GEOTEchnical engineering considerations for energy development projects
Introduction

- Future Energy Demand Projections
- Energy Facilities
  - Liquefied Natural Gas (LNG)
  - Electric Transmission Lines
  - Gas Pipelines
  - Geothermal Energy
- Brief Overview of Demand for Projects
- Geotechnical Design Aspects
- Case Histories
Energy Demand Projections

Figure 35. Delivered energy use by fuel, 1980-2030 (quadrillion Btu)

- History
- Projections
- Liquid fuels
- Natural gas
- Electricity
- Coal
- Renewables

Courtesy of Energy Information Administration
Annual Energy Outlook 2007
Energy Demand Projections

Figure 77. Net U.S. imports of natural gas by source, 1990-2030 (trillion cubic feet)

- History
- Projections
- Overseas LNG
- Canada
- Mexico


Courtesy of Energy Information Administration
Annual Energy Outlook 2007
LNG Facilities - Introduction

FERC

Existing and Proposed North American LNG Terminals

As of February 14, 2007

* US pipeline approved, LNG terminal pending in Balances
** Construction suspended

Office of Energy Projects
LNG Facilities - Introduction

- LNG sites are located in waterfront environments
- Marine depositional environment – challenging subsurface conditions
- Seismic risk evaluation
- Liquefaction susceptibility and lateral spreading
LNG Facilities - Introduction

- Pressurized storage tank
- Containment dike
- Waterfront structures
- Ancillary equipment
LNG Facilities – Tank Design

- Walls supported on ringwall foundation (typical load = 10 kips per l.f. of wall)
- Tank bottom supported on ground. (Pressure across tank bottom = 3,600 psf).

Settlement Criteria
- Dishing settlement criteria (6 in. from edge to center)
- Differential settlement around ringwall (3/8 in. max over 30 ft. arc length)
- Tilting settlement (<4 in. from side to side)
LNG Facilities – Tank Design

- Subsurface Investigations
  - Minimum of five borings at tanks (more where subsurface conditions are complex)
  - Large footprint results in deep zone of influence
  - Four to eight borings at containment dike
  - Install wells to determine groundwater level
LNG Facilities – Tank Design

- Foundation Design Analyses
  - Total Settlement
  - Differential Settlement
- Global Bearing Capacity
- Shallow foundations
- Consider ground improvement
Sites often have limited footprint.

Depending on location, materials suitable for dike construction may not be readily available.

Steepened sideslopes (1.5H:1V)

Soil-cement on flanks (2.5 m wide).

Perform slope stability analysis to estimate shear strength needed for adequate safety factor.

Estimate percent cement required with laboratory testing.
LNG Facilities – Waterfront Structures

- Unloading Platform
- Mooring Dolphins
- Breasting Dolphins

Photo Courtesy of Chicago Bridge & Iron Company
LNG Facilities – Waterfront Structures

- Structures subjected to high lateral loads from:
  - Tanker loads
  - Wind and wave action (design for Category 5 hurricane)
LNG Facilities – Waterfront Structures

- Features typically supported on driven piles or drilled piers depending on subsurface conditions
- Lateral loads on vertical piles result in high bending stresses
- Large diameter foundation elements to control lateral deflections
- Lateral loads commonly resisted by battered piles
- Uplift loads (100 to 550 kips per pile)
- Compression loads (160 to 480 kips per pile)
- Design to limit lateral deflections to 1 in. max.
LNG Facilities – Waterfront Structures

■ Engineering Analysis
  • Axial Capacity
    u Estimate soil properties (friction angle, cohesion, and unit weight).
    u Estimate rock properties including compressive strength.
    u Use engineering properties to estimate allowable skin friction and end-bearing.
    u Driven Piles - Wave equation analysis to determine capacity, driving criteria, and to evaluate driving stresses.
    u Evaluate allowable uplift – consider two mechanisms
      o Skin friction along foundation element
      o Weight of soil or rock engaged by skin friction.
LNG Facilities – Waterfront Structures

- Engineering Analysis
  - Lateral Capacity
    - Estimate Young’s Modulus values of soil or rock along pile or drilled pier.
    - Evaluate lateral load, bending stresses, and deflections of foundations using LPile or other techniques.
    - Consider group action.
LNG Facilities – Shipping Channel

- 800-ft. wide shipping channel at least 45 ft. deep.
- Dredging often required.
- Slope stability of dredged channel
- Re-use of dredged materials during site development to avoid disposal.
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History

- Tank Area
  - Drilled 5 test borings and 83 test probes. (Probes intended to investigate for solution cavities)
  - Limestone – Rock generally competent with the exception of two 1-m. dia. solution cavities
  - Footings on bedrock
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History

