AECOM

EARTHQUAKES AND WATER STORAGE RESERVOIR DESIGN

April 29, 2015

AGENDA

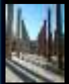
- Background - Seismic Sloshing
- Codes and Load Development
- Implication to a Project
- Impact of Shape on Seismic Loads
- Foundation Alternatives

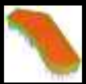
BACKGROUND

- **Earthquake impact on stored water?**
- **April 04, 2010, Baja Mexico**
- **M7.2**
- **Depth ~10Km**

BACKGROUND

- Time Lapse = 25s
- Short period shaking
- Local waves only





BACKGROUND

- Time Lapse = 29s
- Oscillation 0
- Wave height = +1 ft

BACKGROUND

- Time Lapse = 32 sec
- Oscillation 1 = 3 sec
- Wave height = +1 ft

BACKGROUND

- Time Lapse = 38 sec
- Oscillation 2 = 6 sec
- Wave height = 2-3 ft

BACKGROUND

- Time Lapse = 42 sec
- Oscillation 3 = 4 sec
- Wave height = 3-4 ft

BACKGROUND

- **Time Lapse = 46s**
- **Oscillation 4 = 3 sec**
- **Wave height = 3-4 ft**

LOAD DEVELOPMENT

<u>Model Structure Codes:</u>

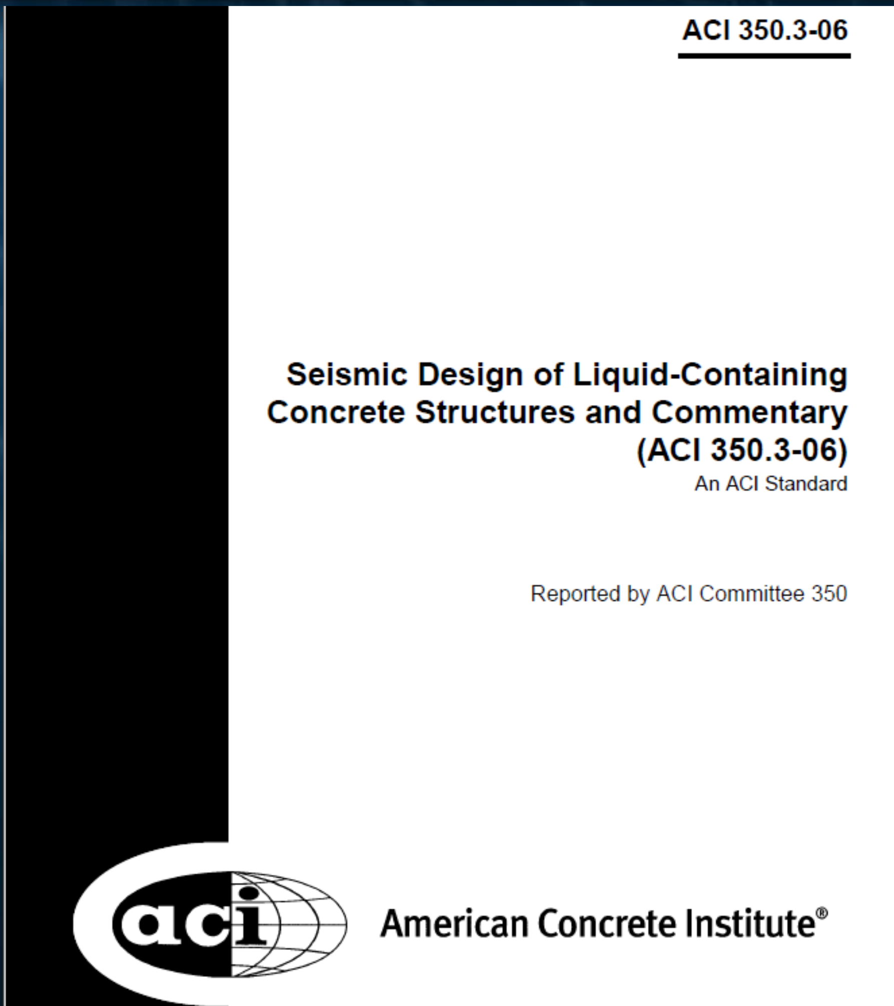
- **Washington State Building Code (SBCC)**
- **Oregon Structural Specialty Code (OSSC)**
- **International Building Code**

<u>Load Development:</u>

- **ASCE7 – Minimum Design Loads for Buildings and Other Structures**
- **Defers to tank specific codes with modifications**

All Concrete	Stressed Concrete	Steel	Other
ACI 350.3	AWWA D110, D115	AWWA D100, D103	API 650

SEISMIC SLOSHING LOADS


ACI 350.3-06

Seismic Design of Liquid-Containing Concrete Structures and Commentary (ACI 350.3-06)

