Air Flow and Ventilation in Sewers and Tunnels

Adam Dellinger, P.E.
Jennie Celik, P.E.

OWEA Conference, June 27, 2019, 9 AM
Why is air flow in sewers & tunnels important?
01 Basics of Air-Water Interactions
Basics of Air-Water Interactions

- Forces at work
  - Friction
  - Pressure-gradient
  - Buoyancy

- Of interest for many types of hydraulic structures
  - Dam spillways and outlet gates
  - Inverted siphons
  - Pipelines
  - Drop shafts
  - Closed conduits
Factors Affecting Air Flow in Sewers and Tunnels
What Causes Air Flow in Sewers and Tunnels

- Friction drag force
- Displacement air
- Flushing airflow effect
- Buoyancy airflow effect
- Drop structure eduction
What Causes Air Flow in Sewers and Tunnels

- Friction drag force – any sewer/tunnel with hydraulic flows
- Displacement air – occurs while sewer/tunnel is filling (storm or diurnal)
- Flushing airflow effect – rapid displacement, at the start of storm events
- Buoyancy airflow effect – sewer/tunnel with no dry weather flows, cold-weather climate
- Drop structure eduction – large-diameter tunnels
What Causes Air Flow in Sewers and Tunnels

- **Friction drag force** – any sewer/tunnel with hydraulic flows
- **Displacement air** – occurs while sewer/tunnel is filling (storm or diurnal)
- **Flushing airflow effect** – rapid displacement, at the start of storm events
- **Buoyancy airflow effect** – sewer/tunnel with no dry weather flows, cold-weather climate
- **Drop structure eduction** – large-diameter tunnels
Friction Drag Airflow

- Flowing wastewater results in friction at air-water interface, which induces flow of air
- Predominant factor influencing ventilation in sewers and tunnels with dry-weather flows
- Air flows maximized when $d/D = 0.5$
- Modeled by Pescod & Price (1982)
- More recent models developed
  - HDR First Principles
Displacement Air

- Rising water levels during wet-weather events forces air out of the sewer or tunnel
- Air Emission Time and Flow Rate – inversely proportional
- Tends to exhaust at the farthest downstream outlet that is not occluded (blocked) by water levels
Flushing Airflow Effect

- Short-term displacement event in which a nearly-empty tunnel experiences a rapid inflow of water
- Can create high air pressures, blowing manhole covers or damaging ventilation structures
- Mitigate through design by spreading out hydraulic inlets to tunnel/sewer
**Buoyancy Effect**

- Temperature difference between tunnel air and atmospheric air causes pressure gradient
- Most common during cold weather
- Air flow travels upstream
- Has been observed in tunnels with no dry weather flow
Drop Structure Eduction

- Acceleration of falling wastewater induces airflow as a result of drag force
- Increased surface area $\rightarrow$ greater airflow
- Mitigation options:
Drop Structure Eduction

- Acceleration of falling wastewater induces airflow as a result of drag force
- Increased surface area $\rightarrow$ greater airflow
- Mitigation options:
  - Baffle drop structure $\rightarrow$ reduce formation of droplets and dissipate energy
Acceleration of falling wastewater induces airflow as a result of drag force

- Increased surface area → greater airflow

Mitigation options:
  - Baffle drop structure → reduce formation of droplets and dissipate energy
  - Return air duct → reduce net airflow into tunnel
03 Airflow & Odor Considerations for Sewer Design
Considerations for Sewer and Tunnel Ventilation Design

- **Friction drag**
  - Minimize slope/diameter changes
  - Wind over an open stack/manhole can induce air flow – seal or use dampers.
  - Select pipe diameters considering both wastewater flow rate and air flow at different storm conditions

- **Displacement airflows**
  - Consider occlusion of the sewer/tunnel during different storm conditions

- **Buoyancy airflows**
  - Consider siting of tunnel drop shafts
  - Use of dampers to manage airflow
Considerations for Sewer and Tunnel Ventilation Design

- Drop structure eduction
  - Mitigate through design
- Flushing airflow
  - Allow sewer/tunnel to “breathe”
  - Hydraulic modeling of flow inputs
- Other considerations:
  - Use of a fan to pull air from a sewer or tunnel
  - Selection of Materials: Consider corrosion resistant materials
Case Study: Doan Valley Tunnel (NEORSD)
Case Study: Doan Valley Tunnel (NEORSD)

