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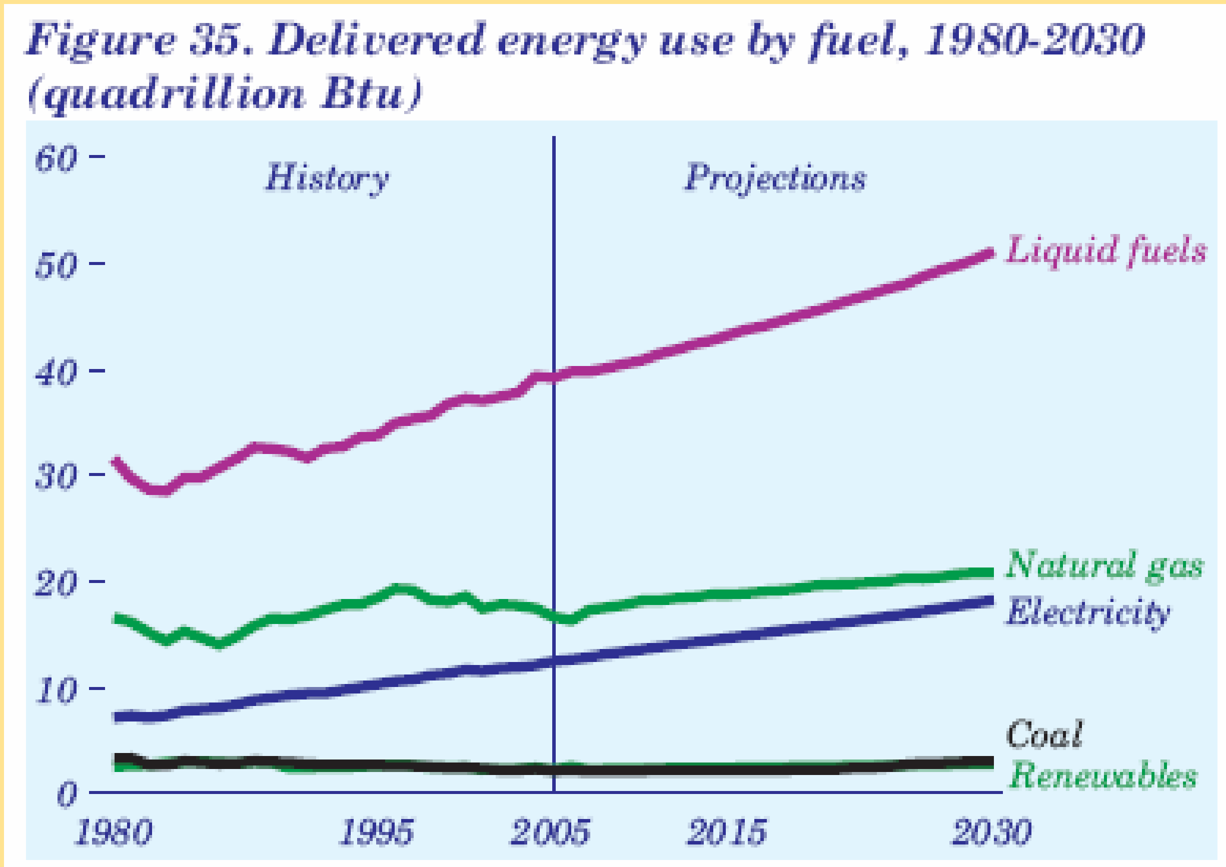
GEOTECHNICAL ENGINEERING CONSIDERATIONS FOR ENERGY DEVELOPMENT PROJECTS

Introduction

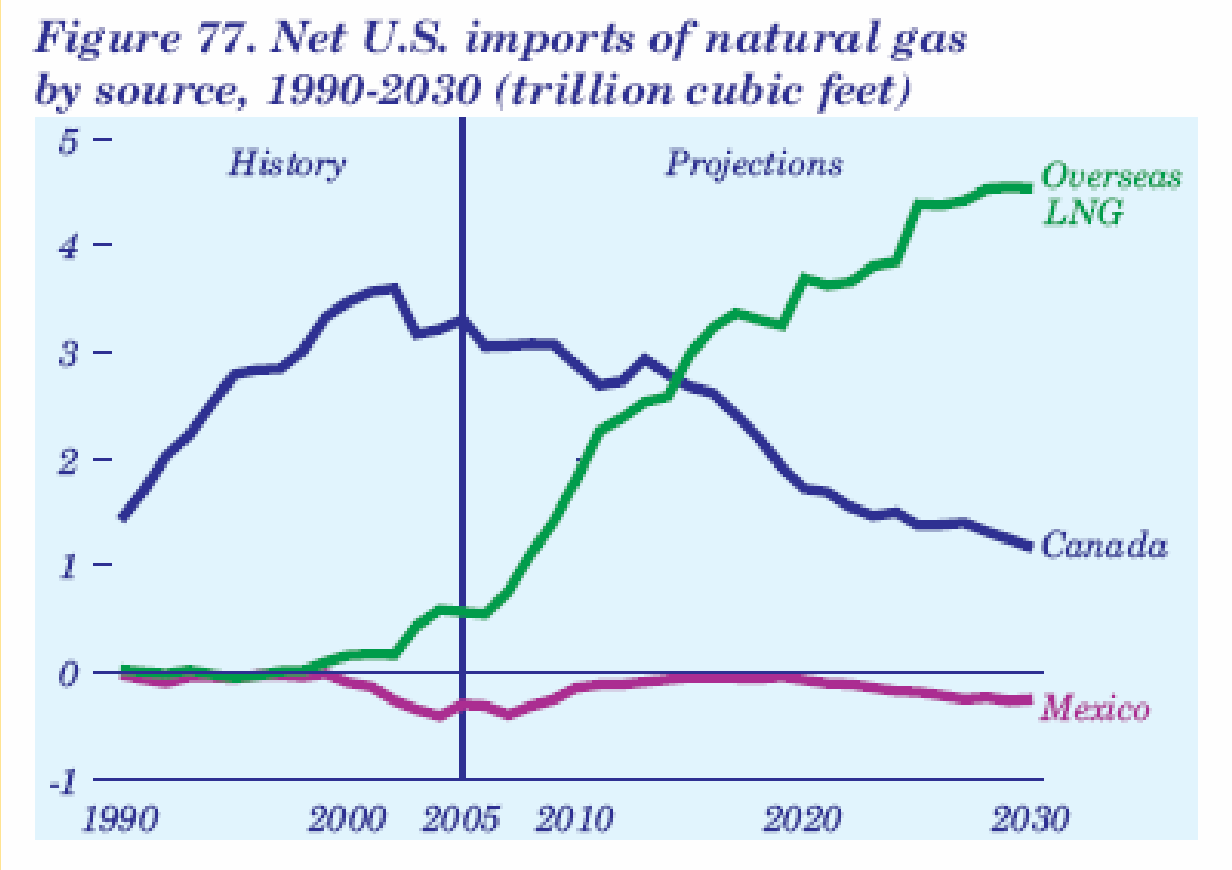
- Future Energy Demand Projections
- Energy Facilities
  - Liquefied Natural Gas (LNG)
  - Electric Transmission Lines
  - Gas Pipelines
  - Geothermal Energy
- Brief Overview of Demand for Projects
- Geotechnical Design Aspects
- Case Histories

