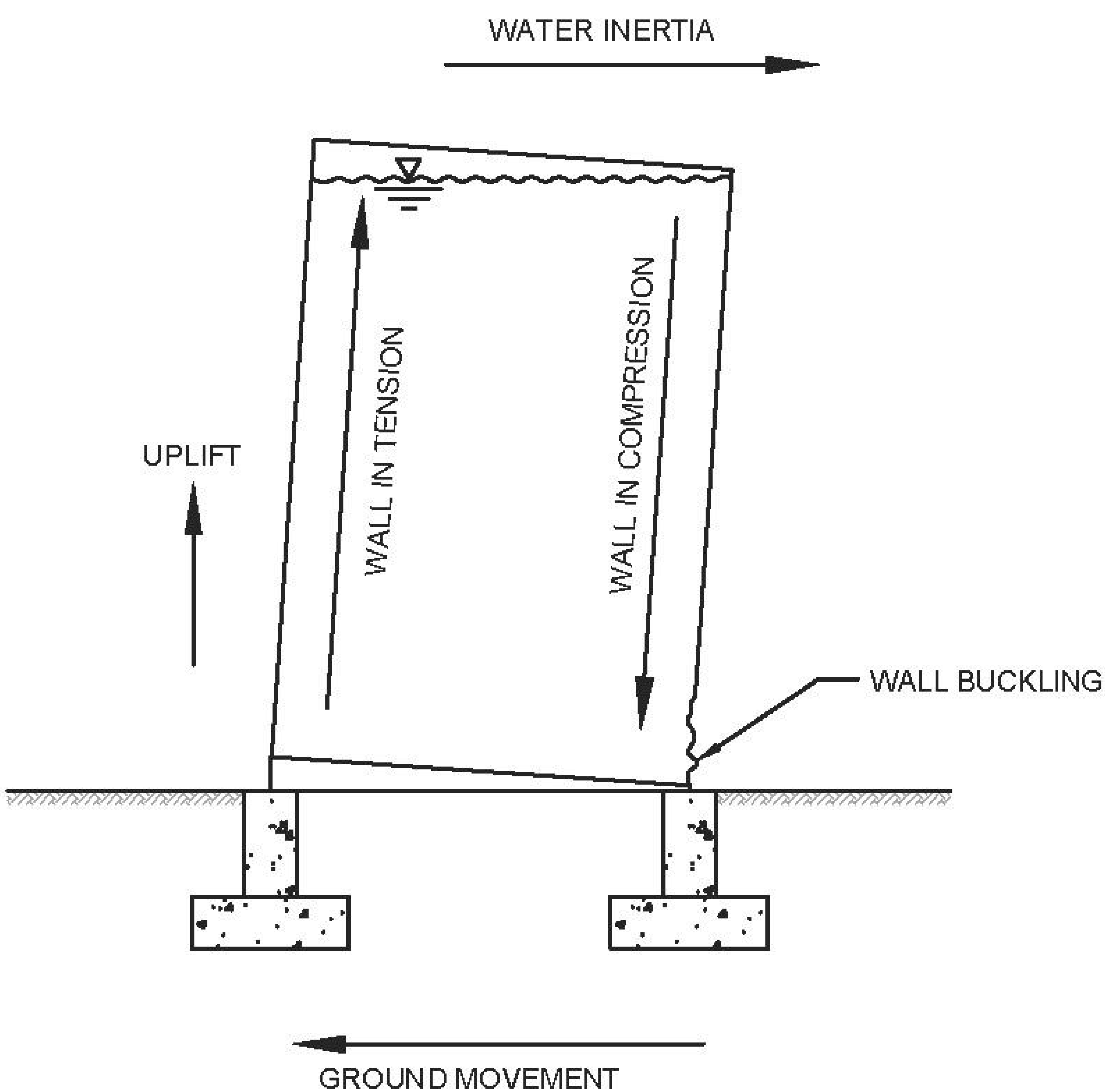
As the ground movement reverses, the tank motion reverses. Buckling can occur as the tank shell impacts the foundation after uplift.



