Lifecycle Considerations for Highway Culverts

Tyson Dyck, P. Eng.
Tyson.Dyck@lehighhanson.com
Inland Pipe
Overview

- **Pipe Options**
  - Different Pipe Types
  - How It’s Made

- **Culvert Structure**

- **Installation of Culverts**

- **Culvert Hydraulics**

- **In the News**
  - Sinkholes
  - Canmore/MD Bighorn
Different Culvert Types

Flexible Culverts:
- CMP
- HDPE
Different Culvert Types

Flexible Culverts:
- CMP
- HDPE

Rigid Culverts:
- Precast Concrete Boxes
- Reinforced Concrete Pipe
How it’s made
How do we supply AB?

Spy Hill Plant
Calgary, AB
Concrete Pipe

- Rigid pipe

- Comprised of:
  - Aggregates
  - Cement
  - Fly ash
  - Reinforcement

- Zero Slump Concrete

- 100 year design life
Manufacturing Process - Curing

- Kilned for 6-7 hrs at 60°C
- 100% Humidity
- Moving Kiln Floor
- 1 day strength ~ 25 MPa
Inspection & Testing

- Visual inspection
  - Cracks, chips
- Go-No-Go gauge
- Hydrostatic
- Three Edge Bearing (3EB)
Relevant Products

- Concrete Pipe (ASTM C-76 or CSA 257)
  - Diameters 300mm to 3000mm
Relevant Products

- Box Culverts and Manholes (ASTM C1433)

<table>
<thead>
<tr>
<th>Span</th>
<th>Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>1200</td>
<td>900</td>
</tr>
<tr>
<td>1800</td>
<td>900</td>
</tr>
<tr>
<td>1800</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>1800</td>
</tr>
<tr>
<td>2400</td>
<td>2400</td>
</tr>
<tr>
<td>3000</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>3600</td>
</tr>
</tbody>
</table>

Boxes are available in the following lengths: 2.5m, 2.0m, 1.8m, 1.5m, 1.2m, and 0.6m
Relevant Products

- Reinforced Concrete Jacking Pipe (designed as per ASCE 27-00)
New Product Applications
Canadian Precast Concrete Quality Assurance (CPCQA)
CPCQA

- Voluntary
- Harmonized QA Program from CPCI and CCPPA
- Intermediate and detailed inspections carried out by a third party engineer
- Inland has been prequalified since early 2000’s
- Plant inspections occur yearly
- Inspect product, equipment, and processes
Requirements for Certification

- Management practices
- QC procedures & documentation
- Raw materials & Concrete mix designs
- Production practices & Formwork
- Reinforcement fabrication
- Pre-pour & Post-pour checks
- Concrete curing
- Final inspections
- Product marking
- Handling & Storage
- Product performance testing
Pipe Characteristics
Structure: Three Edge Bearing Test
3 Edge Bearing Test
Rigid VS Flexible – Passive Earth Pressures

Flexible pipe deflects until the side soil can carry the load.

Lateral support has slight affect on the overall structural strength.
Classed Pipe – The Proof

- 3EB Test is an external load crushing test
- Confirms product was manufactured correctly
3 Edge Bearing Test

Hairline flexural crack - indicates load has shifted to reinforcement
Pipe Strength

- **Class II** = 50 N/m/mm or 1000 lbs/ft/ft
- **Class III** = 65 N/m/mm or 1350 lbs/ft/ft
- **Class IV** = 100 N/m/mm or 2000 lbs/ft/ft
- **Class V** = 140 N/m/mm or 3000 lbs/ft/ft
Pipe Strength

Class V = 140 N/m/mm or 3000 lbs/ft/ft

For standard 900mm (914mm) RCP:

140N/m/mm * 914mm * 2.5m / 9.81N/kg

= 32610kg of load.