- Northeast Ohio Regional Sewer District (NEORSD)
- DVT project team:
  - McMillen Jacobs Associates and Wade Trim Joint Venture
  - HDR subconsultant to Joint Venture
- HDR performed ventilation study
- Ventilation study goals:
  - Provide review of existing odor control (air treatment) technologies and case studies
  - Determine potential locations of odorous air emissions
  - Evaluate potential capital costs and required land areas for odor control facilities
Lake Erie

SHORELINE STORAGE TUNNEL
21' DIAMETER
16,500' LONG
ADVERTISE FOR BID

WESTERLY STORAGE TUNNEL
25' DIAMETER
9,600' LONG
Construction On-going

BIG CREEK STORAGE TUNNEL
20' DIAMETER
22,400' LONG
2029 ADVERTISE FOR BID

EASTERLY TUNNEL DEWATERING PUMP STATION
200' DEEP
160 MGD
Complete

DUGWAY STORAGE TUNNEL
24' DIAMETER
15,000' LONG
Construction On-going

DOAN VALLEY STORAGE TUNNEL
18' DIAMETER
10,000' LONG
Construction On-going

SOUTHERLY STORAGE TUNNEL
23' DIAMETER
18,300' LONG
2024 ADVERTISE FOR BID

EASTERLY STORAGE TUNNEL
215' DEEP
36 MGD
2020 ADVERTISE FOR BID

Contruction On-going

SOUTHERLY DEWATERING PUMP STATION
175' DEEP
56 MGD
2027 ADVERTISE FOR BID

Complete

Cleveland Heights

CLEVELAND

CLEVELAND

University Circle

Ambler Park

Baldwin Water Plant

E.115th St

Baldwin Water Plant

Project Location
Doan Valley Tunnel

- **Project Overview**
  - 3.7 miles total of rock tunnel
  - 18-ft to 8.5-ft diameter
  - (3) Tunnel segments
  - (6) Shaft sites
  - Contractor: McNally/Kiewit JV
  - Scheduled Completion: End of 2021
Doan Valley Tunnel

- Ventilation Evaluation
  - Technology, Industry Reviews
  - Two conditions:
    - Dry weather
    - Wet weather (1-month, 6-hour storm)

- Study Deliverables:
  - Locations of pressurization and approximate air emission flow rates (friction drag)
  - Theoretical buoyancy flow rates at each shaft
  - Odor control facility alternatives
    - Locations, prioritized
    - Cost estimates
    - Required footprint
DVT System Schematic for Analysis
Doan Valley Tunnel

Results

- Risk of emissions during dry & wet weather:
  - DVT-1
  - WCT-2
  - DSRCS-6

- Risk of emissions during wet weather:
  - MLK-1

- Low risk of emissions:
  - WCT-3
  - WCT-1 FCS (duct carries airflow to DVT-2)
  - MLK-2

Table 4-8. Potential Airflow Emissions at Shafts due to Friction Drag

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Diameter (ft)</th>
<th>Vent Vault Area (ft²)</th>
<th>Friction Drag Airflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>DWF (cfm)</td>
</tr>
<tr>
<td>WCT-3</td>
<td>34</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>WCT-2</td>
<td>55</td>
<td>20</td>
<td>650</td>
</tr>
<tr>
<td>WCT-1 FCS</td>
<td>28 X 37</td>
<td>TBD</td>
<td>1,100</td>
</tr>
<tr>
<td>MLK-2</td>
<td>20</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>MLK-1</td>
<td>7</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>DVT-2</td>
<td>16</td>
<td>49</td>
<td>200</td>
</tr>
<tr>
<td>DVT-1</td>
<td>18</td>
<td>70</td>
<td>1,600</td>
</tr>
</tbody>
</table>
# Doan Valley Tunnel