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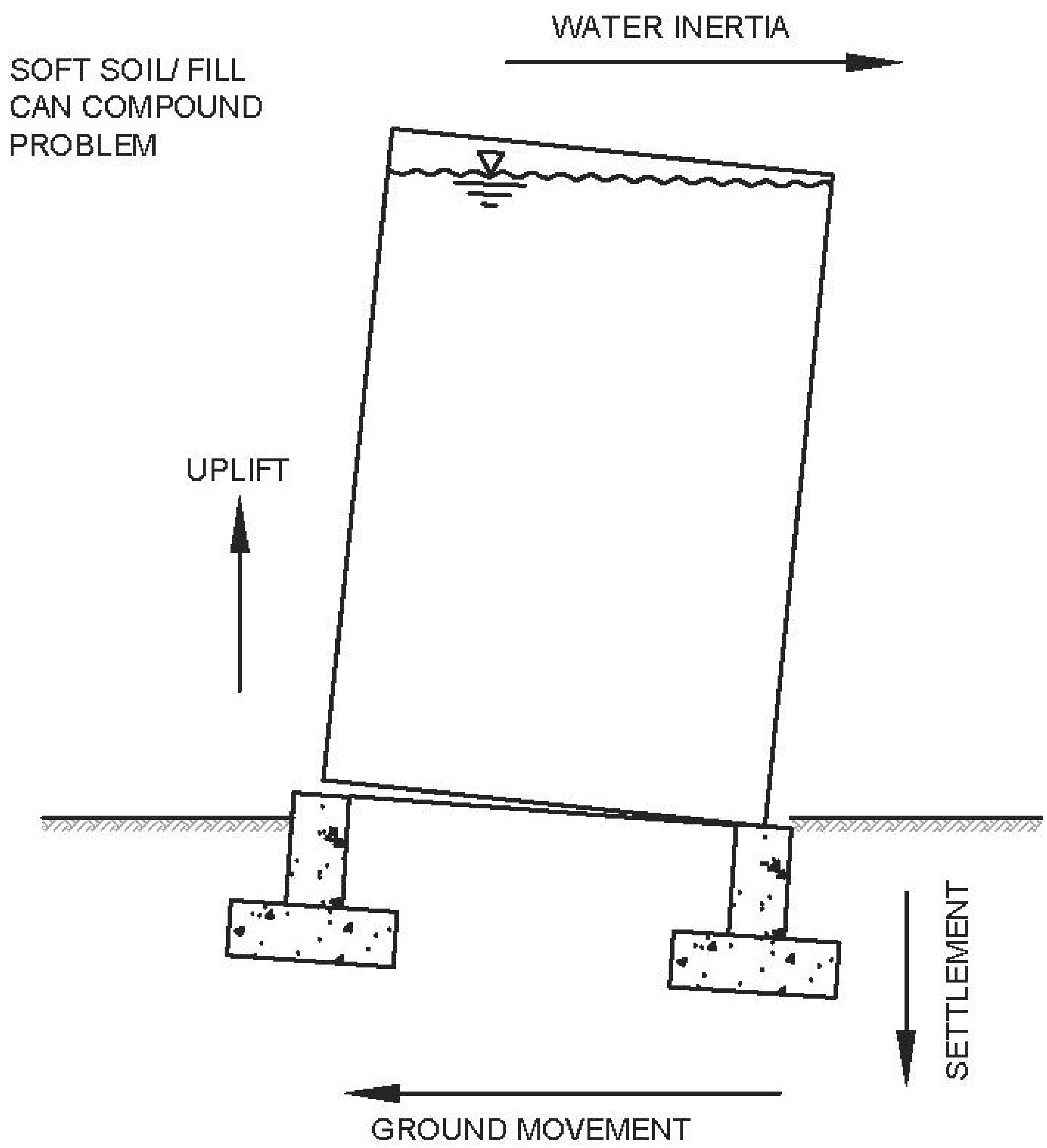
Soft soils or fill can exaggerate the seismic effect by settling or liquefaction under the foundation.



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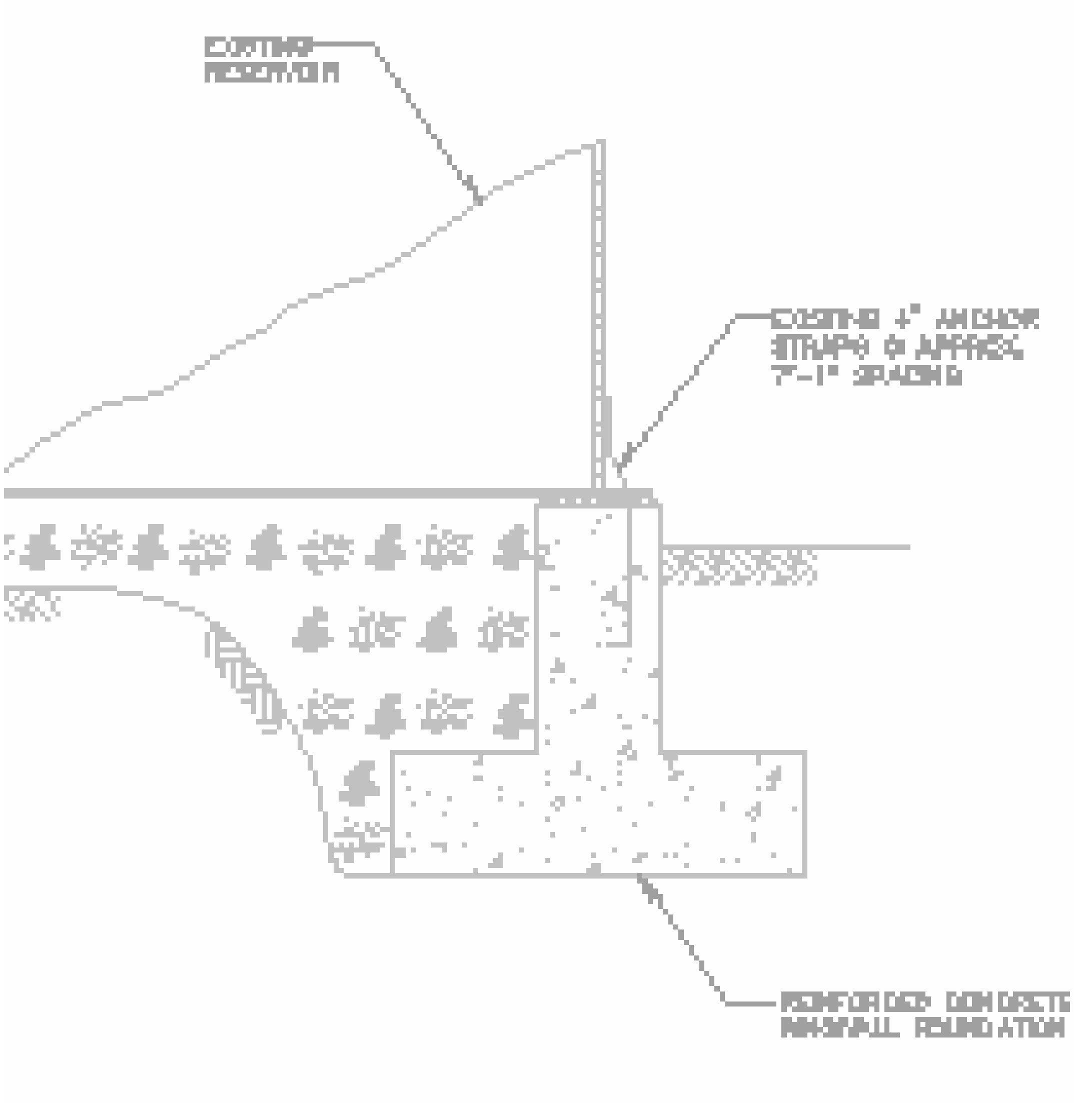
Seismic Failure Examples