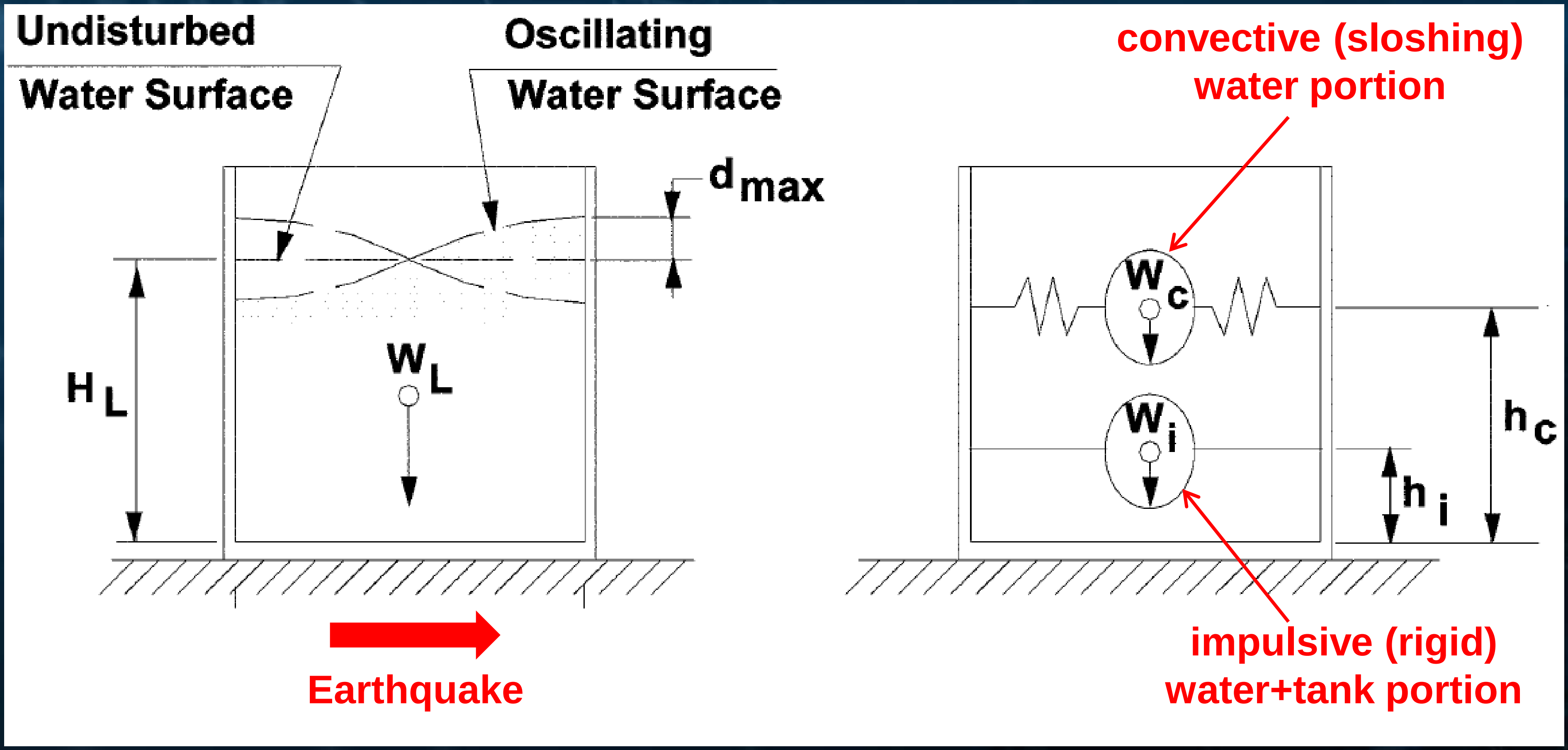
An ACI Standard

Reported by ACI Committee 350

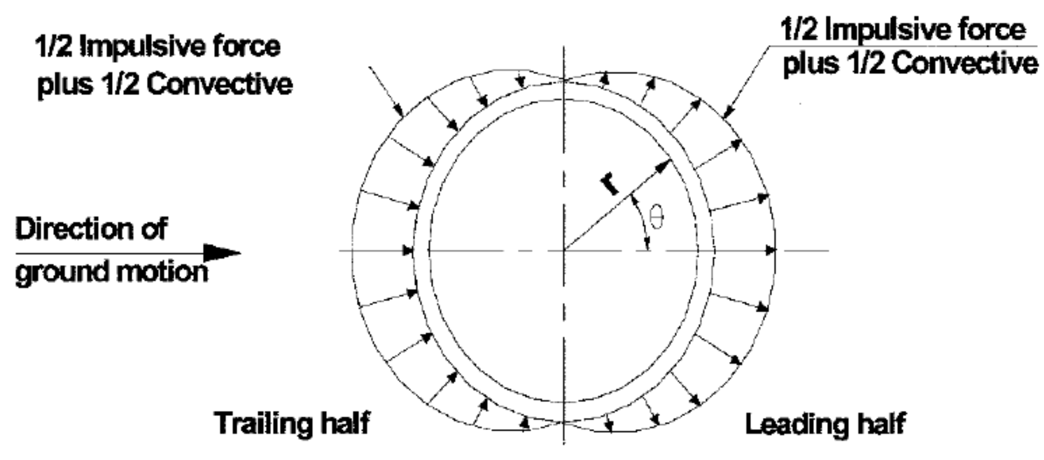
American Concrete Institute®

- ACI 350.3, AWWA and API publications all generally rely on G.W. Housner methodology for sloshing (hydrodynamic) loads
- Housner 1963 methodology adopted in USA, NZ, Japan, India, others

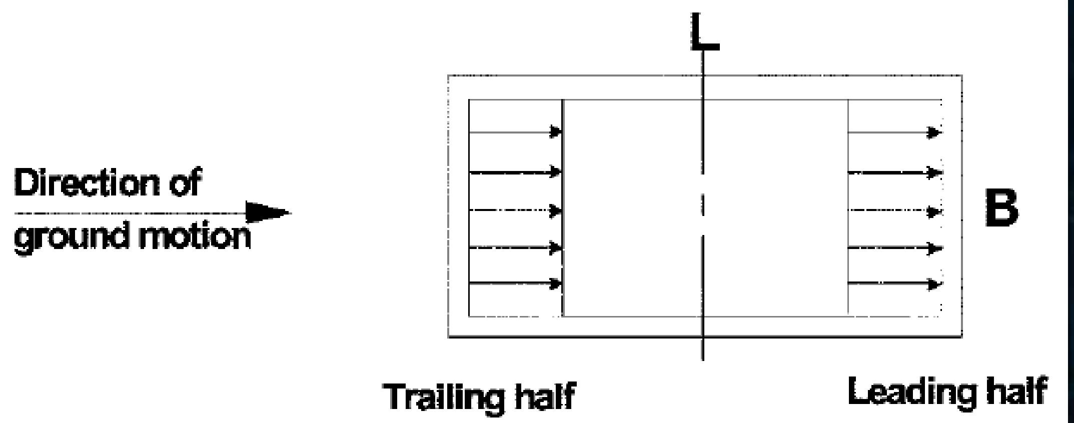
LOAD DEVELOPMENT



LOAD DEVELOPMENT

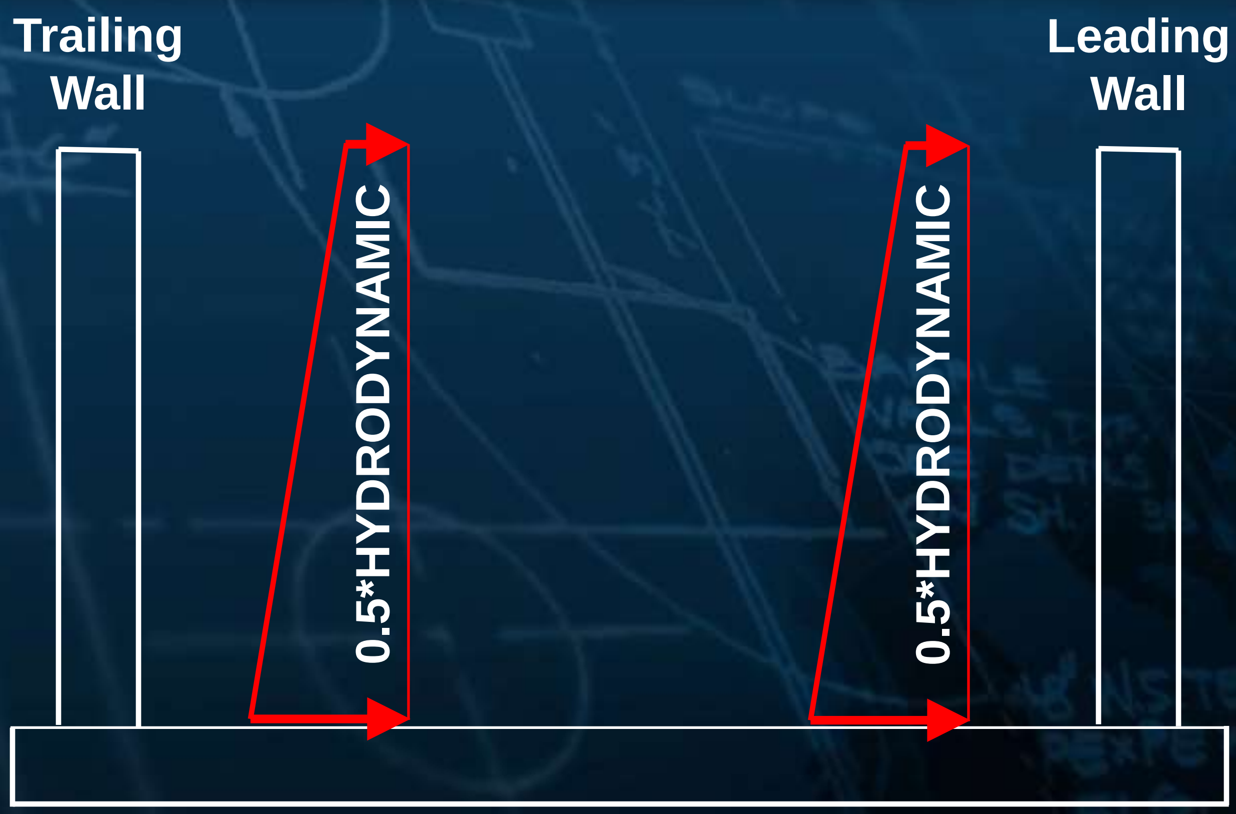


CIRCULAR TANK



RECTANGULAR TANK

LOAD DEVELOPMENT



TYPICAL PROJECT

THE GOAL:

Seismically resilient system

SEISMIC DILEMA?

