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Durability Design of Tunnel Liners

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PARSONS CORPORATION

Monday August 14: 4:40 to 5:00 PM
1. Corrosion Considerations
2. One versus Two Pass Linings
3. Definitions
4. Innovations in One Pass Corrosion Resistant Linings
5. Conclusions
1 Corrosion Considerations

- External
- Internal
  - Life Cycle Costs
Tunnel Facility Types and Typical Exposure Conditions
Codes & Practices, Design Life

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Groundwater</th>
<th>Air</th>
<th>Hydrogen Sulfide</th>
<th>Erosion</th>
<th>Biological Action</th>
<th>Chlorides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater Tunnel</td>
<td>X</td>
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<tr>
<td>Water Tunnel</td>
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<tr>
<td>Rail Transit Tunnel</td>
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<tr>
<td>Vehicular Tunnel</td>
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</tbody>
</table>

Formal Definition of Design Life

\[
t_i + t_p = t_{\text{service}}
\]

- Delineation of specific service life requirements for specific elements of the work;
- Design life modeling methods such as probabilistic approach;
- Performance of site investigations specifically related to durability;
- Consideration of internal and external corrosive exposures including chemical, biological and mechanical deterioration as well as thermal impacts;
- Compliance with specific building code provisions;
- Detailed description of the corrosion protection system;
- Definition of inspection and maintenance provisions;
- Durability assessment reports documenting durability design efforts; and
- Designer’s certification of durability.

ACI 222.3R-11 (Guide to Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures),
ACI 224R-01 (Control of Cracking in Concrete Structures),
ACI 308R-01 (Guide to Curing Concrete),
ACI 350-06 (Code Requirements for Environmental Engineering Concrete Structures),
ACI 350.5-12 (Specifications for Environmental Concrete Structures),
ACI 365.1R-00 (Service Life Prediction),
ACI 201.2-08 (Guide to Durable Concrete)
ACI 210R-93 (Erosion of Concrete in Hydraulic Structures).

(Joye et al., 2016)
Without the damaging effects of pressures created by corroding steel, concrete can be made to literally last thousands of years. In underground structures we have a unique opportunity to do just this, because we often build arches which under uniform pressures have no tension and require no steel reinforcing for structural adequacy.

(Joye et al., 2016)
External: Darcy’s Law

\[ v = \frac{Q}{A} = i \frac{k}{k} = \frac{h}{l} k \]

where:
- \( v \) = flow velocity
- \( i \) = hydraulic gradient
- \( Q \) = flow volume
- \( A \) = cross sectional area
- \( h \) = head lost in medium
- \( l \) = flow path length
- \( k \) = coefficient of permeability

\( h \propto l/k \)

\( H = h_1 + h_2 + h_3 + h_4 \)

\( p_1 = \frac{h_1}{H} \times 100\% \) or \( p_1 = h_1 / (h_1 + h_2 + h_3 + h_4) \)

\( p_1 = \left[ \frac{l_1/k_1}{l_1/k_1 + l_1/k_1 + l_1/k_1 + l_1/k_1} \right] \times 100\% \)

Ground segments = 4
Segments = 3
Concrete = 2
Protection Liner = 1

\[ p_1 = \frac{\ell_1/k_1}{\sum_{n=1}^{n} \ell_n/k_n} \times 100\% \]
**External Corrosion**

\[
V = k \times i
\]

\[
D = k \times H \times \frac{DL}{t}
\]

D = length of column of water that will flow thru liner over design life
k = permeability of liner
H = Hydraulic Head
t = Liner thickness
DL = Design life (in seconds)

Cl migration mass/unit = D x 1 x 1 x Cl gw concentration

BS 8110 Part 1, Table 6.4: 0.4% allowable concentration
Conclusions External Corrosion

- Internal Coatings help limit seepage/flow through of ions
- External Coatings can also be of benefit
- Reduce Permeability of Materials
- Micro Silica, Silica fume, PFA, GGBFS
- Increase thickness

- Life 365 Service Life Prediction Model
- ASTM
Internal Corrosion

The Sewer Sulfide Cycle

- Turbulence, Splashing and Aeration
- Oxygen and CO₂
- Thiobacillus Bacteria
- Hydrogen Sulfide Gas

DISSOLVED SULFIDE

- With D.O. or Nitrate Present
- Biological Oxidation to Sulfate
- Sulfate Reducing Bacteria (SRBs) in the Slime Layer

SULFATE

- Alkalinity Production
- Alkalinity Destruction

SULFURIC ACID

AIR

WATER

Example of Internal Corrosion
Internal Abrasion

GreenRock SCP
Abrasion Tests (ASTM C-704)
2 One vs. Two Pass
2 One vs. Two Pass Linings