Anchorage Failure

Shell Wall Failure

Piping Connection Failure



Typical Strap Anchor

Typical Anchor Straps

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Nisqually Earthquake Effect on Steel Reservoir

Stress and Flexure of Steel Strap

Failure of Steel Strap to Foundation Anchorage

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Nisqually Earthquake Effect on Steel Reservoir

Failure of Steel Straps
Foundation Damage

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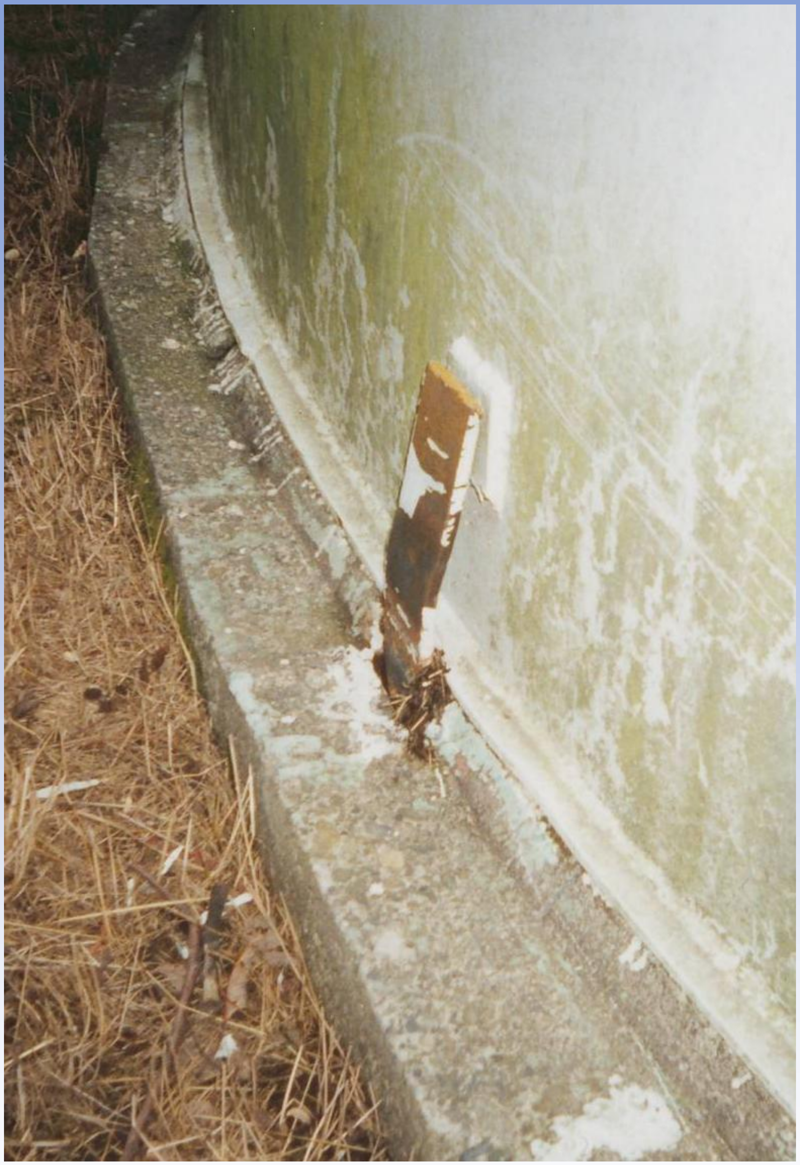
Nisqually Earthquake
Effect on Steel Reservoir

Severed Strap



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Nisqually Earthquake Effect on Steel Reservoir

Elongated Anchor Bolt

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Tank Wall Failure

"Elephant Foot"

Don Ballantyne photo

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Reservoir Seismic Design Considerations

- Reservoir Size and Shape (Diameter and Height)
- Applicable Design Codes (International Building Code, AWWA-D101)
- Seismic Determinations and Anchoring Design
- Available Options And Impacts On Storage Capacity
- Supporting Soil Capacity
- Inlet and Outlet Piping Shear Protection Design
- Inlet and Outlet Piping Shutdown Upon Pipe Failure

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Reservoir Geometry Determines Anchorage Requirements

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Reservoir Geometry Determines Anchorage Requirements

In general, reservoirs that have a diameter to height ratio of 1.5:1 do not require seismic anchorage between tank and foundation.

Geometry prevents uplift forces during ground movement.