Energy Demand Projections



Courtesy of Energy Information Administration
Annual Energy Outlook 2007

Energy Demand Projections

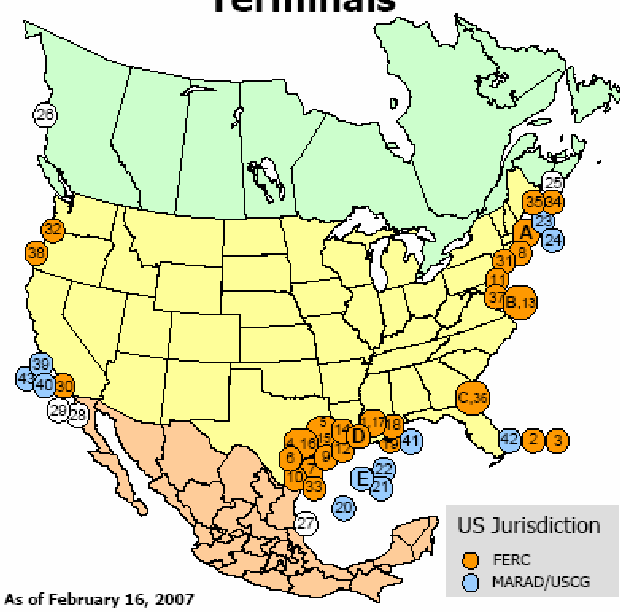


Courtesy of Energy Information Administration
Annual Energy Outlook 2007

LNG Facilities - Introduction

FERC

Existing and Proposed North American LNG Terminals



CONSTRUCTED
A. Everett, MA : 1.035 Bcfd (DOMAC - SUEZ LNG)
B. Cove Point, MD : 1.0 Bcfd (Dominion - Cove Point LNG)
C. Elba Island, GA : 1.2 Bcfd (El Paso - Southern LNG)
D. Lake Charles, LA : 2.1 Bcfd (Southern Union - Trunkline LNG)
E. Gulf of Mexico: 0.5 Bcfd (Gulf Gateway Energy Bridge - Excelerate Energy)

APPROVED BY FERC
1. Hackberry, LA : 1.5 Bcfd (Cameron LNG - Sempra Energy)
2. Bahamas : 0.84 Bcfd (AES Ocean Express)*
3. Bahamas : 0.83 Bcfd (Calypso Tractebel)*
4. Freeport, TX : 1.5 Bcfd (Cheniere/Freeport LNG Dev.)
5. Sabine, LA : 2.6 Bcfd (Sabine Pass Cheniere LNG)
6. Corpus Christi, TX: 2.6 Bcfd (Cheniere LNG)
7. Corpus Christi, TX : 1.1 Bcfd (Vista Del Sol - ExxonMobil)
8. Fall River, MA : 0.8 Bcfd (Weaver's Cove Energy/Hess LNG)
9. Sabine, TX : 2.0 Bcfd (Golden Pass - ExxonMobil)
10. Corpus Christi, TX: 1.0 Bcfd (Ingleside Energy - Occidental Energy Ventures)**
11. Logan Township, NJ : 1.2 Bcfd (Crown Landing LNG - BP)
12. Port Arthur, TX: 3.0 Bcfd (Sempra Energy)
13. Cove Point, MD : 0.8 Bcfd (Dominion)
14. Cameron, LA: 3.3 Bcfd (Creole Trail LNG - Cheniere LNG)
15. Sabine, LA: 1.4 Bcfd (Sabine Pass Cheniere LNG - Expansion)
16. Freeport, TX: 2.5 Bcfd (Cheniere/Freeport LNG Dev. - Expansion)
17. Hackberry, LA : 1.15 Bcfd (Cameron LNG - Sempra Energy - Expansion)
18. Pascagoula, MS: 1.5 Bcfd (Gulf LNG Energy LLC)
19. Pascagoula, MS: 1.3 Bcfd (Bayou Casotte Energy LLC - ChevronTexaco)