One and Two Pass Jacked

Initial liner with corrosion-resistant carrier pipe

Initial liner with cast-in-place concrete and plastic liner

One-pass segmented, corrosion-resistant liner or conventional segments with plastic liner welded in field

One and Two Pass Tunneled
# Two-pass versus one-pass liner system

<table>
<thead>
<tr>
<th>Main Advantages of Two-Pass System:</th>
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</thead>
<tbody>
<tr>
<td>• Longer life span</td>
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<tr>
<td>• Very low leakage rate, less joints</td>
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<tr>
<td>• Less concern over quality initial support</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Main Disadvantages of Two Pass System:</th>
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</thead>
<tbody>
<tr>
<td>• More costly</td>
</tr>
<tr>
<td>• Longer construction schedule</td>
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<tr>
<td>• Construction challenge of pipe installation</td>
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<tr>
<td>• Requires larger outside diameter tunnel</td>
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</table>
3 Definitions
3 Definitions

EPA – Emerging Technologies for Conveyance Systems 2006

**Embryonic** – They are in the development stage and/or have been tested at laboratory, bench, or pilot-scale only.

**Innovative** – They have been tested at a demonstration scale, are available and implemented in at least some locations in the United States, or have some degree of initial use (i.e., implemented in less than 1 percent of rehabilitation/replacement projects throughout the United States).

**Established** – They have been utilized in many locations (i.e., more than 1 percent of the rehabilitation/replacement projects), or have been available and implemented in the United States for more than 5 years.
Internal Liner Protection

- Standard of Practice (Established)
- State of the Art (Emerged, Innovative)
- Emerging (Innovative)
- Embryonic
# Tunneling Technology Liner Status

<table>
<thead>
<tr>
<th>Category</th>
<th>Technology</th>
<th>SOP</th>
<th>SOA</th>
<th>Emerging</th>
<th>Embryonic</th>
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</thead>
<tbody>
<tr>
<td>One Pass Segmented</td>
<td>Ameron T-Lock - PVC</td>
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<td>X</td>
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<td></td>
<td>Herrenknecht - GRP</td>
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<td></td>
<td>Steuler - HDPE</td>
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<td>Semans - Geomembrane</td>
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<td></td>
<td>Solid Cast Polymer</td>
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<tr>
<td></td>
<td>Other Polymer</td>
<td></td>
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<tr>
<td>One Pass Jacking</td>
<td>Ameron T-Lock in Conc. Pipe</td>
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<tr>
<td></td>
<td>FRP/GRP/VCP/Polymer Pipe</td>
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<tr>
<td>Two Pass Install</td>
<td>Ameron T-Lock in Conc. Pipe</td>
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<td>FRP/GRP/VCP/Polymer Pipe</td>
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<tr>
<td>Two Pass Cast in Place</td>
<td>Plastic Liner PVC, HDPE, Sekusui</td>
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<tr>
<td>Two Pass Mastic Applied</td>
<td>Linabond</td>
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4 Innovations
4 Innovations in One Pass Corrosion Resistant Linings

State-of-the-Art

Emerged/Emerging Technologies
Upper Northwest Interceptor
Sacramento Regional County Sanitation District

Embedded PVC Liner in Segmented Liner, Sacramento, CA

>19000 ft / 5.8 km
12 ft diameter
Upper Northwest Interceptor
Sacramento Regional County Sanitation District
Gravity Sewer Tunnel, Panama City

27,000 ft/8.2 km
11 ft/3.4 m ID, 3.8 OD
Gravity Sewer Tunnel, Panama City

Minimum radius = 190 m

Many curves radius = 250 m +
Gravity Sewer Tunnel, Panama City
Yuzhny sewage, Tsaritsyno, Moscow
MGUP Mosvodokanal

Combisegments w/GRP Innerliner

500-m-long section
Yuzhny sewage, Tsaritsyno, Moscow

Combisegments w/GRP Innerliner
Yuzhny sewage, Tsaritsyno, Moscow

Combisegments w/GRP Innerliner
Yuzhny sewage, Tsaritsyno, Moscow

Combi-segments w/ GRP Innerliner
Polymer

102” ID Direct Bury Pipe

120” ID Junction Structures – City of Houston

SCP Precast Floor Slabs – Dow Chemical (Magnesium Plant), Freeport, TX

96’L x 40’W x 15’D Panelized Acid Neuralization Pit – Dow, Canada
Solidcast Polymer
Steuler HDPE
Seaman bonded woven geomembrane
5 Conclusions
Conclusions

- Establish Corrosion Criteria:
  - External and Internal
- Alternatives
- Embryonic, Emerging, SOA, SOP
- Market Place to Decide
References

1. ACI [American Concrete Institute]. 2008. ACI 201.2 R-08. Guide to durable concrete.
2. ACI-350-06, Code requirements for environmental engineering.
References (cont.)


Thank You!