Reservoir Geometry Determines Anchorage Requirements

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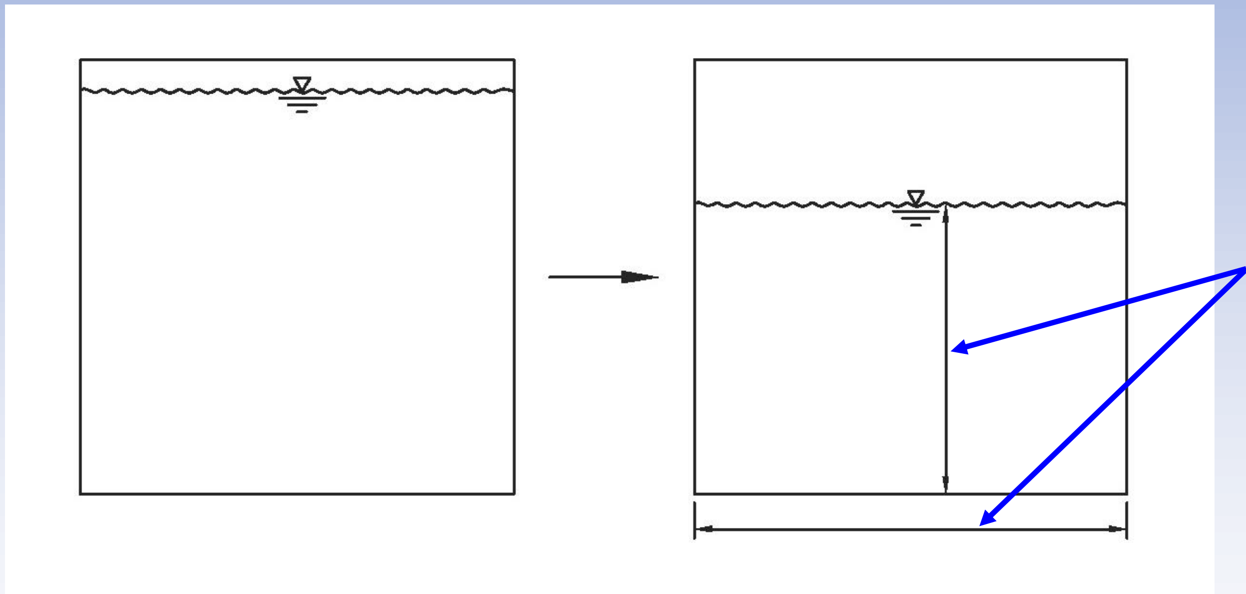
Reservoir Geometry Determines Anchorage Requirements

In general, tank height for seismic purposes is water level. One strategy for seismic retrofit is to lower water level to achieve 1.5:1 diameter to water level height.



Diameter to Water Level Ratio = 1.5:1

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Retrofit Strategies

In general, retrofits to prevent tank damage focus on stabilizing the reservoir by preventing uplift either through increasing weight resistance or anchorage.

- **Internal ballast ring**
- **External foundation supplementation**
- **External foundation supplementation with micro-piles**
- **External foundation supplementation with auger cast piles**

Internal Ballast Ring

Goal: To increase foundation weight to resist uplift. Improved anchorage between tank and foundation is not necessary, but a good connection between the ballast ring and the tank wall is necessary.

Tank is removed from service for the work.

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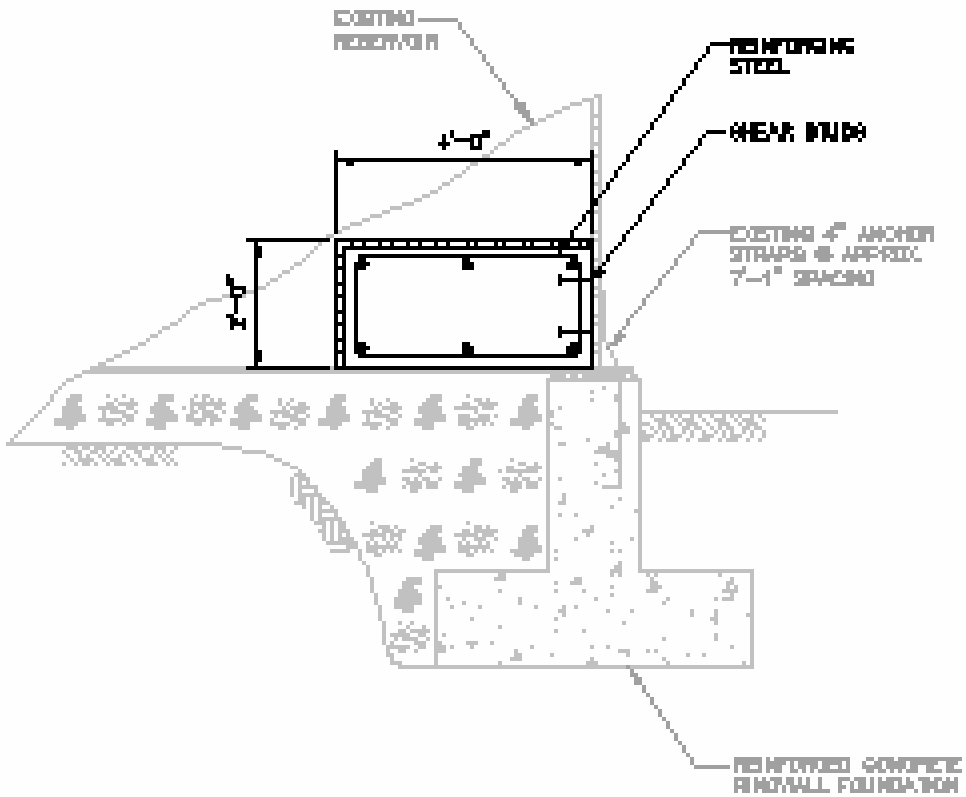

Internal “Doughnut”
Ballast Ring

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Internal Doughnut Ballast

Access Opening

Doughnut Ballast Reinforcement

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External Foundation Supplementation

Goal: To increase foundation weight to resist uplift. May need improved anchorage between tank and foundation.

Tank may or may not remain in service depending upon extent of anchorage improvements.

