Structural Condition Assessment of Combined Sewer Overflow Culvert, City of Lynchburg, VA

Horseford Culvert
Lynchburg, Virginia
17 January 2020
SGH Project 191233
17 January 2020

Mr. Ben Custalow
Greeley and Hansen
9020 Stony Point Parkway
Suite 475
Richmond, VA  23235

Project 191233 –  Structural Condition Assessment of Combined Sewer Overflow Culvert, City of Lynchburg, VA

Re:  Report of Findings

Dear Mr. Custlaow:

We submit the enclosed report to convey the findings our recent structural condition assessment of the combined sewer overflow culvert in Lynchburg, Virginia. We look forward to discussing our finding with you.

Sincerely yours,

Rasko P. Ojdrovic, P.E. Matthew C. Richie
Senior Principal Senior Consulting Engineer
VA License No. 0402054676

Encl.
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Letter of Transmittal

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**ILLUSTRATIONS**

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APPENDIX A – Plan and Profile Drawing
APPENDIX B – Proposed CSO Regulator Vault Drawings
1. INTRODUCTION

1.1 Background

The City of Lynchburg (the City) commissioned a structural evaluation of the current condition of the Horseford Culvert, a historic stone arch culvert in Lynchburg, Virginia. Greeley and Hansen (GH), on behalf of the City, contacted Simpson Gumpertz & Heger Inc. (SGH) to assist with the condition assessment, and to identify and design repairs (if needed). The subject culvert is an early 1800s¹ era stone arch drainage tunnel that flows in an easterly direction from downtown Lynchburg towards the James River. Fill cover over the culvert ranges from 3 ft to approximately 27 ft. The construction and cross-sectional geometry of the culvert vary along its length. The culvert varies along its length and includes portions of arch-shaped, rectangular, and “irregular” sections. A plan of the culvert is depicted in Figures 1 and 2.

¹ Date of construction of the culvert is unknown. Estimates on age of culvert, based on surrounding structures, is early 1800s.
Figure 2 – Approximate Plan and Profile of Culvert Inspection Scope
(Red line is inspection scope, red shading excluded due to access restrictions)
The construction of the culvert includes granite block, concrete, bedrock tunnel, and other building materials. At several locations, the culvert passes beneath existing buildings and it has street crossings at Main Street, Commerce Street, and Jefferson Street. There is also an active CSX railroad crossing between Jefferson Street and the James River. A detailed plan and profile drawing, prepared by Hurt & Proffitt, is included in Appendix A.

During our initial discussions for this work, we were informed by GH that the City is planning improvement to the CSO vault which includes a new concrete regulator structure. The new regulator structure will replace approximately 50 lf of the stone arch culvert downstream from the existing CSO vault. Plan and sections of the proposed CSO regulator structure are included in Appendix B.

1.2 Scope of Work

1.2.1 Phased Approach to Culvert Improvements

Since no as-built drawings are available for the culvert or the Piedmont Flour Mill Building foundation, a multi-phased approach was recommended for improving the existing culvert. Per our subconsultant agreement\(^2\) for this assignment, the approach to the culvert improvements consists of the following phases:

- **Phase 1 – Structural Field Assessment of Culvert.** Conduct a structural field investigation to attain culvert condition information and prepare a condition report with recommendations for improvements to be designed in Phase 2. The scope of any material sampling or further analysis will be determined in Phase 1, as a recommendation for Phase 2 of this work.

- **Phase 2 – Analysis and Improvement Options.** After completion of Phase 1, the second phase consists of a preliminary engineering report where various structural improvement options are presented conceptually, evaluated, and an approach is recommended. If Phase 1 identifies a need for further analysis, such as finite element analysis, or for material sampling, this would be included in Phase 2, to be conducted prior to finalizing the preliminary engineering report.

- **Phase 3 – Design of Improvements.** Once a recommended improvement approach has been selected, final design will be completed.