If funding is limited and seismic loads add to the total design load, do you have to build a smaller Reservoir?

THE CHALLENGE:

Utilize a design approach that minimizes seismic loads

SEISMIC DESIGN PARAMETERS WE CAN CONTROL

- **Intensity of ground shaking, acceleration**
  - Site specific history, but low rate of return

- **Reservoir layout (buried, above grade, plan dimensions, depth)**
  - What impact does reservoir shape have on seismic sloshing loads

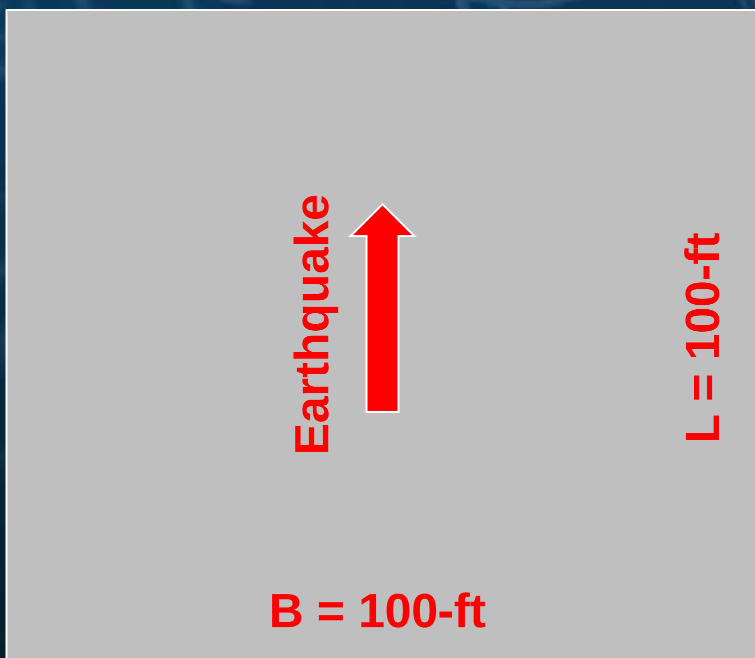
- **Site selection and geotechnical conditions**
  - How do different foundation types resist seismic sloshing and inertia loads

ABOVE GROUND vs BELOW GROUND

Above Ground

Buried (getting there)

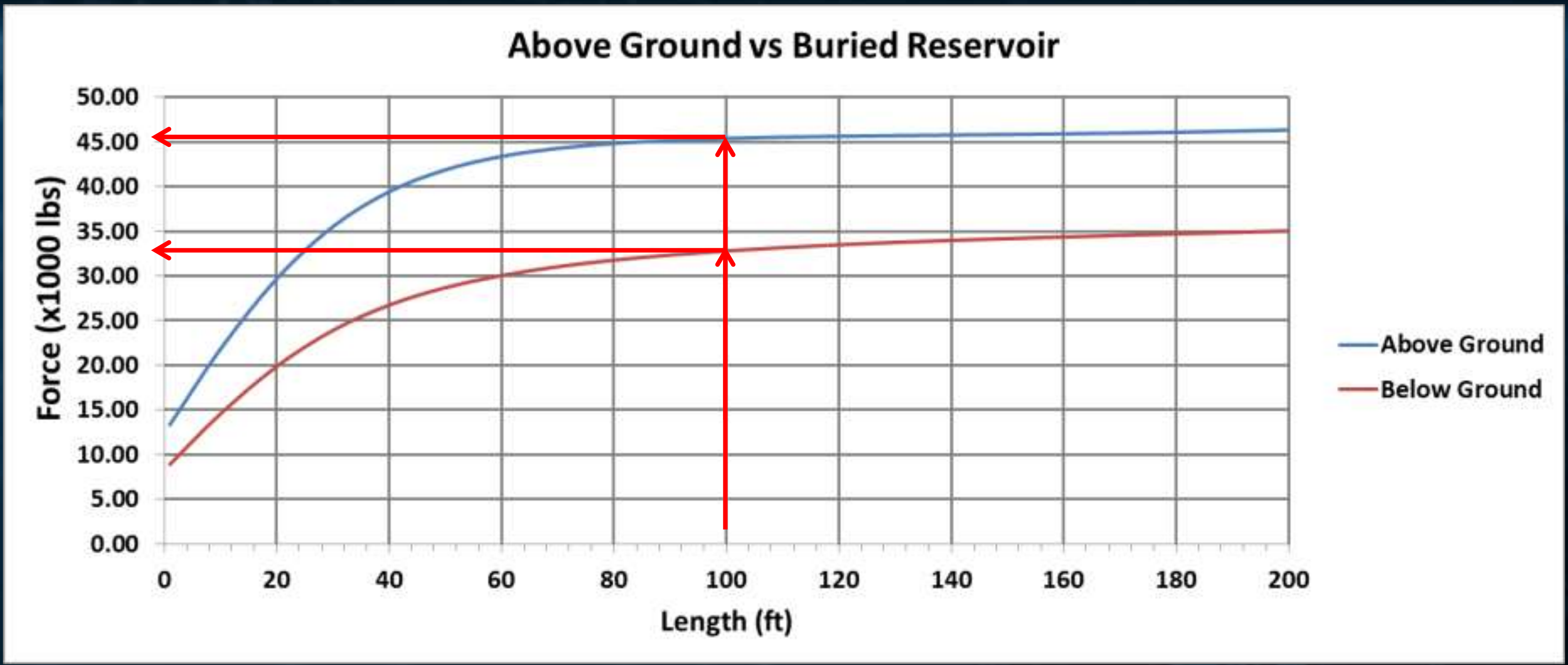
ABOVE GROUND vs BELOW GROUND



Plan Layout

- **Plan length (L) = 100-ft**
- **Plan width (B) = 100-ft**
- **Water depth (HL) = 30-ft**
- **Sds = 0.73**
- **Ie = 1.50**
- **Ri = 2.0 (above)**
- **Ri = 3.0 (below)**
  - Response modification coefficient