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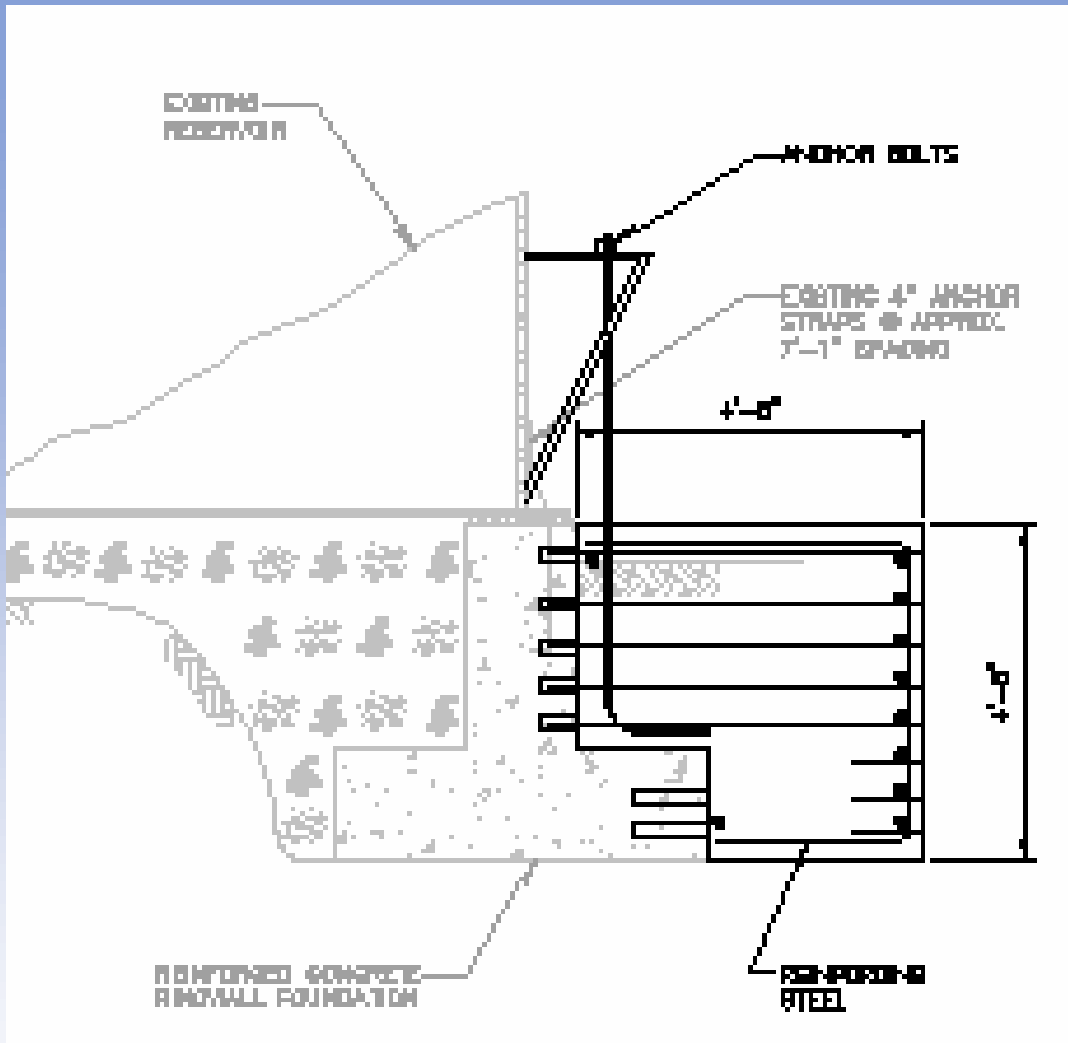

External Anchor Ring Addition and Improved Anchorage

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External Anchor Ring
Example – Before Retrofit

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External Anchor Ring

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External Anchor Ring

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External Anchor Ring

Before

After

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External Foundation Supplementation with Piles

Goal: To increase foundation weight to resist uplift and connect foundation to soil with piles. May need improved anchorage between tank and foundation.

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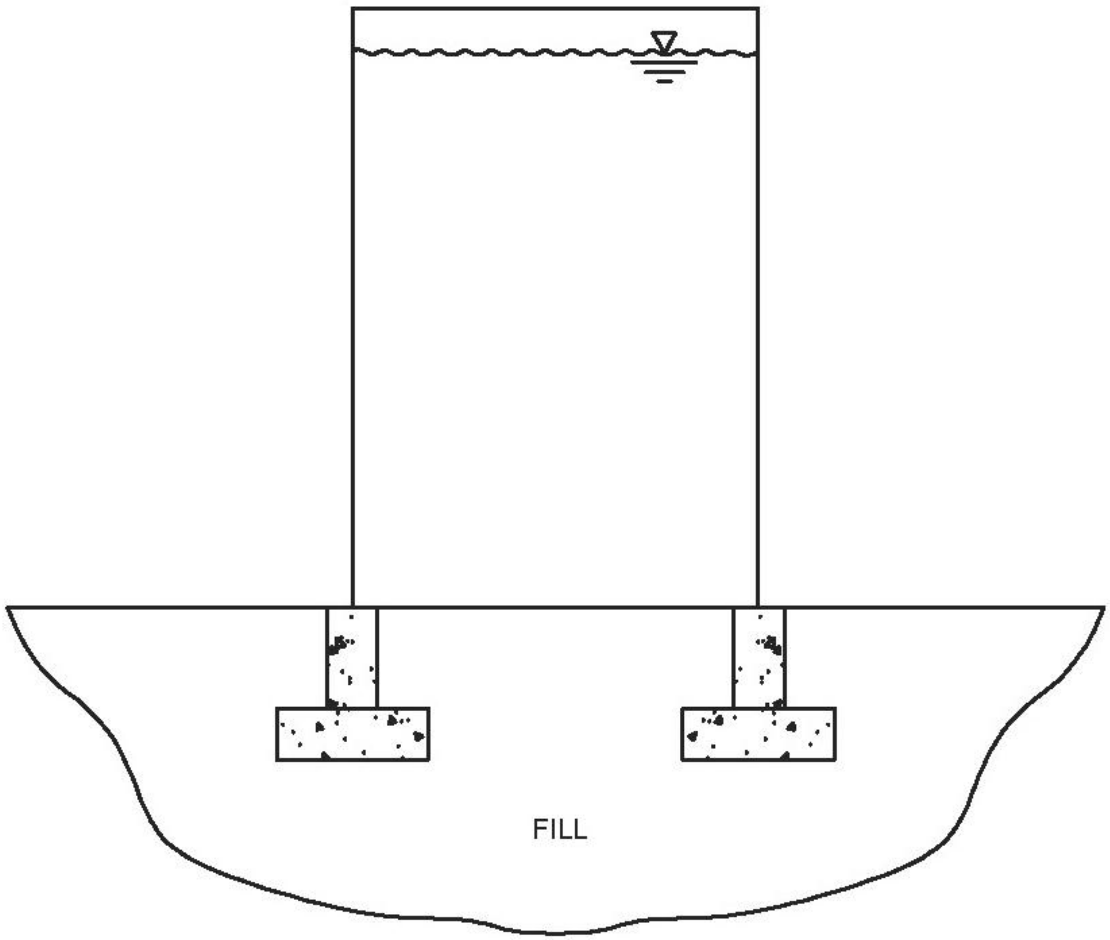
Reservoir on fill with inadequate anchorage