The work presented in this report constitutes our Phase 1 deliverable for structural field assessment of the Horseford Culvert. Phase 2 and 3 will be included under a separate task order.

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\(^2\) Refer to Attachment C of subconsultant agreement between Greeley Hansen and SGH, dated 18 June 2019.
1.2.2 Phase 1 Scope of Work

The City of Lynchburg identified the scope of this Phase 1 inspection to be the section of culvert between the outfall at the James River and the sanitary sewer vault structure (Station 10+00 to 14+47 on Hurt & Proffitt drawing, Appendix A) where the culvert passes beneath the Piedmont Flour Mill Lofts; a historic five-story brick apartment building built in the 1870s. The final 100 ft of culvert that outfalls to the James river contained heavy sediment buildup and water up to 4 ft deep. Due to safety concerns, this portion was eliminated from the scope, and limited to visual inspection to the extent possible from a safe vantage point on both ends of the section. Our tasks for this evaluation include the following:

- **Internal Condition Assessment**
  - Perform visual inspection of the culvert interior to identify structural distress, material degradation, or other anomalies that may affect structural integrity or performance.
  - Perform sporadic hammer sounding of concrete walls and floors to identify delamination.
  - Document our observations with detailed notes and representative photographs.
  - Perform GPR assessment of reinforced concrete sections to evaluate the concrete thickness and rebar size. To the extent possible, perform GPR in a targeted capacity to evaluate areas of concern identified during our internal condition assessment, and to evaluate the ability to identify voids behind the culvert.

- Perform an external assessment of the accessible public spaces at the ground surface immediately above the culvert, including visual assessment of roadway and railroad crossings to evaluate roadway condition, and approach roadway above the culvert and the headwall and outlet structure.

- **Piedmont Flour Mill Building Condition Assessment**
  - Perform an interior and exterior structural condition assessment of the Piedmont Flour Mill Lofts, limited to visual inspection of the building exterior and interior common areas only. Conduct exterior assessment of the building from the ground level and document readily accessible portions of the structure for evidence of visually detectable deterioration, distress, movement/deflection, or other conditions of concern that may be related to culvert distress.

- **Debrief Meeting:** Participate in an in-person meeting the day after the field assessment is completed to review observations, and identify any follow-up inspections or testing that may be needed.

- **Report:** Prepare a report detailing the results of our document review, field investigations, and recommendations for repair with repair priorities. Our repair recommendations also include location and approximate quantity/size of repair items.
1.3 Purpose

The purpose of our work is to evaluate the current condition of the culvert and to identify any repairs required to maintain safe operation of the culvert.
2. CRITERIA FOR CONDITION EVALUATION

SGH recently completed National Cooperative Highway Research Program (NCHRP) Project 14-26 to develop the Culvert and Storm Drain System Inspection Guide. This Guide establishes criteria for assessing the condition of in-service culvert and storm drain systems to help maintain system safety, functional performance, and the economical use of owner resources. The Guide will be published by the American Association of State Highway and Transportation Officials (AASHTO) later in 2019. The NCHRP 14-26 Final Report is available online and contains sample ratings and condition assessment criteria pertaining to reinforced concrete pipe.

We evaluated the condition of the stone arch tunnel based on our research from NCHRP 14-26 and the condition assessment criteria established in the upcoming publication, the AASHTO Culvert and Storm Drain Inspection Guide. The condition rating system established in the AASHTO Guide is based on a “4” numerical scale. A rating of “1” (Good) indicates little or no deterioration, structurally sound and functionally adequate. Rating numbers increase with worsening condition, up to a rating of “4” (Severe), indicating the component requires special inspection with structural evaluation or immediate maintenance, depending on the component. Condition ratings are based on a comparison of the existing condition with the as-designed condition. When new, a properly designed and installed culvert or storm drain system would have a condition rating of “1” for all system components. Table 1 summarizes the general rating scale with associated actions.