APPROVED BY MARAD/COAST GUARD
20. Port Pelican: 1.6 Bcfd (Chevron Texaco)
21. Louisiana Offshore : 1.0 Bcfd (Gulf Landing - Shell)
22. Offshore Louisiana : 1.0 Bcfd (Main Pass McMoRan Exp.)
23. Offshore Boston: 0.4 Bcfd (Neptune LNG - SUEZ LNG)
24. Offshore Boston: 0.8 Bcfd (Northeast Gateway - Excelerate Energy)

CANADIAN APPROVED TERMINALS
25. St. John, NB : 1.0 Bcfd (Canaport - Irving Oil/Repsol)
26. Kitimat, BC: 1.0 Bcfd (Kitimat LNG - Galveston LNG)

MEXICAN APPROVED TERMINALS
27. Altamira, Tamulipas : 0.7 Bcfd (Shell/Total/Mitsui)
28. Baja California, MX : 1.0 Bcfd (Energia Costa Azul - Sempra Energy)
29. Baja California - Offshore : 1.4 Bcfd (Chevron Texaco)

PROPOSED TO FERC
30. Long Beach, CA : 0.7 Bcfd, (Mitsubishi/ConocoPhillips - Sound Energy Solutions)
31. LI Sound, NY: 1.0 Bcfd (Broadwater Energy - TransCanada/Shell)
32. Bradwood, OR: 1.0 Bcfd (Northern Star LNG - Northern Star Natural Gas LLC)
33. Port Lavaca, TX: 1.0 Bcfd (Calhoun LNG - Gulf Coast LNG Partners)
34. Pleasant Point, ME : 2.0 Bcfd (Quoddy Bay, LLC)
35. Robbinston, ME: 0.5 Bcfd (Downeast LNG - Kestrel Energy)
36. Elba Island, GA: 0.9 Bcfd (El Paso - Southern LNG)
37. Baltimore, MD: 1.5 Bcfd (AES Sparrows Point – AES Corp.)
38. Coos Bay, OR: 1.0 Bcfd (Jordan Cove Energy Project)

PROPOSED TO MARAD/COAST GUARD
39. Offshore California : 1.5 Bcfd (Cabrillo Port - BHP Billiton)
40. Offshore California : 0.5 Bcfd, (Clearwater Port LLC - NorthernStar NG LLC)
41. Gulf of Mexico: 1.4 Bcfd (Bienville Offshore Energy Terminal - TORP)
42. Offshore Florida: 1.9 Bcfd (SUEZ Calypso - SUEZ LNG)
43. Offshore California: 1.2 Bcfd (OceanWay - Woodside Natural Gas)

As of February 16, 2007

** US pipeline approved; LNG terminal pending in Bahamas*
*** 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

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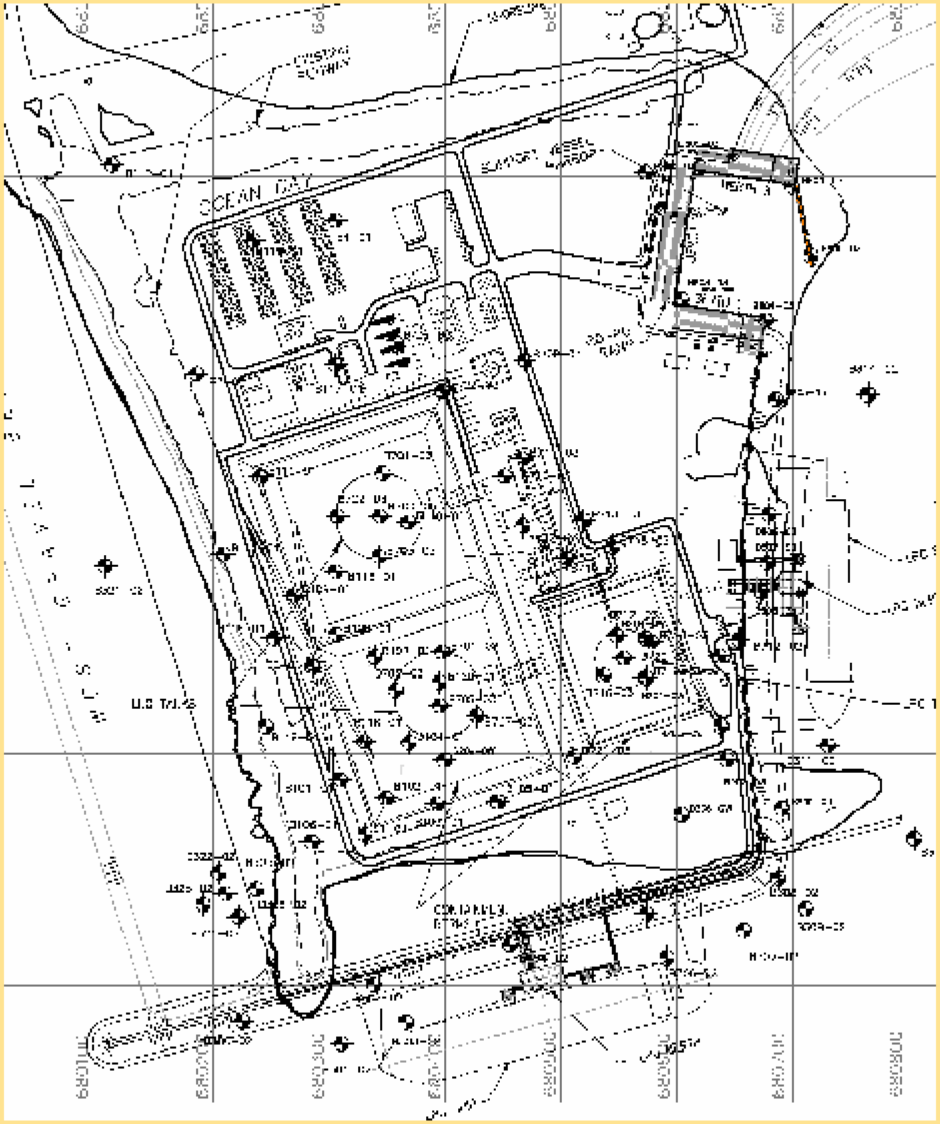
LNG Facilities - Introduction