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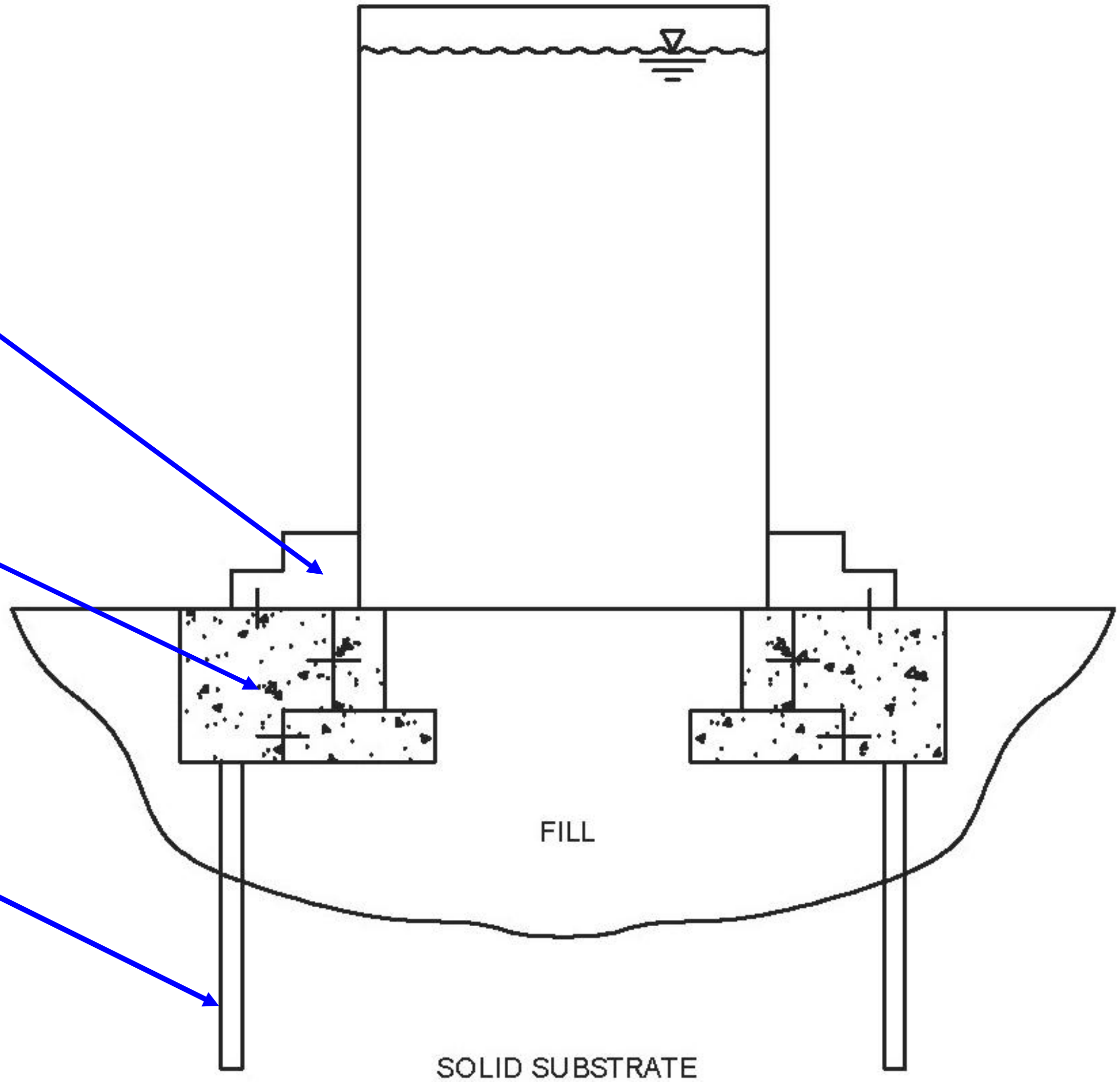
Improved Anchorage

Foundation Enlargement

Piles



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Example of Pile and Foundation Retrofit