= The full weight of a Sherman Tank!
Pipe Installation
Standard Embankment Installation

<table>
<thead>
<tr>
<th>Grade</th>
<th>Final Backfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haunching</td>
<td>Springline</td>
</tr>
<tr>
<td>Bedding (3&quot;-6&quot;)</td>
<td>Loosely Placed Middle 1/3</td>
</tr>
<tr>
<td>Foundation</td>
<td>Embankment</td>
</tr>
</tbody>
</table>

ASTM C1479
## Standard Installation Types

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Bedding Thickness</th>
<th>Haunch and Outer Bedding</th>
<th>Lower Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>( D_0/24 ) minimum, not less than 3 in. If rock foundation, use ( D_0/12 ) minimum, not less than 6 in.</td>
<td>95% Category I</td>
<td>90% Category I, 95% Category II, or 100% Category III</td>
</tr>
<tr>
<td>Type 2</td>
<td>( D_0/24 ) minimum, not less than 3 in. If rock foundation, use ( D_0/12 ) minimum, not less than 6 in.</td>
<td>90% Category I or Category II</td>
<td>85% Category I, 90% Category II, or 95% Category III</td>
</tr>
<tr>
<td>Type 3</td>
<td>( D_0/24 ) minimum, not less than 3 in. If rock foundation, use ( D_0/12 ) minimum, not less than 6 in.</td>
<td>85% Category I, 90% Category II, or 95% Category III</td>
<td>85% Category I, 90% Category II, or 95% Category III</td>
</tr>
<tr>
<td>Type 4</td>
<td>( D_0/24 ) minimum, not less than 3 in. If rock foundation, use ( D_0/12 ) minimum, not less than 6 in.</td>
<td>No compaction required, except if Category III, use 85% Category III</td>
<td>No compaction required, except if Category III, use 85% Category III</td>
</tr>
</tbody>
</table>
Heger Pressure Distribution

[ASCE Type 1]
- VAF = 1.35
- HAF = 0.45
- A2/A1 = 1.18

[ASCE Type 2]
- VAF = 1.40
- HAF = 0.40
- A2/A1 = 0.65

[ASCE Type 3]
- VAF = 1.40
- HAF = 0.37
- A2/A1 = 0.33

[ASCE Type 4]
- VAF = 1.45
- HAF = 0.30
- A2/A1 = 0.00

[Heger Pressure Distributions for Direct Design of Concrete Pipe]
SITE SPECIFIC DESIGN

INSTALLATION TYPE

PIPE COST

INCREASED PIPE DESIGN

INCREASED EMBEDMENT QUALITY

INSTALLATION COST

1  2  3  4
Pipe Jacking

- What is Jacking?
- Why Jack?
- What do you need?
- Equipment
- Site conditions
- Axial Design per ASCE 27-00
What is Jacking?

- The act of pushing a pipe horizontally through soil without an open excavation.
Why Jack?

- Minimal to no social costs
  - traffic impact
- Construction savings
  - Minimal road repair or environmental impact
  - Shorter schedule
  - Lower class of pipe
Rigid Pipe Installation Types
What do you need?

- Specific soil conditions
- Access pit at each end
- A contractor with the correct equipment
- A well inspected site
- Complete engineering calculations
Flexible Pipe
Rigid VS Flexible

% DEFLECTION = \frac{\text{CHANGE IN DIAMETER}}{\text{ORIGINAL DIAMETER}} \times 100
403.13.04.03 Short and Long Term Deflection Requirements

MAXIMUM ALLOWABLE DEFLECTION

<table>
<thead>
<tr>
<th>Short Term</th>
<th>Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0%</td>
<td>7.5%</td>
</tr>
</tbody>
</table>

Short-term deflection, (testing is at the discretion of the developer/contractor) shall be deemed to be any deflection measured between one month and one year after backfilling.
Time dependent factors

- Soil loads

- 30 days - 75% of long term
- 1 year - 90% of long term
Flexible Pipe Embedment
ASTM D2321
Flexible Pipe Embedment

402.03.03 PVC Pipe

All PVC pipe shall be CSA approved. Materials used for pipe shall come from a single compound manufacturer and have a cell classification of 12454-B, 12454-C, or 12364-C as defined in ASTM D1784 (Rigid PVC Compounds and CPVC Compounds). All PVC pipe shall be designed for CL-800 truck loading as per CAN/CSA-S6-00 (Canadian Highway Bridge Design Code). Where warranted based on traffic volumes, sewer alignment, and the nature of the traffic route, the designer shall review the possible impact of dual or passing CL-800 trucks.