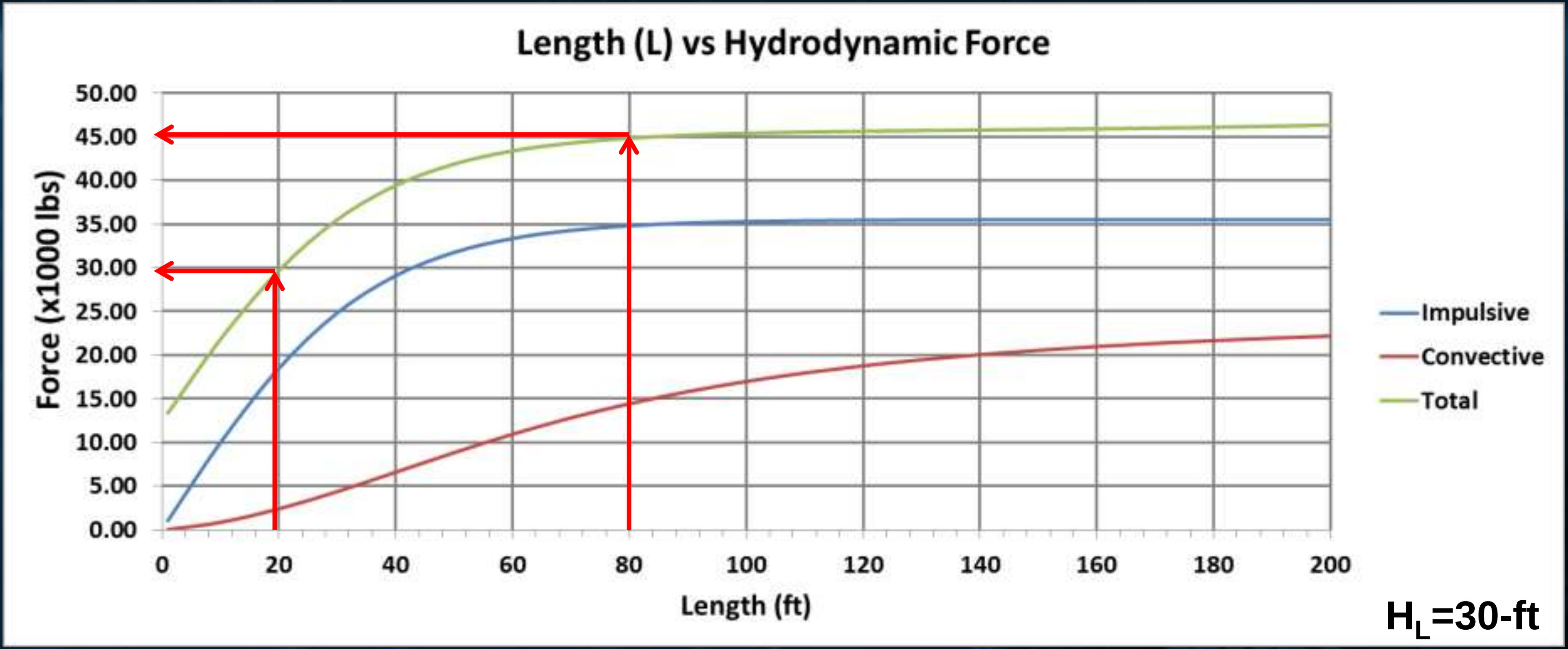
ABOVE GROUND vs BELOW GROUND



Observation:

Buried reservoir seismic for 40% less

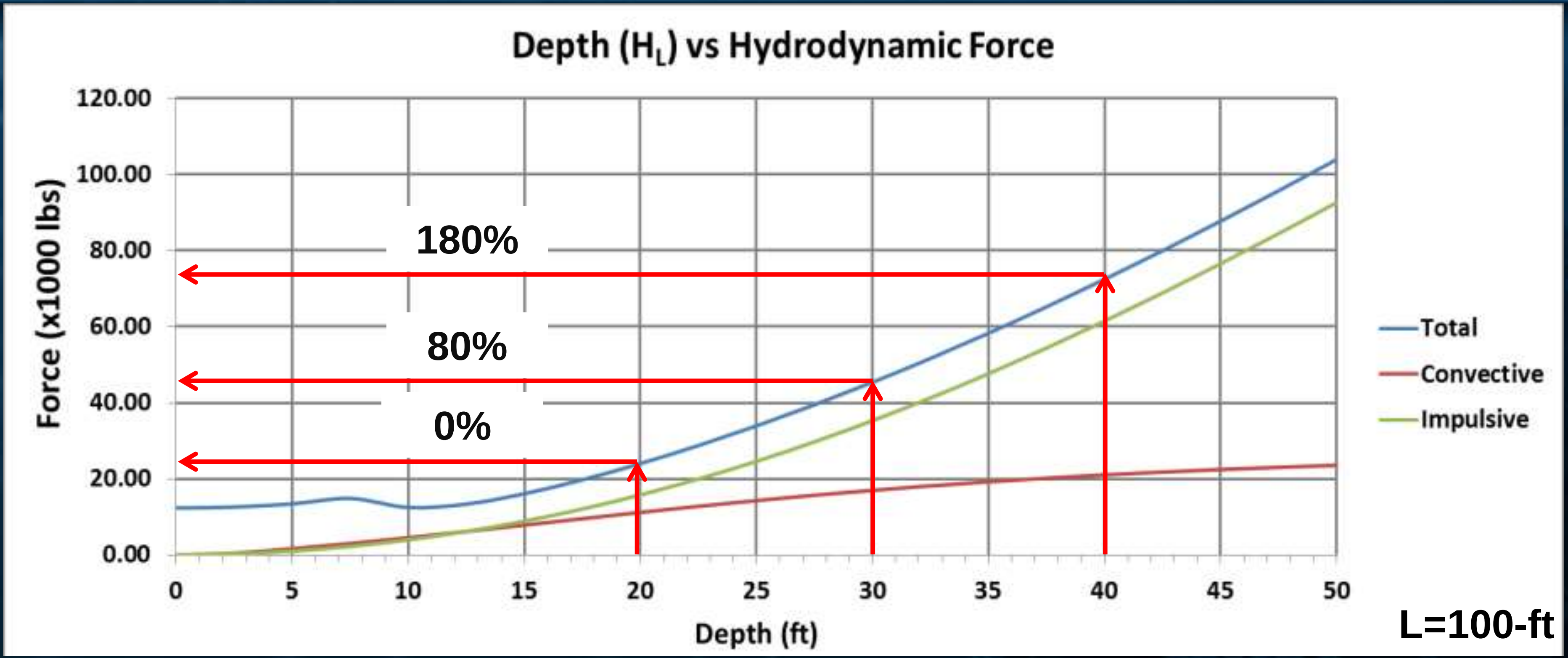
PLAN DIMENSIONS (L & W)



Observation:

In order to get a reduction in load, impractical reservoir size is required

DEPTH (HL)



Observation:

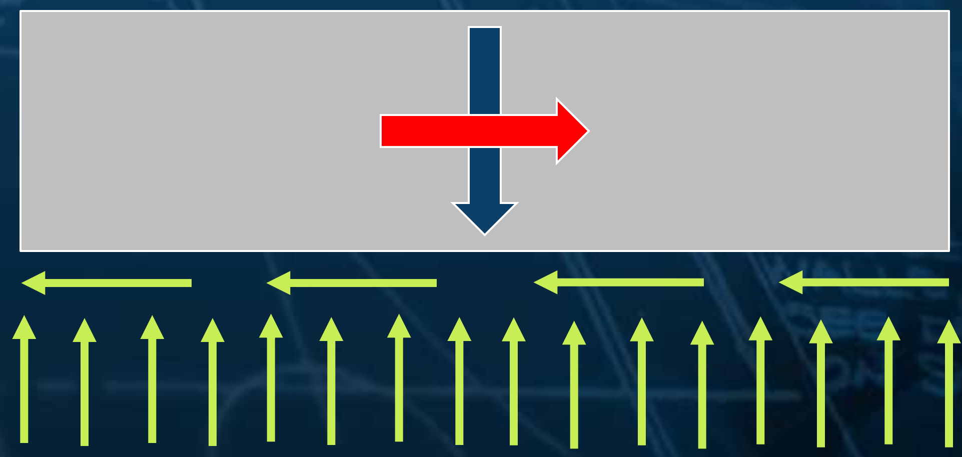
Depth plays a significant role in seismic load

Consider larger footprint, shallower depth

FOUNDATION SYSTEMS

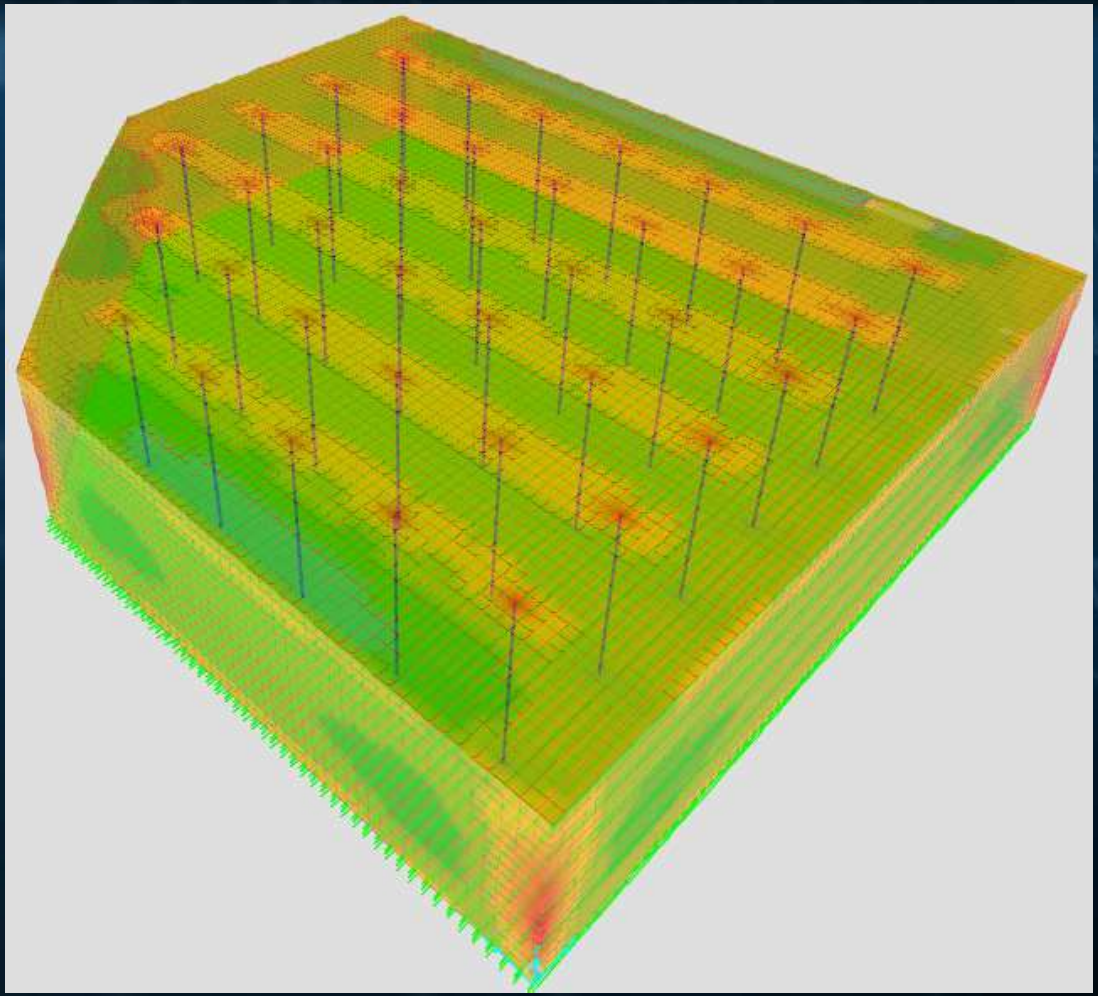
- **Site geology**
  - Quality of below ground soils
  - Stability, landslide, groundwater
- **Sensitivity to ground movement / settlement**
  - Water tightness
- **Two common foundation systems**
  - *Slab on grade, mat foundation*
  - *Deep foundations (piers, piles)*

MAT FOUNDATION



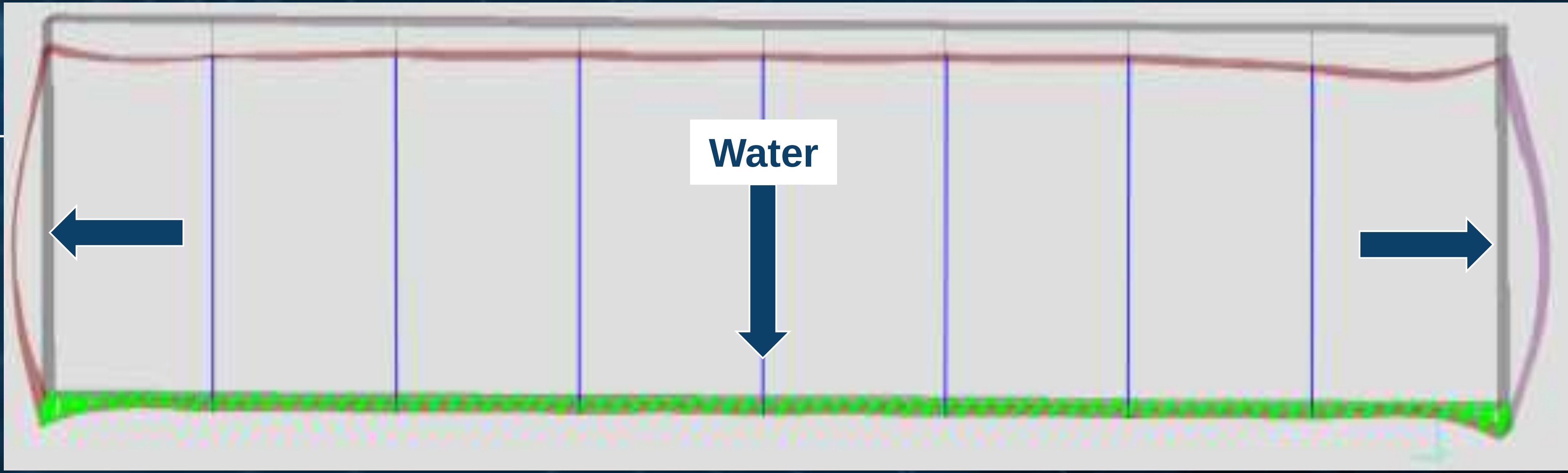
- **Vertical loads to soil via contact area of mat**
- **Horizontal loads to soil via friction over area of mat**