Existing Reservoir
100' Tall
36' Diameter

Built on ~15' of fill

Existing reservoir anchor straps and slab foundation

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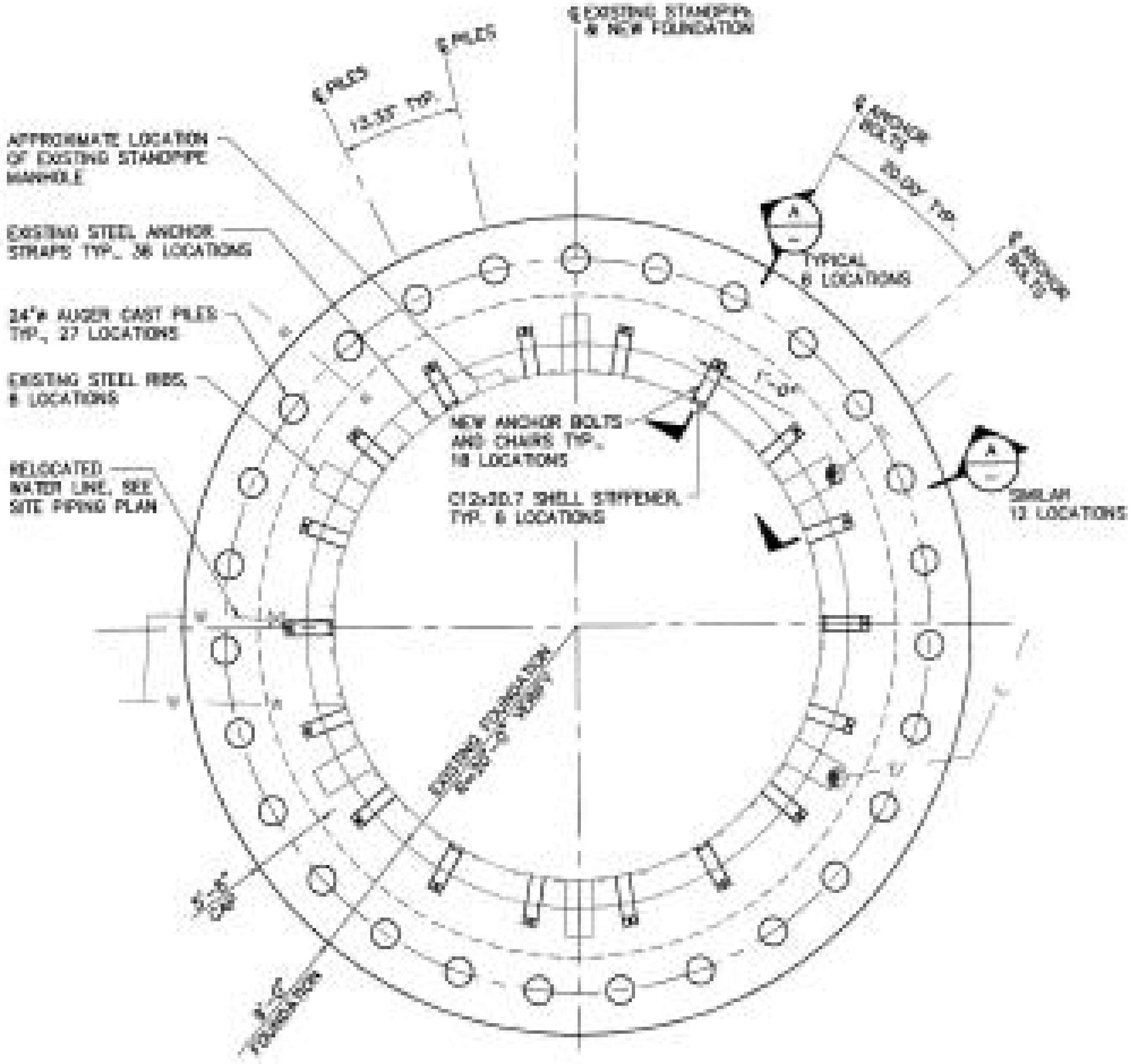
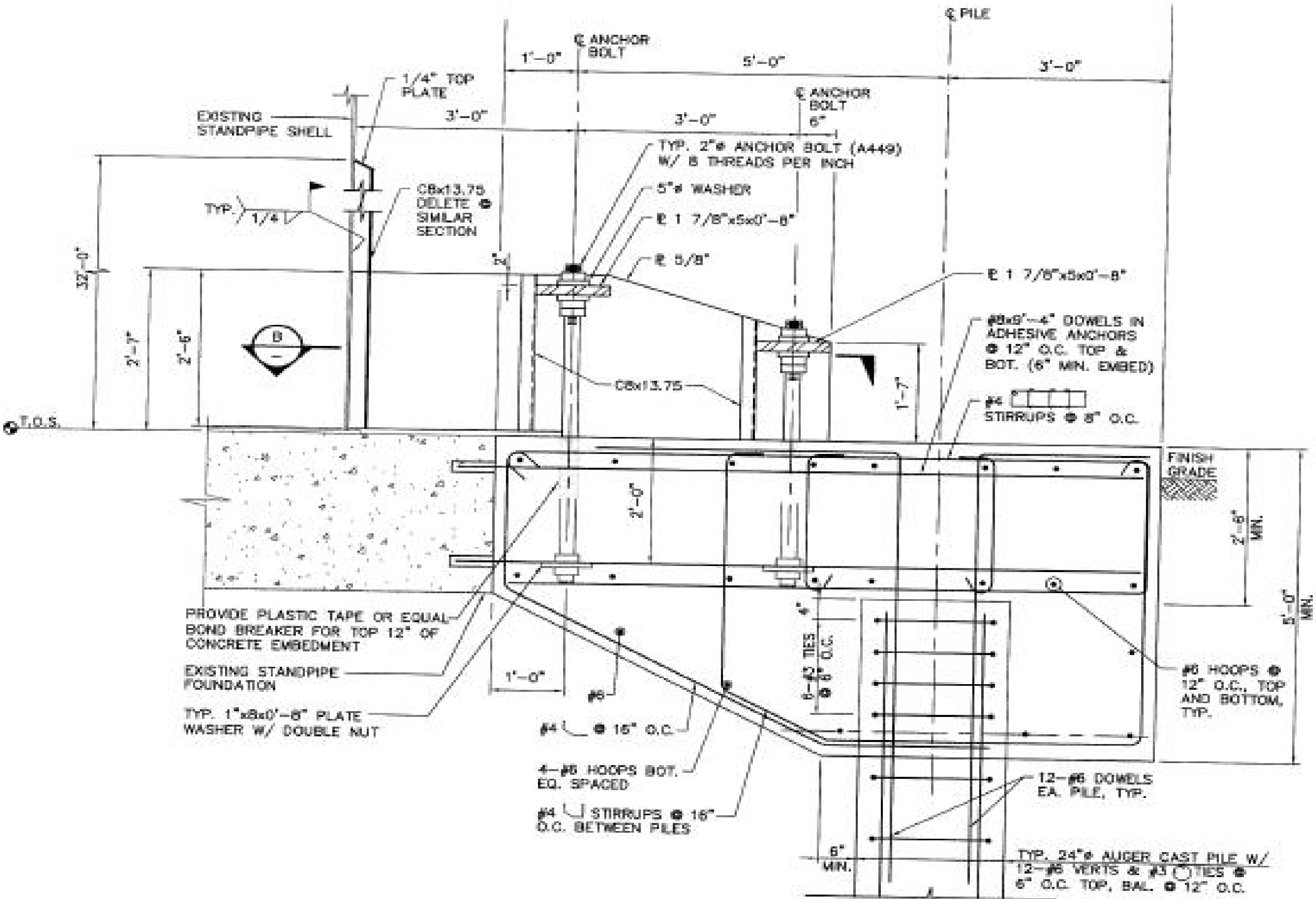