- Plant Area
  - Drilled 7 test borings, and 59 test probes.
  - Limestone – More significant voids encountered in bedrock. Precipitation leaching through vegetation created carbonic acid, which promoted solution cavities.
  - Also observed surface voids up to 10 m deep. Often filled with loose soil or rock.
  - Recommended pressure grouting to improve bedrock for support of spread footings.
  - Grout holes advanced on 3 to 4 m square primary pattern to depths ranging between 5 and 10 m depending on rock conditions and structure load.
  - Loose soil or rock in surface voids was removed and voids were filled with concrete.
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
LNG Facilities – Case History
Electric Transmission Lines - Introduction

- FERC providing incentives for development of transmission lines to create more competitive markets for electricity.
- Upgrade transmission systems with more efficient technologies to meet increased demand.
- Transmit electricity from regions with resources to areas of demand (e.g. wind energy from Plains States or coal from Wyoming).
- Several thousand miles of new transmission lines planned
# Electric Transmission Lines - Introduction

![Image](https://kevinasche 통하여기억하기)

## Major Electric Transmission Spending Initiatives

<table>
<thead>
<tr>
<th>Company</th>
<th>Region</th>
<th>Capital Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allegheny Energy</td>
<td>Mid-Atlantic</td>
<td>$350-million project 2007-2011</td>
</tr>
<tr>
<td>American Electric Power</td>
<td>Mid-Atlantic South</td>
<td>$9 billion of identified projects</td>
</tr>
<tr>
<td>ITC Holdings</td>
<td>Michigan</td>
<td>$1.8 billion 2005-2012</td>
</tr>
<tr>
<td>Northeast Utilities</td>
<td>New England</td>
<td>$2.4 billion 2006-2011</td>
</tr>
<tr>
<td>Xcel Energy</td>
<td>Great Plains</td>
<td>$1.5 billion-$2.0 billion</td>
</tr>
<tr>
<td>PG&amp;E Corp.</td>
<td>Northern &amp; Central Calif.</td>
<td>$1.8 billion 2006-2010</td>
</tr>
<tr>
<td>Edison International</td>
<td>Southern Calif.</td>
<td>$2.5 billion 2006-2010</td>
</tr>
<tr>
<td>Sierra Pacific Resources</td>
<td>Nevada</td>
<td>$1.3 billion 2007-2014</td>
</tr>
</tbody>
</table>

*Source: EEI*

Courtesy Engineering News Record
Electric Transmission Lines -
Introduction

- Wide range in subsurface conditions due to changes in geology along alignment.
- Projects often routed through remote areas
- High lateral loads and moments.
Electric Transmission Lines – Foundation Design

- Subsurface Investigations
  - One boring at each tower, 20 to 60 ft. deep. Towers typically 300 to 400 ft. apart.
  - Projects often along alignments of existing transmission lines. Maintain clearance of drilling equipment.
  - Portable equipment needed in areas with challenging access.
Electric Transmission Lines

- Laboratory Testing
  - Unconfined Compressive Strength
  - Brazilian Tensile Test
  - Grain Size Analyses
  - Moisture Content
  - Atterberg Limits
Electric Transmission Lines – Foundation Design

- Lateral loads from wind action and cable (45 to 200 kips).
- Much of the lateral loads is applied near top of tower. High moments (2,800 to 13,000 k-ft.)
- Compression loads (65 to 200 kips)
- Towers typically supported on drilled piers – efficiently resist lateral loads and moments.
- In locations with shallow bedrock, can consider spread footings with tie-down anchors.
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Electric Transmission Lines – Case History
Gas Pipelines - Introduction

- Wide range in subsurface conditions due to changes in geology along alignment.
- Often routed through remote areas; difficult access during explorations and construction.
- River crossings – horizontal directional drilling.
Gas Pipelines - Investigations

- Less intensive subsurface exploration program.
- Light loads – low stress increases.
Gas Pipelines - Investigations

■ Phase One
  • Assist with route selection.
  • Aerial photographic interpretation and review of available published geologic information.
  • Initial terrain analysis to assess surficial conditions and geologic conditions along potential routes.

■ Phase Two
  • Geologic mapping along pipeline route.
  • Test borings on land and from barges at river crossings.
  • Laboratory testing on soil and rock samples.
Gas Pipelines – Design Issues

- Bedrock Excavation
  - Rippable Bedrock/Hoe-Ram
  - Controlled Blasting – cost-effective bedrock removal
  - Vibrations at adjacent structures
  - Avoid fly rock
  - Impact on residential wells
Gas Pipelines – Design Issues

- **Blast Round Design**
  - Use adequate charge weight per volume of rock to break rock thoroughly.
  - Control charge weight detonated at one time to reduce ground vibrations.
  - Delay blasting – 25 to 50 ms delays
Gas Pipelines – Case History
Gas Pipelines – Case History
Gas Pipelines – Case History
Gas Pipelines – Case History
Gas Pipelines – Case History
Gas Pipelines – Case History
Gas Pipelines - Horizontal Directional Drilling