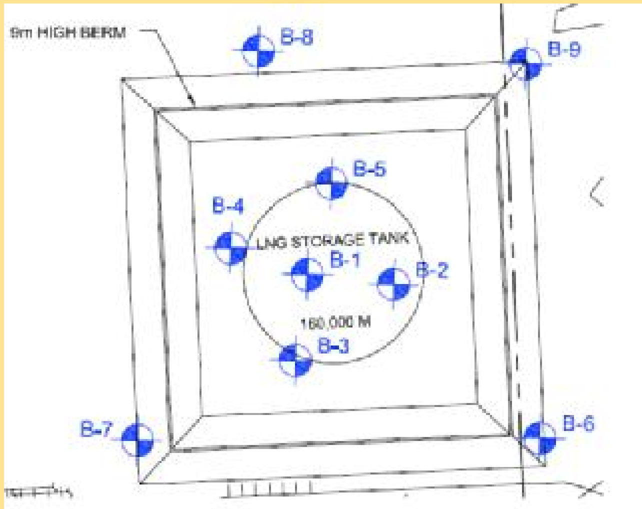
- Pressurized storage tank
- Containment dike
- Waterfront structures
- Ancillary equipment

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

LNG Facilities – Containment Dike Design

- 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.

TXC1

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LNG Facilities – Waterfront Structures

- **Unloading Platform**
- **Mooring Dolphins**
- **Breasting Dolphins**

Photo Courtesy of Chicago Bridge & Iron Company

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LNG Facilities – Waterfront Structures

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

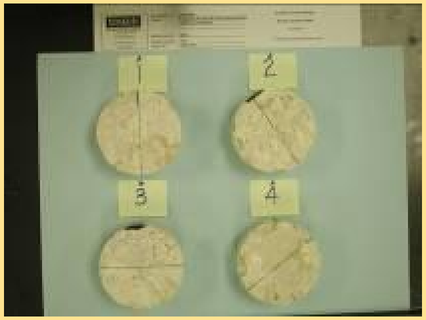
LNG Vessel
Photo courtesy of CH-IV International
http://www.ch-IV.com