MAT FOUNDATION – Sample Reservoir



- 8.0MG
- 175ft x 200ft
- 38-ft deep
- Bury depth varied from full to half

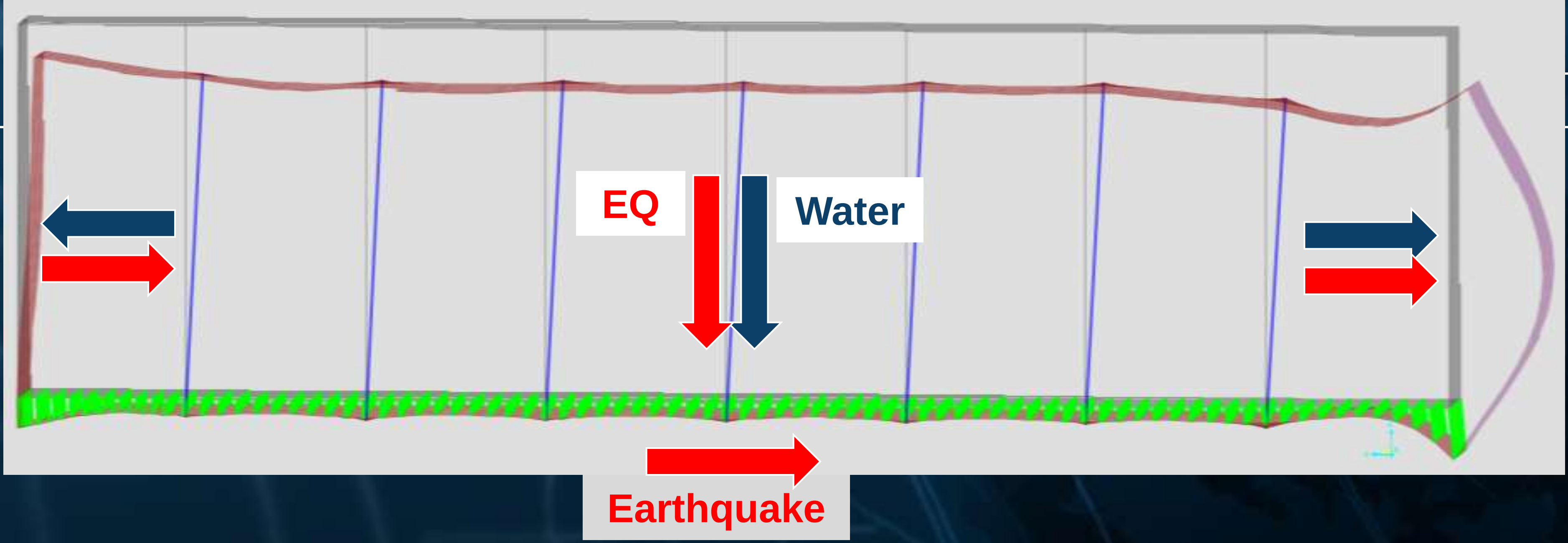
MAT FOUNDATION – Normal Operation



Observation:

Mat foundation effective, max loads at perimeter walls

MAT FOUNDATION – Seismic

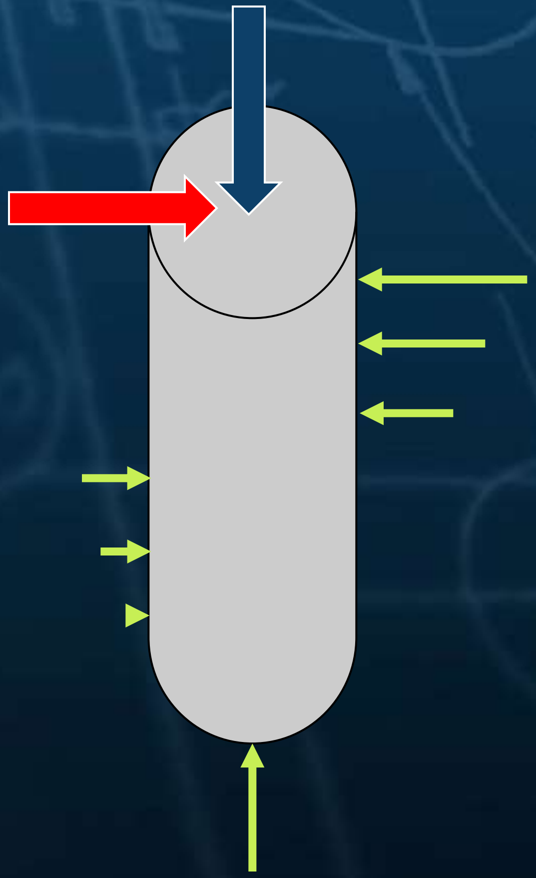


Observation:

Mat foundation effective limiting movement

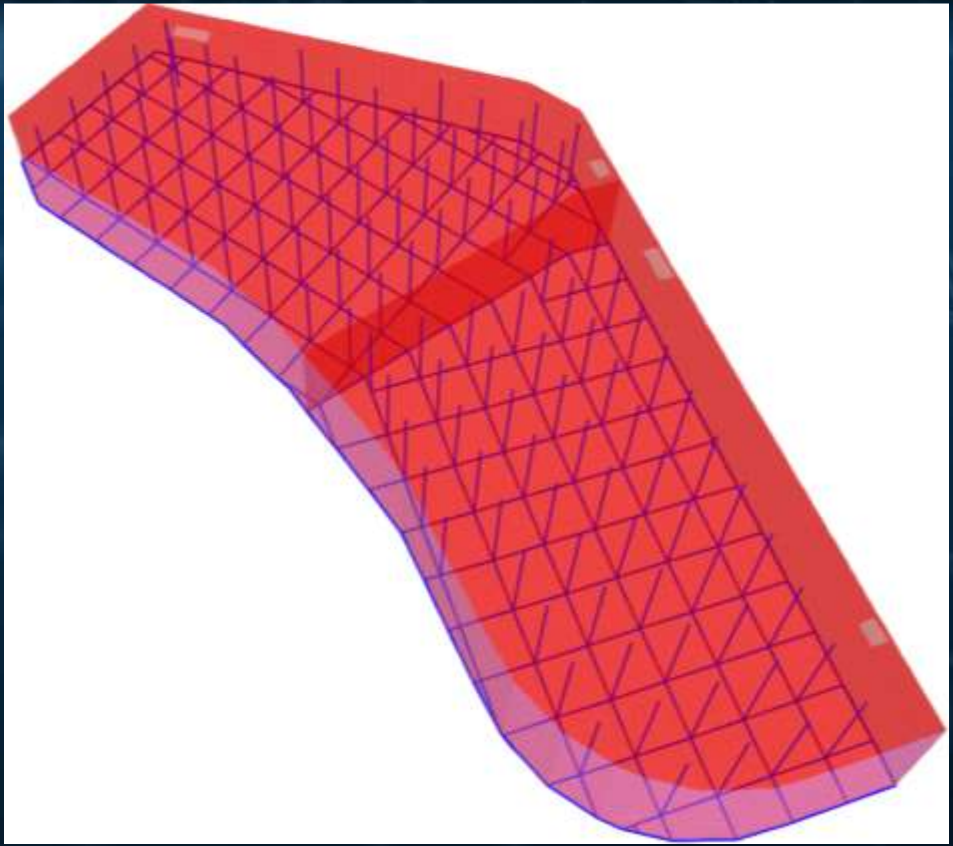
Careful attention to perimeter wall loads