<table>
<thead>
<tr>
<th>CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Like new, with little or no deterioration, structurally sound and functionally adequate.</td>
</tr>
<tr>
<td>Some deterioration, but structurally sound and functionally adequate.</td>
</tr>
<tr>
<td>Significant deterioration, functional inadequacy, or both, requiring maintenance or repair.</td>
</tr>
<tr>
<td>Very poor conditions that indicate possible imminent failure, or failure which could threaten public safety.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTION INDICATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action is recommended. Note in inspection report only.</td>
</tr>
<tr>
<td>No immediate action is recommended, but more frequent inspection may be warranted. Maintenance personnel should be informed.</td>
</tr>
<tr>
<td>Team Leader (Inspector) evaluates need for corrective action and makes recommendation in the inspection report.</td>
</tr>
<tr>
<td>Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.</td>
</tr>
</tbody>
</table>

Table 1 – Rating System and Associated Indicated Actions
Masonry culverts, which refers to culverts constructed of individual units of stone, brick, or concrete block, are typically evaluated based on the condition of the masonry units and mortar, indications of movement or distortion, and weathering or degradation of the masonry. Table 2 provides the specific evaluation criteria for masonry culverts, excerpted from the AASHTO guide. Additional explanation of the evaluation criteria is summarized below:

- **Movement**: Movement of individual or grouped masonry units may occur due to freeze-thaw action, vegetation growth, mortar deterioration, or stress.

- **Shape**: Masonry arches act primarily in compression. Racking, flattened curvature, bulges in walls, or other shape deformations may indicate unstable soil conditions. The vertical and horizontal alignment should be checked visually.

- **Cracking and Splitting**: Cracking and splitting in masonry units are generally caused by tensile stress in the units. Cracking may be due to differential settlement or expansion of foundation soils, increased lateral earth pressure, shifting of units due to mortar deterioration, or impact damage. The Inspector should note the presence and location of cracked masonry units.

- **Freeze-Thaw Cycling**: Expansion of frozen water trapped behind a masonry unit can cause movement of the unit. Under repeated cycling, and sometimes combined with other deterioration and erosion, units can become loose and dislodged.

- **Acid Weathering**: Acidic rainwater and storm water runoff can dissolve the surface of the units. Weathering typically appears as roughened surface with discoloration when compared with unweathered counterparts. Sandstone, limestone, and marble are susceptible to acid attack.

- **Mortar Distress**: In most masonry arch culverts, mortar is used to bond the masonry units together. The condition of the mortar should be checked to ensure that it is still holding strongly. It is particularly important to note cracked, deteriorated, or missing mortar, especially if other deterioration is present such as loose or missing masonry units. The presence of dirt or vegetation between masonry units should be noted as these can be indicators of loss of backfill or erosion behind the structure. Water infiltration can also contribute to mortar distress in cold climates as freeze-thaw cycles break the mortar apart.

- **Vegetation**: Lichen and mosses growing on the face of units can create a moist environment which accelerates chemical weathering. Higher order vegetation and trees can also plant roots between units and dislodge masonry units. Vegetation should be removed from the units as part of regular maintenance.