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



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

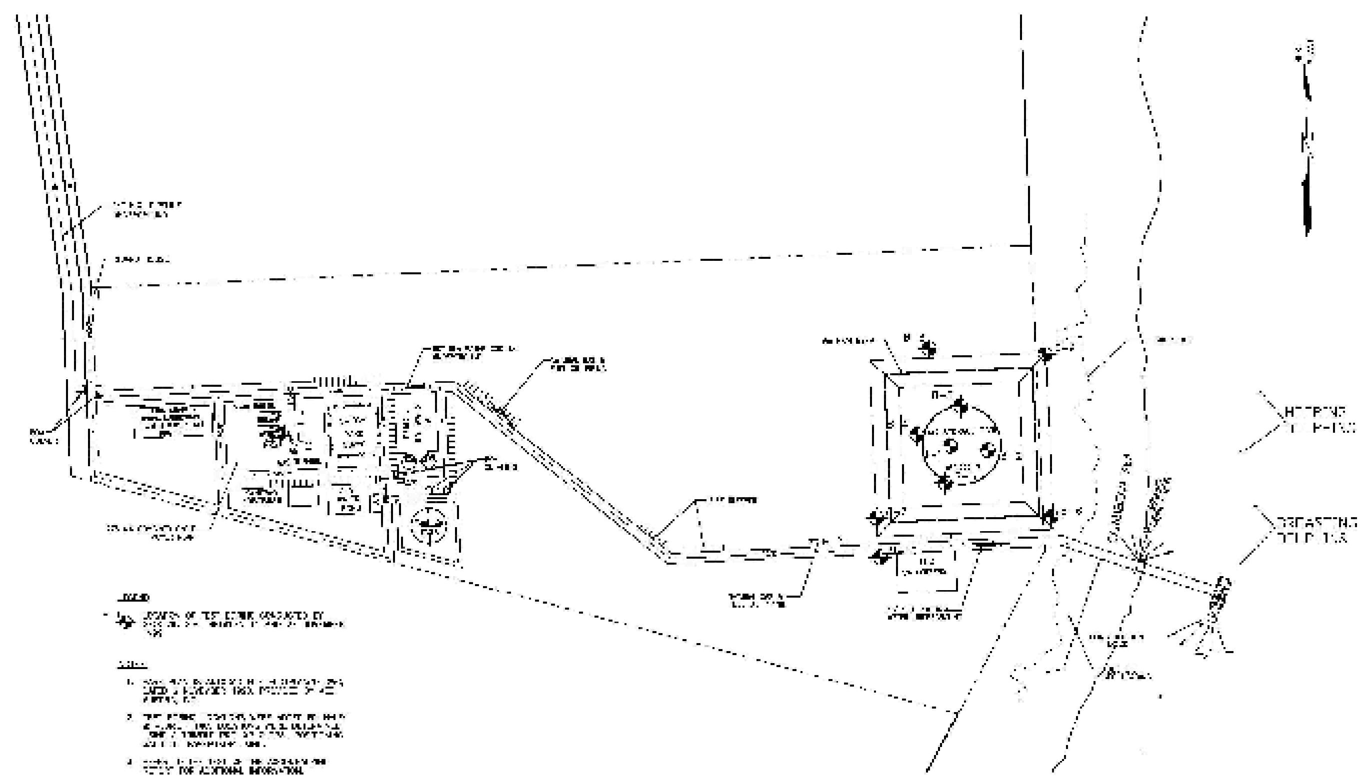
LNG Facilities – Waterfront Structures

- 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.