DEEP (PIER) FOUNDATION



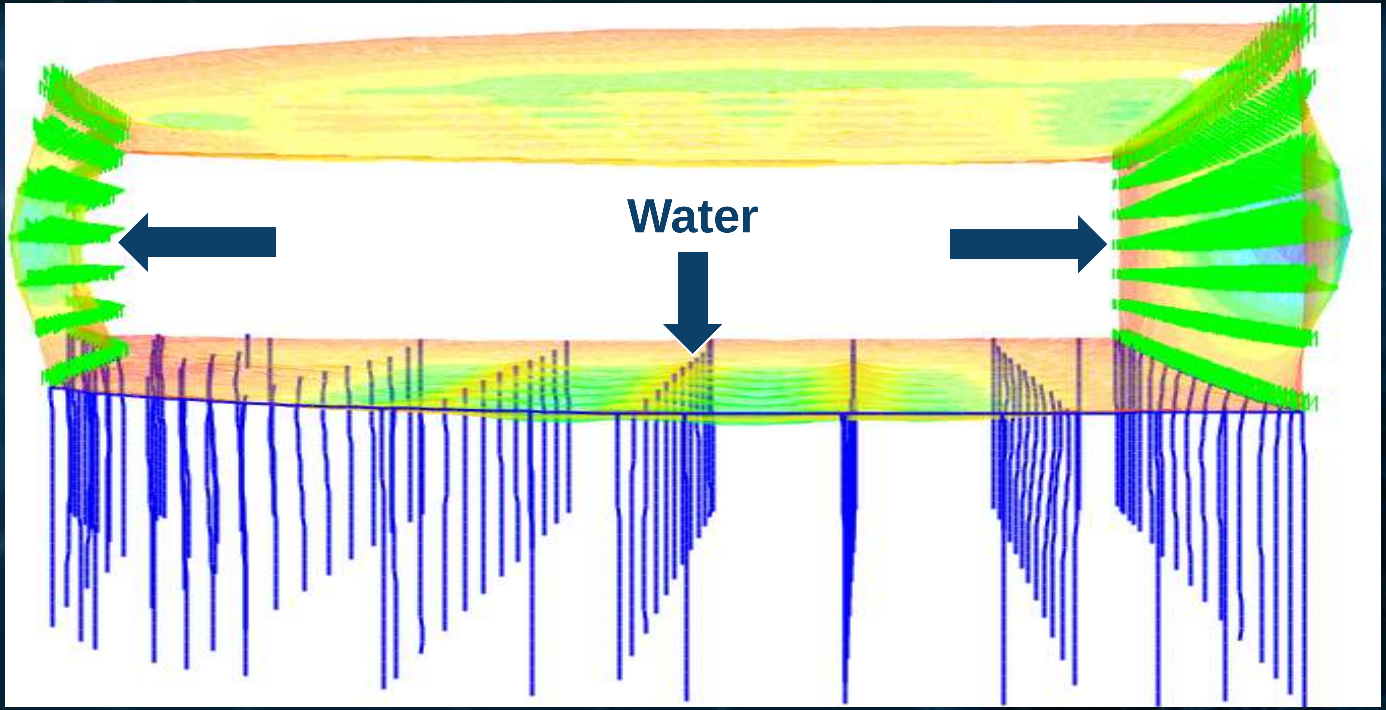
- Vertical load supported by end bearing/skin friction
- Horizontal loads supported by pier deflecting sideways and bearing on soil

DEEP / PIER FOUNDATION – Sample Reservoir



- 12.0MG
- 550ft x 180ft
- Water depth varies 24-ft to 46-ft
- Fully buried

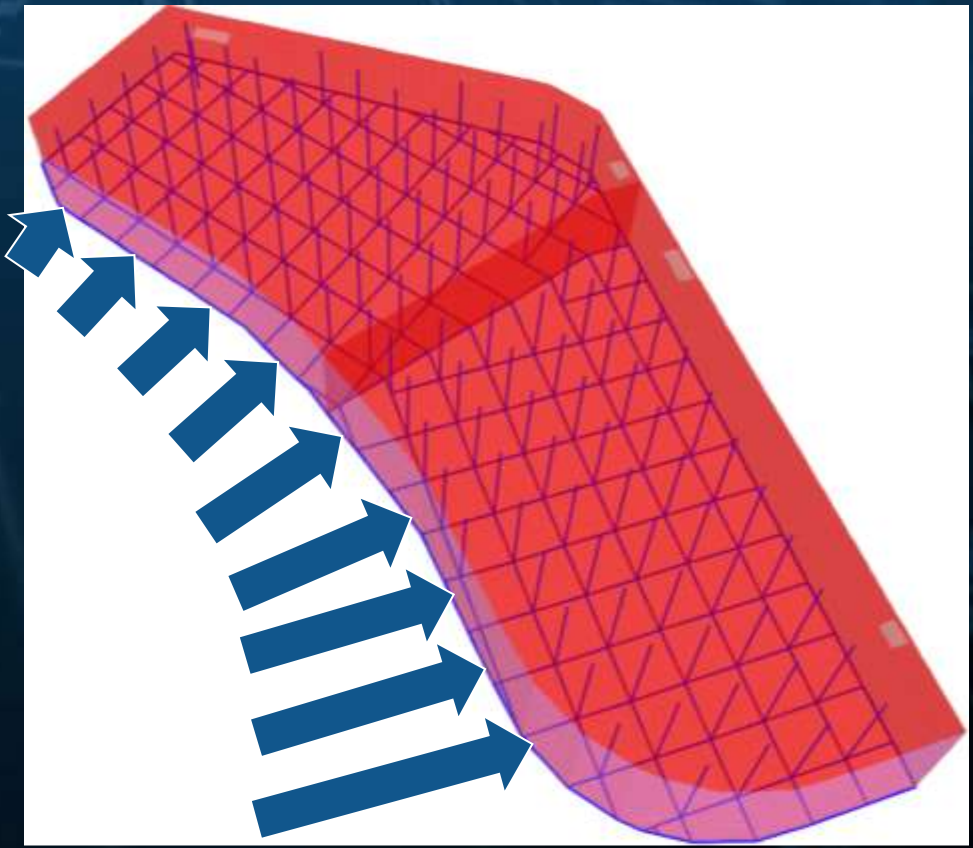
DEEP/PIER FOUNDATION



- Static loading conditions
- Bottom slab spans between individual piers
- Minimal pier deflection at perimeter walls