- Steerable drilling process
- Drilling fluid stabilizes hole and removes cuttings
- Multiple steps:
  - Pilot hole
  - Backreaming
  - Pipe installation
- Diameters: 2 in. to 4 ft.
- Drive length: up to 5,000 ft.
Gas Pipelines – Horizontal Directional Drilling

Pilot Hole

Wash Pipe
Wash Pipe Bit
Survey Tool
Pilot String Bit
Drill Profile
Pilot String

Preream

Wash Pipe
Reamer
Drill Pipe

Pullback

Drill Pipe
Reamer Swivel
Product Pipeline

Courtesy Directional Crossing Contractors Association
Gas Pipelines – Horizontal Directional Drilling

- HDD – Design Issues
  - Top of bedrock profile. Drilling in rock is 6 times more expensive than soil.
  - Rock mineralogy (drilling rate; bit wear)
  - Control drilling fluid pressures to prevent frac out.
  - Safe pulling load
Gas Pipelines – Horizontal Directional Drilling

- HDD Design Investigations
  - Review local geologic references (surficial geology maps, bedrock maps, information on faults, etc.)
  - Develop field investigations based on results of initial geology review
  - Geophysical work
    - River bottom profile
    - Top of bedrock profile
    - Obstructions or objects that may provide path for drilling fluid loss
  - Test borings
Gas Pipelines – Horizontal Directional Drilling

- Field and Laboratory Testing
  - Packer Testing in bedrock to evaluate drill fluid loss into formation
  - Thin sections for petrographic analyses to assess rock abrasion and hardness (drilling difficulty)
  - Rock strength testing (unconfined compressive strength, Cershar Hardness)
Gas Pipelines – Horizontal Directional Drilling

Problem Zone
Gas Pipelines – Horizontal Directional Drilling

Factors for Safe Pull Load

- Geometry
- Length
- Ground friction
- Drill fluid drag
- Weight up/down
- Pull rate
Gas Pipelines – Horizontal Directional Drilling
Gas Pipelines - Horizontal Directional Drilling
Gas Pipelines - Horizontal Directional Drilling
Gas Pipelines - Horizontal Directional Drilling
Gas Pipelines – Horizontal Directional Drilling
Gas Pipelines – Horizontal Directional Drilling
Geothermal Energy Systems

- Renewable energy source
- Sustainability/Carbon Footprint Reduction
- Gaining popularity with Leadership in Energy and Environmental Design (LEED) Green Building Rating System™
- University clients
- Heat pump using ground at constant 55 degree temperature to heat water in cold months and cool water in warm months.
Geothermal Energy Systems

- Two types of vertical systems
  - Vertical Closed Loop – 85% of systems
    - Common choice where bedrock is deep
  - Standing Column (Open) – 15% of systems
    - 10 to 20 times more efficient than closed loop
    - 8 to 10-in. dia. rock well
    - Standing column also an option in permeable overburden deposits
Geothermal Energy Systems

- **Subsurface Investigations**
  - Test borings to determine depth to bedrock and type of bedrock. Determines whether use closed or open system.
  - Open systems – pilot test with one well to evaluate fractured zones in bedrock.

- **Design Issues**
  - **Drawdown**
    - Potentially attract contaminated groundwater.
    - Impact on nearby wells.
    - Potentially cause consolidation of deep clays if lower groundwater. Can use recharge wells to reduce impact.
  - **Water Quality** - Biofouling, salinity, mineral deposits.
Geothermal Energy Systems

- Intermediate depth closed loop installed in deep foundations for buildings.

- Suitable foundation elements include slurry wall used for deep basements, drilled piers, concrete-filled pipe piles.

- Low cost

- Used frequently in Europe – rarely used in United States.
Geothermal Energy Systems (Within Foundation)
Construction Phase Services

- Involvement of design engineer is critical to project success.
- Design engineer has best understanding of design assumptions.
- Confirm work is in conformance with contract documents.
  - Foundation installation.
  - Tie-down anchor installation at tower structures.
  - Review contractor blast round designs, perform vibration monitoring.
  - Monitor earthwork and compaction of fill.
Future Trends

- Increased demand for renewable energy projects
  - Wind energy
  - Biomass
  - Solar energy
  - Geothermal energy
  - Biofuels

- Tamarack Energy
Closing Remarks

- Energy development market likely to remain strong for the foreseeable future due to continued increase in demand.
- Geotechnical engineers play a vital role in the success of energy development projects.
- “Easy” sites are gone. Available land often overlooked previously due to poor subsurface conditions.
- Challenge to geotechnical engineers is to provide cost-effective solutions to make projects viable.
QUESTIONS?