EXISTING STANDPIPE FOUNDATION PLAN



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Finished Retrofit with Anchor Chairs and Tank Sidewall Stiffeners

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Reservoir Piping Connection Improvements

Differential movement between reservoir structure and inlet/outlet piping can create sheer stress on piping that can lead to failure.

Flexibility can be included in design/retrofit to allow for movement.

Improvements to Existing Reservoir Piping

Shear Prevention

Flex-tend Fittings

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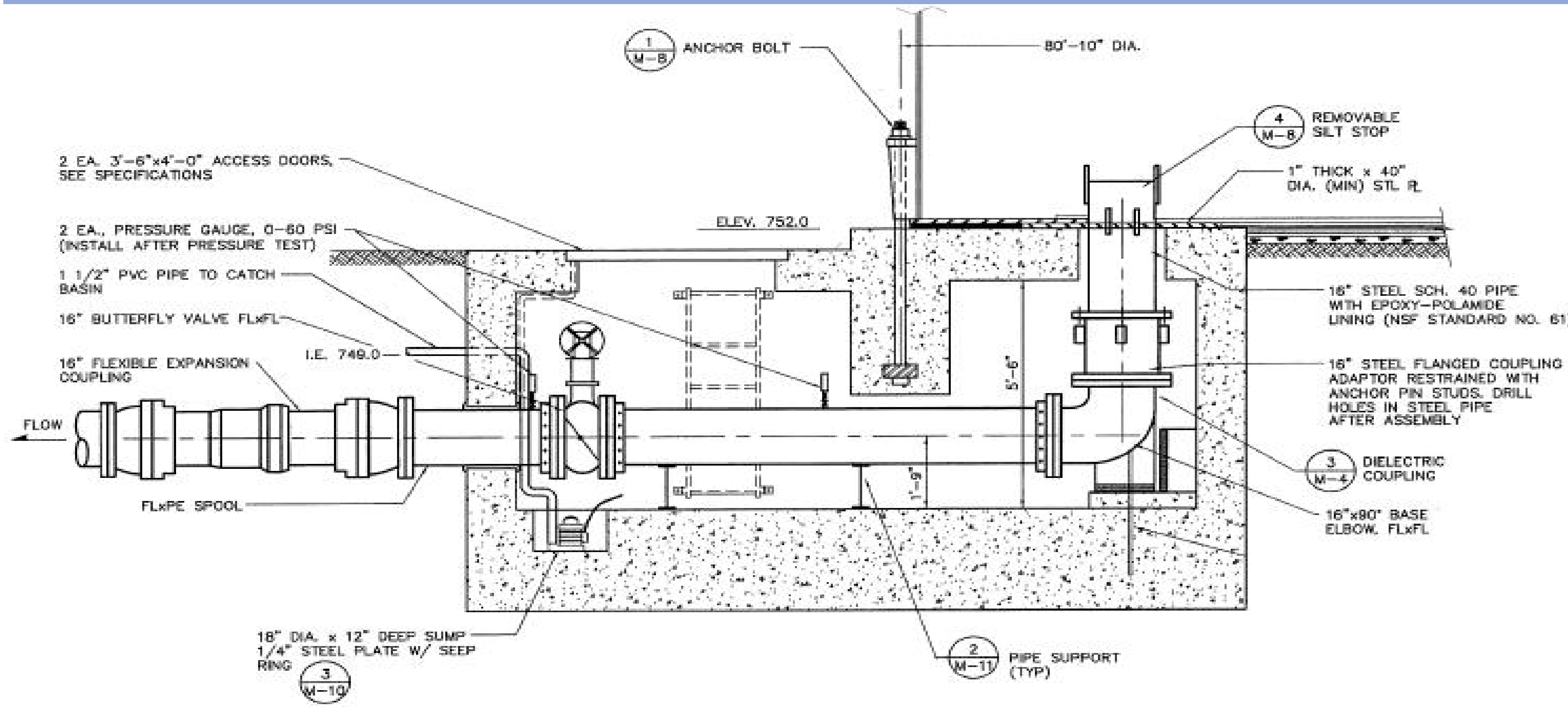
Reservoir Outlet Flexible Coupling



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Seismic Valve

Seismic controllers sense seismic movement and send control signal to valve actuator to close valve.

Can be installed inside a building or at the reservoir.

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Seismic Valve

Seismic valve actuator

Seismic Valve

Seismic valve installation

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Seismic Valve Design Considerations

- Seismic valve must stop catastrophic flows from reservoir due to seismic pipe failure.
- Other types of seismic failures may require water – fireflow, etc.
- Additional controls may improve seismic valve performance.
  - Addition of meter signal
  - Closure only on seismic and very high flow

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Conclusions

- Retrofits are designed to increase stability of the reservoir during seismic events.
- Anchorage and foundation improvements are common.
- Shell reinforcement is sometimes necessary.
- Pipe connection flexibility and seismic valves also may add benefit.

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Questions?

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