EXAMINING PIPE RAMMING DESIGN-
A FORENSIC ANALYSIS OF A HIGH RISK PROJECT

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Presentation Outline

- Pipe Ramming – State of the Art
- Two Pipe Ramming Projects
  - Background
  - Set-up of the Rams
  - Problems experienced during construction
  - Cause of the problems
  - Lessons
  - Contribution to Design

Pipe Ramming

- Open Ended Steel Casing
- Propelled by Ramming
- Pneumatic Hammer (or Hydraulic)
- Displaces Soil
- No Excavation
- No steering control

Types of Hammers

- Hydraulic Hammer
- Pneumatic Hammer

Force and Frequency

Applications

- Crossings
  - Road
  - Railroad
  - Creek Crossings
- Casings for
  - Water
  - Sewer
  - Gas
  - Cables
- HDD
  - Conductor Casings
  - HDD Assist

Pipe Ramming with HDD

- Conductor barrel
  - Steel casing to bridge poor soils
  - HDD drilled through conductor casing
Pipe Ramming

Conductor Casing for a 36” HDD

Pipe Ramming with HDD

• HDD Assist
  – Drill rig needs additional force to complete installation
  – Product Pipe Stuck
• Retrieve Product Pipe

Types of Hammers

Hydraulic Hammer
Pneumatic Hammer

WSDOT Project

• Two Large Pipe Ramming Projects
  – 3.65 meter (144”)
  – 3.05 meter (120”)
• Road Crossings
  – 82 meters (270 feet)
• Culvert Replacements
  – Fish Bearing Streams
• Depth determined by Creek Elevation
Geotechnical

- 7 Geotechnical borings for each crossing
- Fill overlying native glacial soils (glacial till)
- Alignment below Groundwater:
  - Fill: Seepage stabilizes at: 1-2 gal/min [2.8 ft/day]
  - Glacial deposits: low-permeability dense silt, sand, gravel: Pockets 1-2 gal/min [2.8 ft/day]- bleed off

3.65 m (144-inch) Crossing: Ram Shaft
- Hammer Cradle
- Driven H-pile Supports

3.65 m (144-inch) Crossing: Bulkhead
- Foamed Perimeter

3.65 m (144-inch) Crossing: Launch Seal
- Launch Seal
- 31mm (1.125") Steel Casing
- 12.5 mm (0.5") Cutting Shoe Plates

3.65 m (144-inch) Crossing: Hammer Adapter
- Hammer Adapter

144-inch Crossing: Initial Soils
- Cut Through Wood
- Cutting Shoe
Advance Rate Slows...then Refusal!

- Progressed 40m (130 ft) past launch seal
- Stop to remove soils from casing
- Lots of wood/logs/stumps
- Wood concentrated in upper 2/3 of pipe
- Invert deformed upward at 20 m (65 feet)
  - Invert progressively deformed for 21 m (70 feet)
  - Total Deformation of 9 meters

144-inch Crossing: Wood As Expected

Engulfed Wood Logs/Stumps

Invert deformation

Failure Progressed 21 m (70’ feet)

Start of Invert Deformation

Severe Deformation

Casing Crown

Cutting Shoe

Casing Invert

Switch to the 3.05 m (120-inch) Crossing

- Ram 2nd Crossing while investigation continues
- Same setup and geotechnical conditions
- ~610m (2,000 ft) down the road
- Smaller OD, same casing wall and shoe

3.06m (120-inch) Crossing: Launch Seal

Beveled Casing Leading Edge

0.5” Cutting Shoe

Launch Seal
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Sandbag Bulkhead for Groundwater

Sandbags Counterbalance Soil Inflow

Sandbag Bulkhead

Soil Plug Displaces Sandbags

Stop to Check

• Peer
• Excav...
• BUT...

Stop to Check

Wood Stump

Hello Invert... My name is Crown

Casing Crown

Casing Invert

Forensic Investigation of Cause

• Wood? (splinter?, log?, stump?)
• Cobble?
• Boulder?
• All of the above?
• Something else?

3.65m (144-inch) Crossing: Investigation

Cut Out Invert

Initial Point of Failure
3.65m (144-inch) Crossing: Investigation

- Dense Silty Sand (No Cobbles/Boulders/Wood)

Geotechnical Information

- 4’ (1.2m) Groundwater head – Dense soils w/ silt
- Crown (~75%) of casing through Roadway Fill
  - Fill Unit 1a: medium dense to very dense sand/gravel
  - Fill Unit 1b: loose to medium dense silty sand/gravel with larger wood debris, stumps or logs
- Invert (~25%) of casing through native glacial soils
  - Unit 2 Glacial Deposits: Medium dense to very dense sand with silt and gravel. Likely cobbles and boulders.

