




American Concrete Institute®
Advancing concrete knowledge

Design and Construction of Concrete Tanks for Refrigerated Liquefied Gas Containment, Part 2

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Michael S. Brannan, P.E. Retired civil/geotechnical engineer whose worldwide foundation experience in many different projects including refrigerated liquid gas storage provided the committee with a broad perspective on what is necessary and achievable within the code. Mike has provided geotechnical engineering expertise for onshore and offshore projects. Mike was Staff Upstream Civil/Geotechnical Engineer, Chief Geotechnical Engineer for Phillips Petroleum, Civil Engineer for Van Gundy & Associates, and Captain in the US Army Corps of Engineers at Fort Leonard Wood and the Mekong Delta of Viet Nam. He grew up operating heavy construction and farm equipment and attained Eagle Scout rank in Western Kansas. He has degrees in Civil Engineering and Geology from Kansas State University and a Masters in Civil/Environmental Engineering from the University of Oklahoma. He has attended a host of seminars and short courses as well as presenting seminars and portions of courses on several topics.

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Chapter 10 Foundations ACI 376-10

Supporting Concrete Structures
Containing
Refrigerated Liquefied Gases

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Foundation Types


- Shallow Foundations
 - Annular Rings and Mats
- Deep Foundations
 - Driven or Drilled Piles

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Performance Issues

- Support Live and Dead Loads
- Control Settlement
 - Initial, Long term, & Differential
- Survive Extreme Events
 - Floods, Storms, Earthquakes, Fire

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Geotechnical Investigation

“...and we can save 700 lira by not doing a soils investigation.”

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Geotechnical Engineer


- Comprehensive Investigation
 - Regional Information – Published work
 - Remote Sensing – Aerial or Satellite
 - Geophysics – Seismic, Electromagnetic
 - Field Tests – Cone Penetrometer, Drilling
 - Laboratory Tests



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Soils Properties Necessary


- Areal and Vertical Distribution of Soil Units
- Thickness of individual Soil Units
- Unit Soil Properties
 - Compressibility – Initial and long term
 - Shear Strength
 - Shear modulus
 - Thermal and Electrical Conductivity
 - Drainage properties



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Basic Information


- Structural Engineer to Geotechnical Engineer
- Tank and Foundation Configuration
- Gravity Loads, Wind & Seismic forces
- Tension Uplift Forces
- Permissible Settlement Limits
- Types of Foundations to be considered



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Boreholes & Cone Penetrometers


- One at Center & Three on Perimeter
- Greater than 100 ft, one additional for each 10,000 sq ft of tank area.
- Depth to below significant influence < 10% or to competent stratum
- Push CPT's to refusal (25 ton)
- Center to 1.5 D, perimeter to 0.85 D min.



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Earthquake Geotechnics


- Site Specific Seismic Hazard Assessment
 - Ground Accelerations, Velocities, & Displacements
 - Used to calculate seismic response of structure
 - Soil-Structure Interaction (Not on Site Class A&B)
 - Soil Liquefaction and Spreading (SSE & OBE)
 - Mitigation methods and potential



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Shallow Foundation Design

- Allowable Bearing Pressure (lesser of)
 - Permissible Total & Differential Settlement
 - Ultimate Bearing Pressure / Min. Factor of Safety
 - Minimum Factor of Safety – Table 10.1
 - Edge shear and Base shear
- Overturning & Anchorage
- Sliding Resistance Min. Factor of Safety
 - 1.5 for Wind & OBE – 1.2 SSE



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SETTLEMENT

- Uniform permitted if structure accommodates
- Differential or Uniform (Planar) tilting limited to 1/500
- Dishing on radial lines (max. 3/8" 1/300)
- Footing around perimeter lesser of
 - 1/500 or maximum calculated for uniform tilting
- Consider adjacent tanks, soil stiffness, etc.

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Deep Foundations

- Numerous individual components additive
- Driven & Cast-In-Place Piles
- Pile Selection Study (Availability & COST)
- Pile Testing Program (Earlier the Better)
- Pile Driving Effects
- Settlement – Down Drag & Negative Skin Friction

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Deep Foundation Design

- Allowable Pile Capacity (lesser of)
 - Permissible Total & Differential Settlement
 - Ultimate Pile Capacity / Min. Factor of Safety
 - Minimum Factor of Safety – Table 10.2
 - Structural Strength of Pile
- Overturning & Uplift
- Lateral Load Resistance

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Ground Improvement

- Remove and replace w/better material
- Soil density improvement
- Vibrating pile driver spud (Vibrocompaction)
- Dynamic compaction (40 to 100ton weight drop)
- Wick drains to enhance settlement
- Preload with excess overburden (20+ meters)
- Deep soil mixing w/cement etc.

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Foundation Details

- Groundwater – bottom of tank always above
- Drainage – away from tank to sump
- Foundation heating – control frost heave
 - Heating cables
 - Ventilated foundation (air gap)
 - Well drained granular soil with deep water table

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Foundation Monitoring

- Settlement
 - Min. 8 permanent survey points (divisible by 4)
 - Spaced no more than 33 ft around perimeter
- Inclinerometers to measure dishing
- Thermal system to cover bottom area
- Seismic w/accelerometers on foundation, roof and free field reference point (total 3)

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Monitoring Frequency

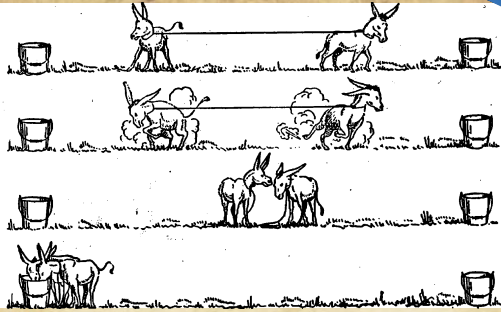
- Settlement – during construction, hydrotesting, commissioning and annually
- Inclinometers – within a week of settlement
- Thermal – cool down, in-service commissioning and at least weekly
- Seismic – continuous w/ regular maintenance
- Corrosion – twice a year

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Inspection & Testing

- Code provides for minimum requirements for testing of materials and installation
- Code also provides for minimum qualifications of welders, inspectors and technicians
- Code provides for minimum documentation to be retained and furnished to the owner

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Communication & Cooperation

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Questions?

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Final Thoughts

- **Dirt Ain't Cheap!!**
- **Mother Earth is very tricky!!**
- Like surgeons, Geotechs bury their mistakes and you still owe the bill.
- The more you know, the lower the safety factor required!
- The sooner you know it, the less it costs

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