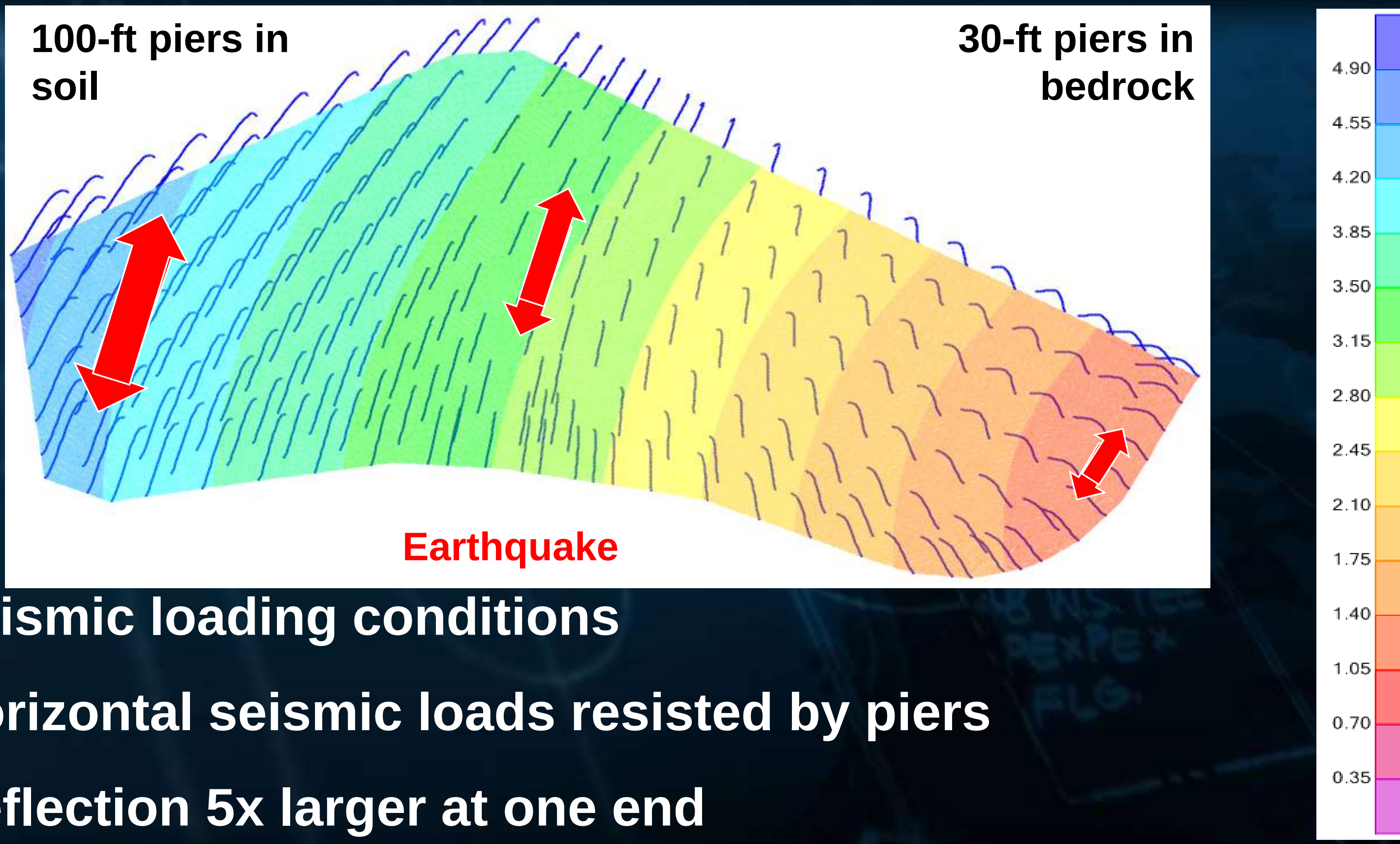
DEEP/PIER FOUNDATION

Hw = 24ft



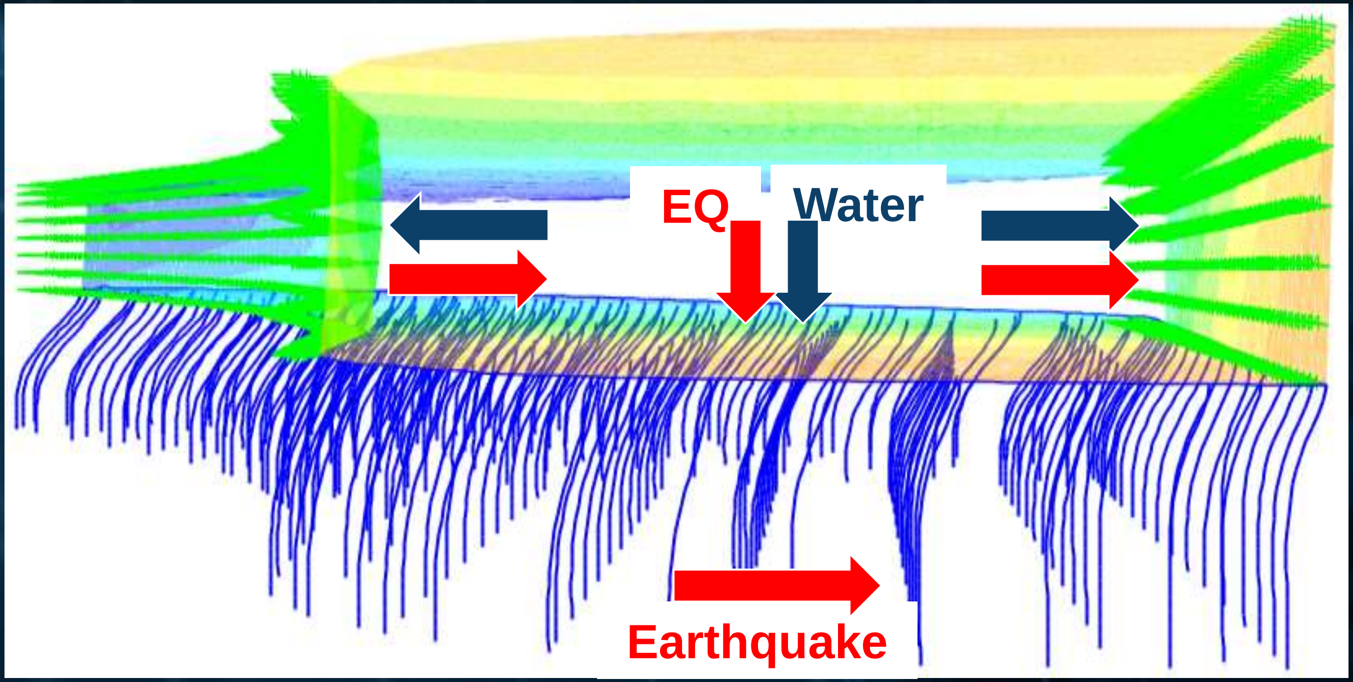
Hw = 46ft

DEEP/PIER FOUNDATION



- Seismic loading conditions
- Horizontal seismic loads resisted by piers
- Deflection 5x larger at one end

DEEP/PIER FOUNDATION



- **Seismic loads deflect structure laterally**
- **Piers deflect, compress soil and provide restraint but only after horizontal deflection**

CONCLUSIONS

- **Seismic loads add to other design loads**
- **Increased loads can = higher construction cost**
- **Select layout and design parameters to minimize seismic effect**
  - Buried vs above ground
  - Plan dimensions
  - Depth
  - Investigate alternative sites, and site geology carefully

QUESTIONS?

Thank You