All PVC pipe shall meet the physical requirements given in CSA B182.1 M (Plastic Drain and Sewer Pipe and Pipe Fittings) and CSA B182.2 M (PVC Sewer Pipe and Fittings). All pipes shall be subject to such tests as required in the CSA standards and results for specific pipe data shall be submitted to Water Resources if requested.

PVC pipe shall be installed according to ASTM D2321 (Underground Installation of Flexible Thermoplastic Sewer Pipe).

For approved materials list see 402.01.01.04 PVC Pipe.

402.03.04 Corrugated Metal Pipe

All materials shall conform to the CSA G401 and shall be subject to such tests as outlined in that standard.

Corrugated metal pipe shall only be used for storm sewer mains to which there are no direct connections from catch basins or house services (weeping tile drains), and only where specifically approved for use by Water Resources.
ASTM D2321

- Use suitable backfill materials
- Ensure placement & compaction under haunches. Work by hand.
- Lifts not exceeding 150mm
- Compact to 95% standard proctor density
- Balance fill on either side as fill progresses
- Maintain culvert shape
- No equipment over culvert until minimum depth of cover. (150mm)
Installation Liability

**Designer**
“as per manufacturer’s recommendations”

**Manufacturer**
“As per ASTM D2321”

**ASTM D2321**
Engineer referenced 29 times
Risk Assessment

Risk = (Probability of Occurrence) * (Consequences of a Failure)
Risk Assessment
Cost Comparison

Rigid

Native Backfill
Compacted to 95%

Granular Fill
Compacted to 95%

Overfill

Pipe Zone

OD

300

100

OD + 600

ASTM C1479
Type 2

Flexible

Granular Fill
Compacted to 95%

OD

300

100

OD + 600

MMCD
Drawing G4
# Summary - Rigid vs Flexible

<table>
<thead>
<tr>
<th></th>
<th>Rigid</th>
<th>Flexible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Strength</td>
<td>Pipe carries the load</td>
<td>Soil Embedment carries the load</td>
</tr>
<tr>
<td>Proof of Design</td>
<td>Tested in the plant – Three edge bearing test</td>
<td>Tested in the field – Deflection testing</td>
</tr>
<tr>
<td>Design Checks</td>
<td>Flexure, Shear</td>
<td>Deflection, Creep, Bending, Buckling, and Strain</td>
</tr>
</tbody>
</table>
Culvert Hydraulics
Outlet vs. Inlet Controlled Flow
Culvert Hydraulics: Outlet Controlled Flow

\[ Q = VA = \left( \frac{1.49}{n} \right) AR^{\frac{2}{3}} \sqrt{S} \quad [U.S.] \]

\[ Q = VA = \left( \frac{1.00}{n} \right) AR^{\frac{2}{3}} \sqrt{S} \quad [SI] \]

Where:
- \( Q \) = Flow Rate, (ft\(^3\)/s)
- \( v \) = Velocity, (ft/s)
- \( A \) = Flow Area, (ft\(^2\))
- \( n \) = Manning’s Roughness Coefficient
- \( R \) = Hydraulic Radius, (ft)
- \( S \) = Channel Slope, (ft/ft)

<table>
<thead>
<tr>
<th>RCP ID (mm)</th>
<th>CSP ID (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=0.012</td>
<td>n=0.024</td>
</tr>
<tr>
<td>305</td>
<td>400</td>
</tr>
<tr>
<td>381</td>
<td>500</td>
</tr>
<tr>
<td>457</td>
<td>600</td>
</tr>
<tr>
<td>533</td>
<td>700</td>
</tr>
<tr>
<td>610</td>
<td>800</td>
</tr>
<tr>
<td>686</td>
<td>900</td>
</tr>
<tr>
<td>762</td>
<td>1000</td>
</tr>
<tr>
<td>914</td>
<td>1200</td>
</tr>
<tr>
<td>1067</td>
<td>1400</td>
</tr>
<tr>
<td>1219</td>
<td>1600</td>
</tr>
</tbody>
</table>
Culvert Hydraulics: Inlet Controlled Flow

Inlet edge configuration is a major factor in inlet control performance.

Figure “C” represents a groove end (bell) or socket inlet which is typical of a concrete pipe or box culvert joint.

The reduced flow contraction shown in “C” indicates increased inlet performance and more flow through the barrel for the same headwater.