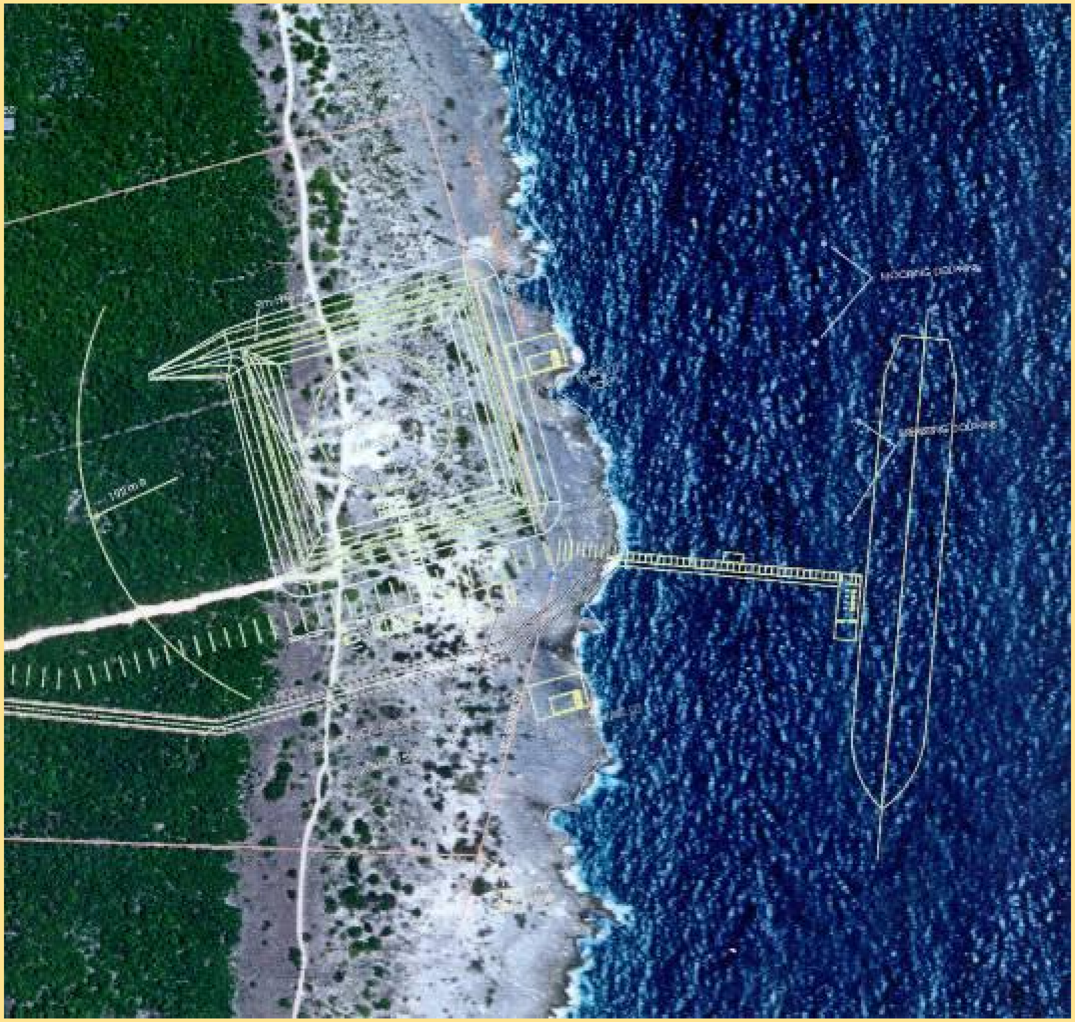
LNG Facilities – Shipping Channel

- 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

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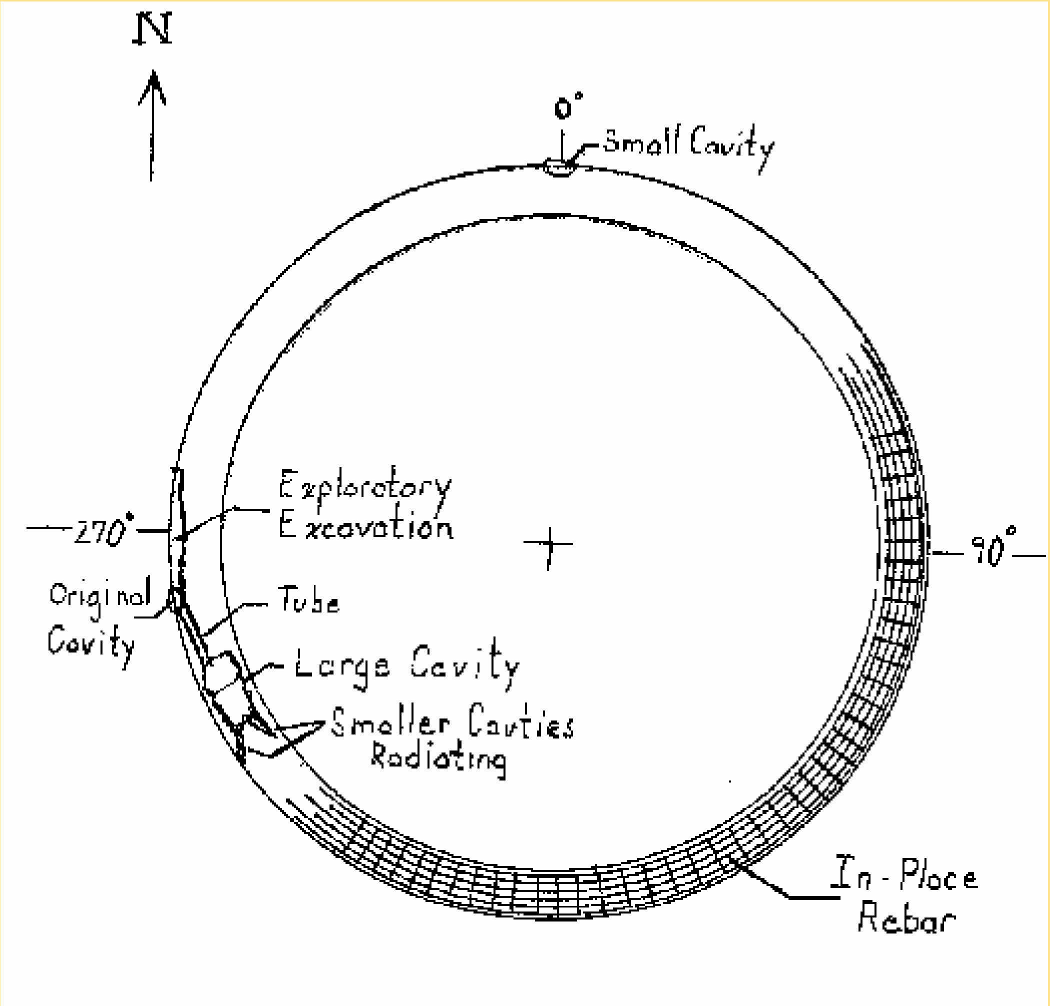

Electric Transmission Lines - Introduction

- 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

Major Electric Transmission Spending Initiatives

Company	Region	Capital Investment
Allegheny Energy	Mid-Atlantic	$850-million project 2007-2011
American Electric Power	Mid-Atlantic South	$9 billion of identified projects
American Transmission Co.	Wisconsin	$3.1 billion 2006-2015
ITC Holdings	Michigan	$1.8 billion 2005-2012
Northeast Utilities	New England	$2.4 billion 2006-2011
Pepco Holdings	Mid-Atlantic	$565 million 2005-2009 $1.24-billion project 2007-2014
Xcel Energy	Great Plains	$1.5 billion-$2.0 billion
PG&E Corp.	Northern & Central Calif.	$1.8 billion 2006-2010
Edison International	Southern Calif.	$2.5 billion 2006-2010
Sierra Pacific Resources	Nevada	$1.3 billion 2007-2014

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.

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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

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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.

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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