## Odor Control Alternatives

<table>
<thead>
<tr>
<th>No.</th>
<th>Alternative</th>
<th>Cost ($MM)</th>
<th>Footprint (SF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No OCFs</td>
<td>$0</td>
<td>0</td>
</tr>
<tr>
<td>2a</td>
<td>DVT-1 OCF: 30,000 cfm (AC)</td>
<td>$1.72</td>
<td>DVT-1: 1,500</td>
</tr>
<tr>
<td>2b</td>
<td>DVT-1 OCF: 30,000 cfm (AC) WCT-2 OCF: 5,000 cfm (AC)</td>
<td>$2.35</td>
<td>DVT-1: 1,500 WCT-2: 250</td>
</tr>
<tr>
<td>3a</td>
<td>DVT-1 OCF: 15,000 cfm (BF) DVT-2 OCF: 15,000 cfm (BF)</td>
<td>$2.43</td>
<td>DVT-1: 16,500 DVT-2: 8,200</td>
</tr>
<tr>
<td>3b</td>
<td>DVT-1 OCF: 15,000 cfm (BF) DVT-2 OCF: 15,000 cfm (BF) WCT-2 OCF: 5,000 cfm (AC)</td>
<td>$3.06</td>
<td>DVT-1: 16,500 DVT-2: 8,200 WCT-2: 250</td>
</tr>
<tr>
<td>4</td>
<td>Option 2a, 2b, 3a, 3b PLUS: MLK-1 OCF: 5,000 cfm (AC, AD)</td>
<td>$2.35-$3.69</td>
<td>MLK-1: 250</td>
</tr>
</tbody>
</table>

AC: Activated Carbon  
BF: Biofilter  
AD: Air Dispersion  

Note: costs in 2016 dollars.
Doan Valley Tunnel

Recommendations

- Planning for space/footprint on site, should potential odor control facilities be needed, at four sites:
  - 30,000 CFM activated carbon at DVT-1
    OR 15,000 CFM biofilter at DVT-1 and 15,000 CFM biofilter at DVT-2
  - 5,000 CFM activated carbon at MLK-1
  - 5,000 CFM activated carbon at WCT-2
- Further ventilation evaluation under a greater range of storm conditions
05 Case Study: Ohio Canal Interceptor Tunnel (City of Akron)
Ohio Canal Interceptor Tunnel (OCIT)

- City of Akron Water Reclamation Services
  - Serves City of Akron and neighboring communities
  - 96 square miles, population of 330,000
  - Akron Waterways Renewed!
    - Series of projects to reduce CSOs
    - OCIT: largest AWR project - $300M

- OCIT Team:
  - DLZ: Lead Designer
  - McMillan-Jacobs: Tunnel Designer
  - HDR: Odor Evaluation & Design
Ohio Canal Interceptor Tunnel (OCIT)

- 6,200 linear feet, 27-foot diameter
- Contractor: Kenny Obayashi Joint Venture
- Completion 2020
- Three dropshaft sites:
  - OCIT-1/TDS: Downstream, residential
  - OCIT-2: Midpoint, potential future development
  - OCIT-3: Downtown
- HDR has performed the following:
  - Odor evaluation of existing system
  - OCIT ventilation study
  - OCIT odor control facility plan
  - OCIT-1 odor control facility design
Ohio Canal Interceptor Tunnel (OCIT)

- Ventilation Evaluation
  - Technology review
  - Typical year storm data

- Facility Plan Deliverables:
  - Frequency/duration/intensity of odorous air emissions – friction drag and displacement
  - Odor control facility alternatives
    - Site layouts
    - Cost estimates
    - Level of service
A picture of 0.1% of the data…
Dry Weather Flow ($d/D \approx 0.07$)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>&gt;90% of Year (&gt;328 days/yr)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Frequency

- **22 / yr**

### Return Interval

- **<2 month**

### Duration

- **Avg event: 5.2 hrs**
- **Max event: 20.4 hrs**
- **Total annual: 124 hrs**

---

**Diagram:**

- **Tunnel Diversion Structure**
- **OCIT-2 Dropshaft**
- **Crown @ EL 820.00**
- **OCIT-2 Adit**
  - **Crown @ EL 813.05**
  - **Invert @ EL 805.05**
- **OCIT-1 Connector**
  - **Crown @ EL 802**
  - **Inv @ EL 794**
- **OCIT-3 Vent Vault**
- **84" Vent**
- **OCIT-3 Dropshaft**
  - **Crown @ EL 829.36**
### d/D at TDS = 0.45 to d/D at TDS = 0.65

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
</table>
| 13 / yr   | Avg event: 2.2 hrs  
Max event: 5.1 hrs  
Total annual: 28.2 hrs | <2 month |
**d/D at TDS = 0.65 to d/D at TDS = 1.0**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 / yr</td>
<td>Avg Event: 4.5 hrs</td>
<td>&gt;2 month</td>
</tr>
<tr>
<td></td>
<td>Max Event: 7.6 hrs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Annual: 26.8 hrs</td>
<td></td>
</tr>
</tbody>
</table>