Flow contractions for various culvert inlets.
Culvert Hydraulics: Inlet Controlled Flow
LCA Factors

- Project design life
- Material service life
- Initial cost (installed)
- Maintenance cost
- Rehabilitation cost
- Replacement cost
Material Service Life

Engineering and Design – Conduits, Culverts and Pipes
By US Army Corps of Engineers – Doc. No. EM 1110-2-2902

Life Cycle Design:

- **Concrete** – Most studies estimate product service life for concrete pipe to be between 70 and 100 years.
- **Steel** – CSP usually fails due to corrosion of the invert or the exterior of the pipe. Properly applied coatings can extend the product life to at least 50 years for most environments.
- **Plastic** – Many different materials fall under the general category of plastic. Each of these materials may have some unique applications where it is suitable or unsuitable. Performance history of plastic pipe is limited. A designer should not expect a product service life of greater than 50 years.
"Sinkholes"

Sinkhole surprises Appleton drivers; City Russell Street project delays hurt at least one business

Road work on East Russell Street is three months behind schedule, and the owner of a downtown Fayettville garden supply store is worried that continued delays will hurt business.

When N.C. Department of Transportation officials closed the two eastbound lanes on Russell Street in August to rebuild a failing storm drainage system, they said the roads would reopen in November.

Three months later, the state now says the work should be finished some time in the spring.

In January, the general contractor, Tara Group of Lumberton, reopen one of the two eastbound lanes to ease the inconvenience the closures have been for businesses along the two-block stretch of construction.

The businesses include two law offices, a bail bondsman shop and Bell's Seed Store, which sells plants.

Witnesses leap to help family stuck in the car. Source: Terra.com

Troy road damaged after collapsed sewer line creates sinkhole

Council leader wanted repair work to start earlier than Monday

By Robert O'Brien Updated 11:07 am, Sunday, February 21, 2010

Real estate agent

82nd soldiers return from Iraq:

Deployment

Photo: Military & Fort B

Most Popular This Week

Articles

The man who Fayetteville police call Dr. Kirkland
Fayetteville police to set up DWI checkpoints this weekend
Retail Therapy: Former Black Knight with different name, same food
Deputies seek witnesses in Shaw homicide
Luke Kneidler only needed one change of clothes memory in Duke UNC rivalry
Help needed identifying couple using credit cards

Bay Photo

second time in six weeks, a problem has torn a hole into a city street.

Troy, N.Y. (Paul Buckowski / Times Union)

It is time. It is a sinkhole on Campbell Avenue — the same thoroughfare shut down four years ago in the wake of damage from Tropical Storm Irene. A second asphalt lay at the top of a hill on the 100 block of Campbell Avenue in front of the Franklin Terrace Ballroom.

In the financially strapped city believed the sinkhole was the result of a sewer line that collapsed early Sunday in the land lane of Campbell between Sherman and Danzegel avenues.

In the area where part of Campbell Avenue collapsed, seen here on Sunday, Feb. 21, 2010, in Troy, N.Y. (Paul Buckowski / Times Union)

sight, a spokesman for the city, said workers would do a camera inspection of the line Monday morning to determine what need to be done.

City Council President Cammellie Mantella, who drove to the site early Sunday afternoon, preferred the work to have started Sunday.

"Obviously, I'm not an engineer but it does seem to be more of an immediate emergency than I think is happening at present time," she told the Times Union.

That was never to be seen again. She said at the time.
“Sinkholes”

- Common themes in these events:
  - Road closure for weeks/months
  - Majority were flexible pipe failures
  - Risk to public safety
  - “Caused by severe rainfall”
  - “The sinkhole caused a sewer pipe failure”
  - “Aging infrastructure”
  - “Now have to look left, right, and down when crossing the street”
Pipe Floatation
In the News

Federal government commits $13.7M to protect Bow Valley from flood damage

- **Feds commit $168M to proposed Springbank Reservoir**

"We had full trees — torpedo trees, I call them — battering-ramming houses," he said.

Cooper says the danger and damage was amplified when debris like trees, silt and rock plugged culverts and bridges and pushed water over banks. It destroyed homes, damaged infrastructure and disrupted road and rail travel.

The MD of Bighorn has already done a lot of work to repair culverts, rebuild berms and construct new reservoirs to prepare for future flood events. (CBC)
Thank you