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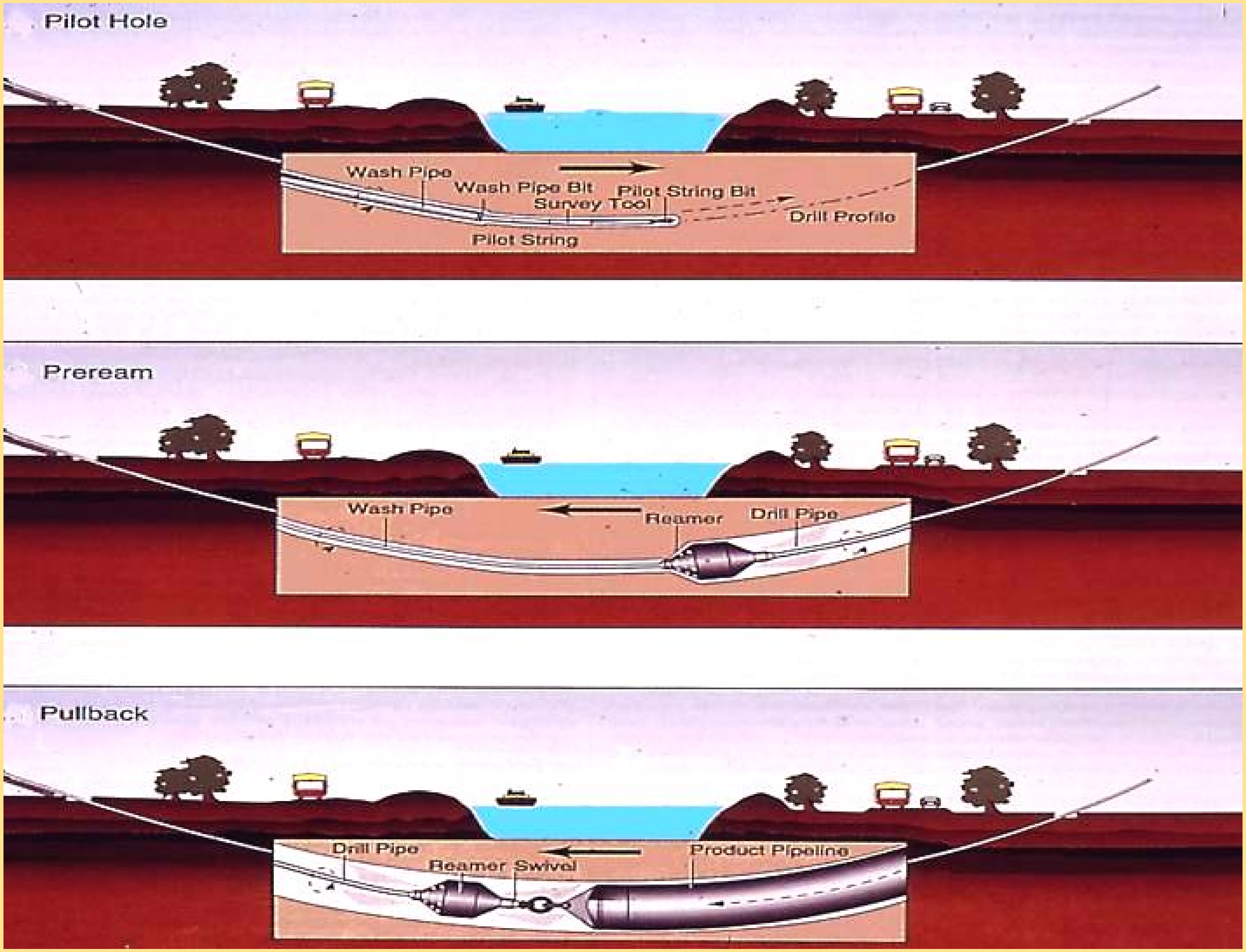
Gas Pipelines – Case History

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



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

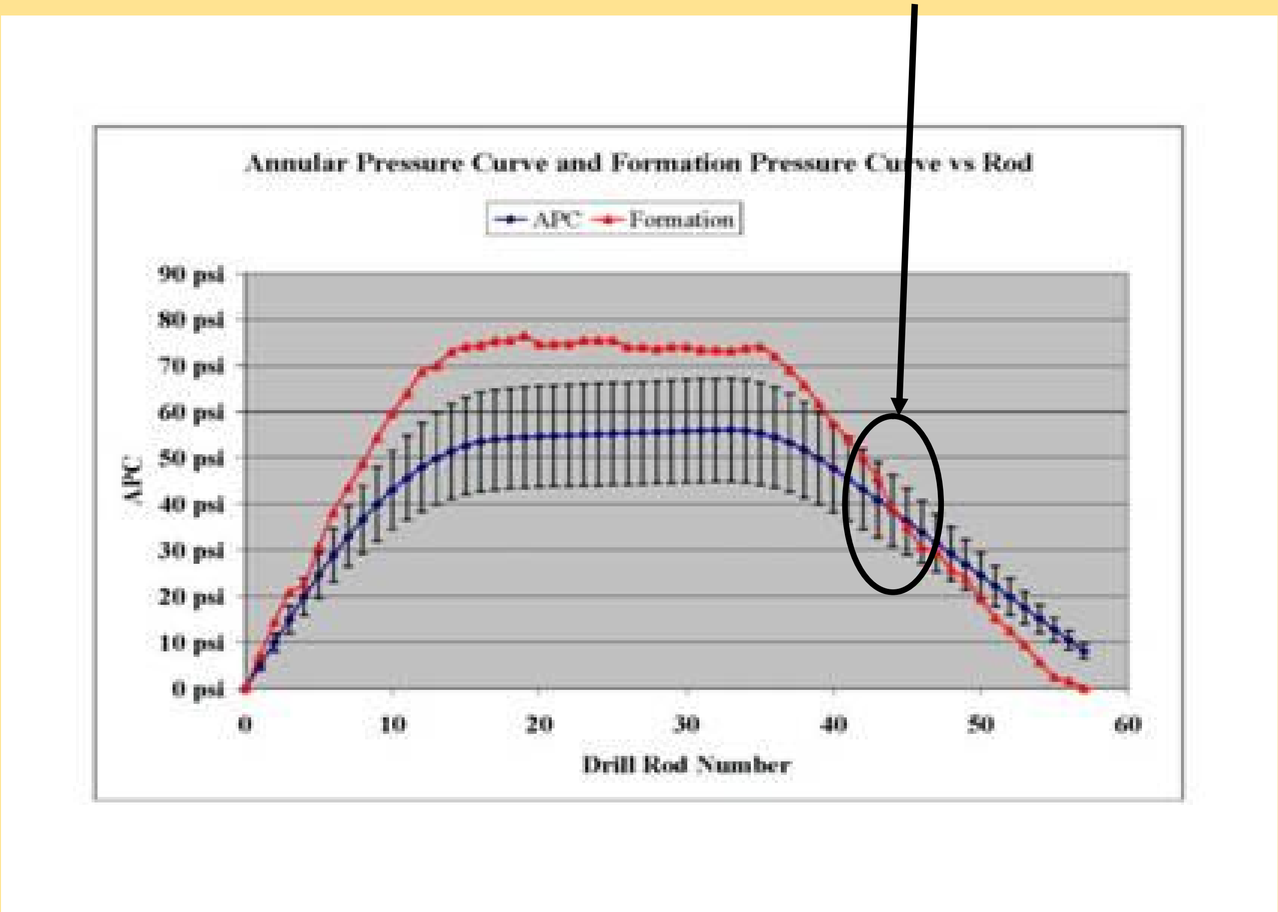
- HDD Design Investigations
  - Review local geologic references (surficial geology maps, bedrock maps, information on faults, etc.)
  - Develop field investigations based on results of initial geology review
  - Geophysical work
    - River bottom profile
    - Top of bedrock profile
    - Obstructions 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