**Diagram:**
- Tunnel Diversion Structure
- OCIT-2 Dropshaft
- Crown @ EL 820.00
- OCIT-2 Adit
  - Crown @ EL 813.05
  - Invert @ EL 805.05
- OCIT-1 Connector
  - Crown @ EL 802
  - Inv @ EL 794
- OCIT-3 Vent Vault
- 84” Vent
- OCIT-3 Dropshaft
- Crown @ EL 829.36
d/D at TDS = 1.0 to d/D at OCIT-2 = 1.0

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 / yr</td>
<td>Avg Event: 1.8 hrs</td>
<td>&gt;3 month</td>
</tr>
<tr>
<td></td>
<td>Max Event: 2.5 hrs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Annual: 8.8 hrs</td>
<td></td>
</tr>
</tbody>
</table>
d/D at OCIT-2 = 1.0 to
d/D at OCIT-3 = 1.0

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 / yr</td>
<td>Avg Event: 1.8 hrs</td>
<td>&gt;3 month</td>
</tr>
<tr>
<td></td>
<td>Max Event: 2.5 hrs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Annual: 8.8 hrs</td>
<td></td>
</tr>
</tbody>
</table>
d/D at OCIT-3 > 1.0

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Duration</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 / yr</td>
<td>Avg Event: 1.8 hrs</td>
<td>&gt;3 month</td>
</tr>
<tr>
<td></td>
<td>Max Event: 2.5 hrs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Annual: 8.8 hrs</td>
<td></td>
</tr>
<tr>
<td>Storm Start Date</td>
<td>Peak d/D</td>
<td>Time Spent In Scenario (hours)</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>4/12</td>
<td>1.57</td>
<td>1.44</td>
</tr>
<tr>
<td>8/13</td>
<td>1.57</td>
<td>1.42</td>
</tr>
<tr>
<td>7/7</td>
<td>1.56</td>
<td>1.42</td>
</tr>
<tr>
<td>7/2</td>
<td>1.11</td>
<td>0.95</td>
</tr>
<tr>
<td>8/20</td>
<td>1.02</td>
<td>0.87</td>
</tr>
<tr>
<td>4/13</td>
<td>0.85</td>
<td>0.70</td>
</tr>
<tr>
<td>7/21</td>
<td>0.65</td>
<td>0.48</td>
</tr>
<tr>
<td>4/9</td>
<td>0.64</td>
<td>0.48</td>
</tr>
<tr>
<td>9/9</td>
<td>0.55</td>
<td>0.40</td>
</tr>
<tr>
<td>7/28</td>
<td>0.55</td>
<td>0.39</td>
</tr>
<tr>
<td>1/27</td>
<td>0.49</td>
<td>0.34</td>
</tr>
<tr>
<td>8/11</td>
<td>0.48</td>
<td>0.31</td>
</tr>
<tr>
<td>6/29</td>
<td>0.46</td>
<td>0.30</td>
</tr>
</tbody>
</table>
# Ohio Canal Interceptor Tunnel

## Airflow Scenario Frequency and Duration

<table>
<thead>
<tr>
<th>Airflow Scenario</th>
<th>Typical Year Frequency</th>
<th>Duration (hours)</th>
<th>Return Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Weather Flow (d/D at TDS&lt;0.07)</td>
<td>&gt;90% of year</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tunnel Full at OCIT-1 Connector (d/D at TDS&gt;0.3)</td>
<td>22 / yr</td>
<td>Avg: 5.2</td>
<td>&gt;1 month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max: 20.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual: 124.0</td>
<td></td>
</tr>
<tr>
<td>Tunnel Full at OCIT-2 Adit Begins to Fill (d/D at TDS&gt;0.45)</td>
<td>13 / yr</td>
<td>Avg: 6.2</td>
<td>&gt;1 month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max: 19.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual: 81.2</td>
<td></td>
</tr>
<tr>
<td>Tunnel Full at OCIT-2 Adit (d/D at TDS&gt;0.65)</td>
<td>6 / yr</td>
<td>Avg: 8.8</td>
<td>&gt;2 month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max: 17.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual: 53.0</td>
<td></td>
</tr>
<tr>
<td>Tunnel Full at TDS (d/D at TDS&gt;1.0)</td>
<td>5 / yr</td>
<td>Avg: 5.2</td>
<td>&gt;3 month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max: 9.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual: 26.2</td>
<td></td>
</tr>
<tr>
<td>Tunnel Full at OCIT-3 (d/D at OCIT-3=1.0)</td>
<td>3 / yr</td>
<td>Avg: 4.6</td>
<td>&gt;7 month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max: 5.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual: 13.7</td>
<td></td>
</tr>
</tbody>
</table>
## Ohio Canal Interceptor Tunnel – Level of Service