Initial Point of Deformation

120-inch Diameter Crossing

Identical Deformation for Both Casings
Comparison of Crossings blows/ft

<table>
<thead>
<tr>
<th>Casing</th>
<th>Casing 1</th>
<th>Casing 2</th>
<th>Casing 3</th>
<th>Casing 4</th>
<th>Casing 5</th>
<th>Casing 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.05 m 120-inch</td>
<td>20-40</td>
<td>50-90</td>
<td>90-130</td>
<td>140-160</td>
<td>175-450</td>
<td>400-1700 Stuck</td>
</tr>
<tr>
<td>3.65 m 144-inch</td>
<td>30-55</td>
<td>60-90</td>
<td>100-125</td>
<td>125-160</td>
<td>220-350</td>
<td>350-560 Stopped</td>
</tr>
</tbody>
</table>

Mode of Deformation/Failure

Pipe Ramming Design Guidance?

- Analysis and Design of Pipe Ramming Installations
- ASCE MOP 115
- NASTT No-Dig Publications
- TTC/USACE Guidelines for Pipe Ramming

Pipe Ramming Components

From Stein (2001)

Geotechnical/Structural Engineering

- Structural Mechanics / Materials
  - Casing Diameter (min ID Typically Set by Product Pipe)
  - Casing steel properties, connections, thickness...
  - Cutting shoe properties, length, geometry, thickness...
  - Energy transfer: Hammer/Casing/Shoe/Soil
- Soil Mechanics
  - Density variations: line & grade, face stress distribution
  - Groundwater: pressure head, soil behavior
  - Friction: internal and external skin friction
  - Obstacles: wood, cobbles, boulders, manmade objects

Cause of Failure

- Inadequate Stiffness of Leading Segment for Site Soils
  - Dense to Very Dense Soils on Bottom
  - Loose to Medium Dense Soils on Top
  - Eccentric Loads on Cutting Shoe
- Contributing Factors
  - Cutting Shoe
    - Design (Shape)
    - Thickness
  - Pipe Wall Thickness
**Pipe Leading Edge**

- 3.2 cm (8”) Diameter
- Single Cast Piece

**Fabricated Cutting Shoe Dimensions for WSDOT Project**

Contractor used a 41 mm (1 1/8”) thick cutting shoe for both the 3.65 and 3.06 m (10' and 12') diameter casings.

**Improper Cutting Shoe Application**

- Leading Edge of Casing
- Welded Steel Plates

**Application of Inner Cutting Band**

- 1.8m (72”) Diameter Pipe Ram
- 360° Banding
- 25mm (1”) Thick Band
According to API, pile geometry slenderness as indicated by D/t ratio may be as high as 60, without reducing the inelastic buckling (yield) strength. In practice, for pipes less than 600mm most designers would not be happy to employ a D/t greater than 40, as it is common to see the use of D/t ratios as low as 24.

**Steel Pipe Diameter vs. Recommended Wall Thickness for Pipe Ramming (Per TT Technologies)**

**Cutting Shoe Thickness Vs. Pipe Diam.**

**Cutting Shoe Diameter Vs. D/t Ratio**

**Cutting Shoe Bevel**

- Maximum design values of D/t ratios for 120" and 144" casings are within the 40 to 60 envelope.
- D/t Ratios of Failed Cutting Shoes
- According to API, pile geometry slenderness as indicated by D/t ratio may be as high as 60, without reducing the inelastic buckling (yield) strength. In practice, for pipes less than 600mm most designers would not be happy to employ a D/t greater than 40, as it is common to see the use of D/t ratios as low as 24.
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Cutting Shoe Bevel

**INCORRECT Cutting Shoe Bevel Direction**

![Diagram showing incorrect bevel direction](image)

- Induced Moment (M) force is greater than the weight of soil plug (W), causing the casing pipe to fail inward.

Improper Cutting Shoe Application

- **Leading Edge of Casing**
- **Welded Steel Plates**

The “fix” reveals the problem.

- How did the contractor “fix” the problem?
- Stiffen the Casing
- Added 31.75mm (1.25”) reinforcing casing:
  - D/t: 48 for Crossing 1 and 40 for Crossing 2.
- Continue to Drive the Casing

With the casing reinforced and stiffened. The pipe ramming could continue.

Clearly the original casing was under-designed. Not providing Adequate Stiffness

Thank You to
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Any Questions?

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