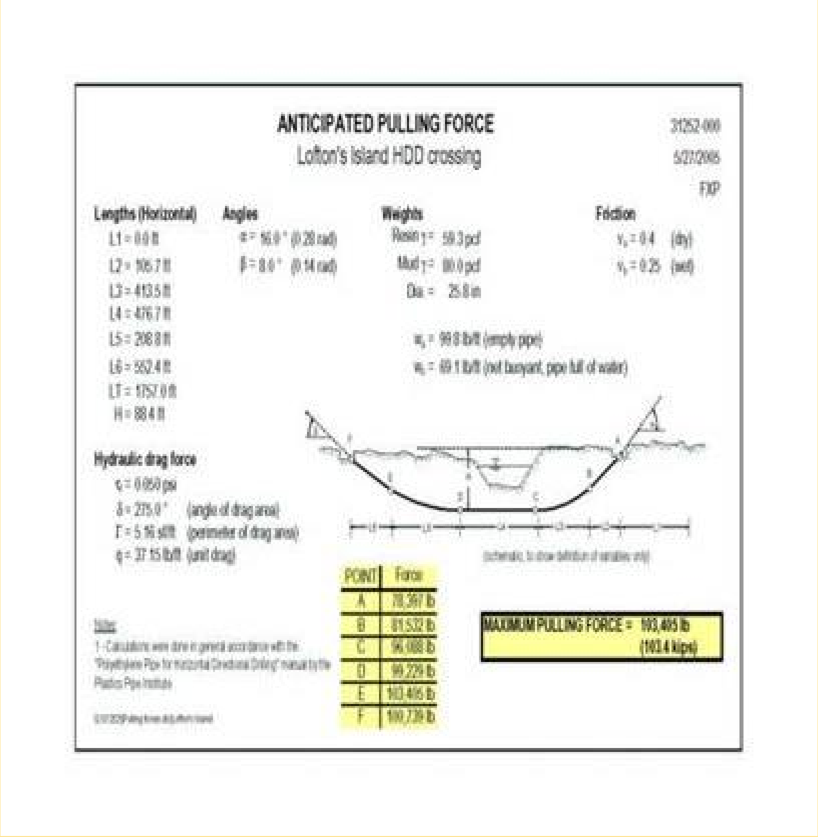
Problem Zone



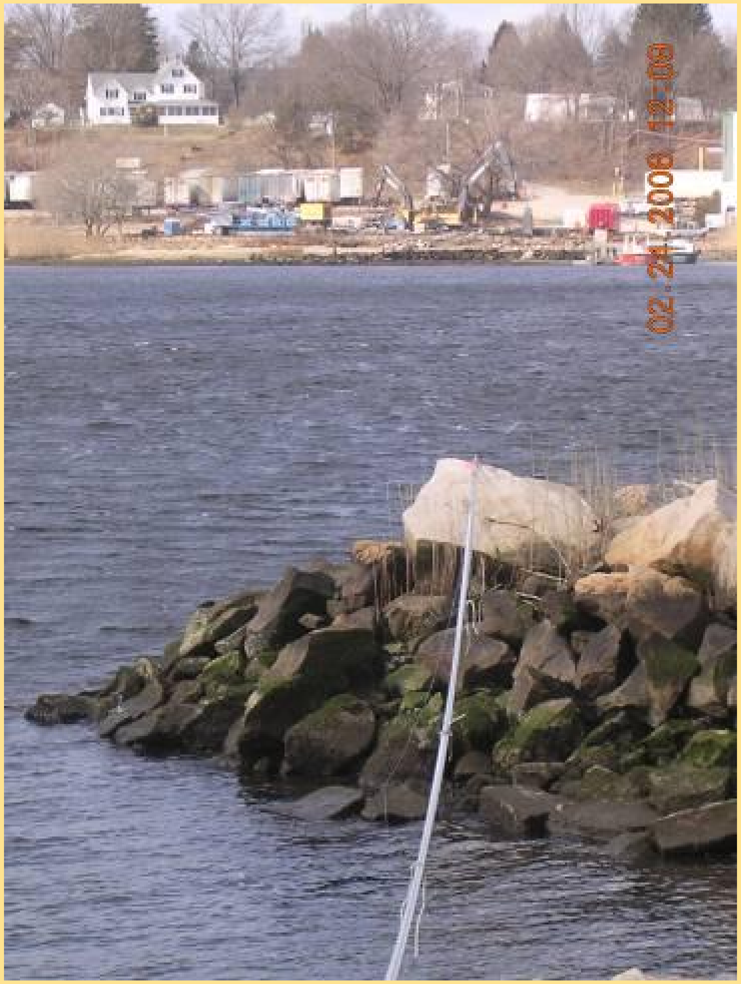
Gas Pipelines – Horizontal Directional Drilling

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

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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?