### Untreated Airflow Emissions at TDS at Various OCF Levels of Service

<table>
<thead>
<tr>
<th>TDS OCF Capacity (cfm)</th>
<th>Level of Service</th>
<th>Frequency of Untreated Emissions</th>
<th>Duration of Untreated Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>DWF Only</td>
<td>10% of typ year. 100+ / yr</td>
<td>Avg: 8 hrs / event Max: 34 hrs / event Annual: 40 days / yr</td>
</tr>
<tr>
<td>40,000</td>
<td>DWF + minor WWF (d/D&lt;0.15)</td>
<td>40 / yr</td>
<td>Avg: 5 hrs / event Max: 21 hrs / event Annual: 16 days / yr</td>
</tr>
<tr>
<td>60,000</td>
<td>DWF + moderate WWF (d/D&lt;0.35)</td>
<td>14 / yr</td>
<td>Avg: 5.5 hrs / event Max: 20 hrs / event Annual: 3 days / yr</td>
</tr>
<tr>
<td>80,000</td>
<td>DWF + all WWF</td>
<td>&lt;1 / yr</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Ohio Canal Interceptor Tunnel

- **Recommendations:**
  - Air Flaps/Ducts throughout system (Auxiliary Structures)
  - OCIT-1 Odor Control Facility
  - OCIT-2 Air Jumper
  - OCIT-3 Air Dispersion Stack
# Ohio Canal Interceptor Tunnel
## Odor Control Alternatives

<table>
<thead>
<tr>
<th>No.</th>
<th>Alternative</th>
<th>Cost ($MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- OCIT-1 Odor Control Facility, 30,000 cfm&lt;br&gt;- OCIT-2 Air Jumper&lt;br&gt;- Ventilation “Auxiliary Structures”</td>
<td>$5.06</td>
</tr>
<tr>
<td>2</td>
<td>Alternative 1 PLUS:&lt;br&gt;- OCIT-2 Odor Control Facility</td>
<td>$6.70</td>
</tr>
<tr>
<td>3</td>
<td>Alternative 2 PLUS:&lt;br&gt;- OCIT-1 Odor Control Facility, add’l 50,000 cfm&lt;br&gt;- OCIT-3 Odor Control Facility</td>
<td>$9.99</td>
</tr>
</tbody>
</table>
Ohio Canal Interceptor Tunnel
OCIT-1 Odor Control Facility

- Technology Selection Workshop
- 30,000 cfm Activated Carbon system
  - Two 15,000 cfm fans
  - Sized to induce negative pressure throughout entire tunnel system
- Vent Vault for control of excess air flows
OCIT
Vent Vault Structural Section

T/CONCRETE EL 817.00

ALL REINFORCING: #5@9" EA. WAY, EA FACE

EXTRA REINFORCING AT ALL OPENINGS AS PER STANDARD DETAILS (TYP.)

ALUM. LADDER WITH SAFETY POST

7'-0" DIA. DUCT

5'-0" DIA. DUCT (FUTURE WET WEATHER)

2" DIA. PIPE (TYP. OF 2)

#57 AGGREGATE FILL

9" WELL COMPACTED AGGREGATE BASE

SERIES 2633 TIDEFLEX CHECK VALVE OR EQUIVALENT (TYP. OF 2)
Summary
Summary

- Air-water interactions are key to many types of structures, including sewers
- Several mechanisms ventilate and move air within sewers and tunnels
- Consider air flow when designing sewers and tunnels.
  - Ventilation considerations may affect sewer diameters and potential air ducts.
- For complex tunnel systems, evaluate the air flow and ventilation strategies of the entire system holistically early in the design
- Two case studies were presented in which tunnels under design were assessed for ventilation and odor control planning
- Proactive air management strategies decrease operations risk upon start-up / commissioning
Acknowledgements & Questions
Acknowledgements

- City of Akron
  - DLZ Corporation
  - V&A Consulting Engineers, Inc.
- NEORSD
  - McMillen Jacobs Associates & Wade Trim Joint Venture
References


Questions?