- **Efflorescence and Staining**: Water infiltration through joints may be indicated by deposits caused by efflorescence (leaching of salts or chlorides) emanating from the mortar joints, or cracking in the stone blocks. Efflorescence and staining on its own are primarily cosmetic issues due to capillary action in porous materials; therefore, its presence alone cannot cause a severe rating. However, it can sometimes lead to spalling and deterioration and should be recorded and tracked during inspection.
<table>
<thead>
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<th>Table 2 – Condition Criteria for Evaluation of Masonry Culverts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MASTERY UNITS AND MOVEMENT</strong></td>
</tr>
<tr>
<td>1 GOOD</td>
</tr>
<tr>
<td>No cracking, split, or missing masonry units.</td>
</tr>
<tr>
<td>No displaced masonry units.</td>
</tr>
<tr>
<td>No surface deterioration.</td>
</tr>
<tr>
<td>No measurable cross-sectional distortion.</td>
</tr>
<tr>
<td>2 FAIR</td>
</tr>
<tr>
<td>Cracking of isolated individual units.</td>
</tr>
<tr>
<td>Surface weathering or spalling.</td>
</tr>
<tr>
<td>No movement of masonry units.</td>
</tr>
<tr>
<td>3 POOR</td>
</tr>
<tr>
<td>Split or cracked masonry units.</td>
</tr>
<tr>
<td>Large areas of moderate spalling, scaling, or weathering.</td>
</tr>
<tr>
<td>Pronounced movement or dislocation of masonry units, but does not warrant engineering evaluation.</td>
</tr>
<tr>
<td>4 SEVERE</td>
</tr>
<tr>
<td>Widespread cracking, splitting, or crushing of masonry units or missing units.</td>
</tr>
<tr>
<td>Large areas of heavy spalling, scaling, or weathering.</td>
</tr>
<tr>
<td>Holes through structure wall.</td>
</tr>
<tr>
<td>Significant movement of individual units.</td>
</tr>
<tr>
<td>Visible movement or distortion of cross-sectional shape, structure appears unstable.</td>
</tr>
<tr>
<td><strong>MORTAR</strong></td>
</tr>
<tr>
<td>1 GOOD</td>
</tr>
<tr>
<td>Mortar is intact with no deterioration.</td>
</tr>
<tr>
<td>2 FAIR</td>
</tr>
<tr>
<td>Localized cracked or missing mortar.</td>
</tr>
<tr>
<td>Widespread areas of shallow mortar deterioration, possible minor water infiltration (no active flow), or exfiltration through joints.</td>
</tr>
<tr>
<td>3 POOR</td>
</tr>
<tr>
<td>Extensive missing mortar.</td>
</tr>
<tr>
<td>Extensive mortar deterioration, small flow but no soil/fines, infiltration, or exfiltration through joints.</td>
</tr>
<tr>
<td>Vegetation sprouting from between units.</td>
</tr>
<tr>
<td>4 SEVERE</td>
</tr>
<tr>
<td>Missing mortar with backfill infiltration, possible voids in roadway.</td>
</tr>
<tr>
<td><strong>EFFLORESCENCE</strong></td>
</tr>
<tr>
<td>1 GOOD</td>
</tr>
<tr>
<td>Localized areas of efflorescence less than 2 in².</td>
</tr>
<tr>
<td>2 FAIR</td>
</tr>
<tr>
<td>Widespread areas of efflorescence without rust staining.</td>
</tr>
<tr>
<td>3 POOR</td>
</tr>
<tr>
<td>Heavy buildup of efflorescence with rust staining.</td>
</tr>
<tr>
<td>4 SEVERE</td>
</tr>
<tr>
<td>Cannot cause Severe rating.</td>
</tr>
</tbody>
</table>
3. INFORMATION FROM OTHERS

3.1 Internal Laser Scan Results by Hurt & Proffitt

We were provided with the results of an internal laser scan performed by Hurt & Proffitt. We understand the internal scan was performed to produce a three-dimensional surface map on the culvert interior. We were provided point cloud files for future use in Phase 2 of this work to generate cross-sectional information and detailed culvert geometry for the purpose of finite element modeling (if required) and developing repair drawings. Converting these point clouds into CAD files is a significant effort that was not included during this scope of work and will be done during Phase 2.

3.2 Geotechnical Report by Schnabel Engineering

We reviewed the geotechnical evaluation report by Schnabel Engineering dated 5 July 2019. Of the five soils borings taken, Borings B-01, B-02, and B-05 were all in close proximity to the existing Horseford Culvert and may be representative of the type of fill material surrounding the culvert. Borings B-03 and B-04 were taken away from the culvert in the vicinity of the proposed 4 ft by 4 ft diversion conduit and are close enough to be relevant to this review. Schnabel reports that for Borings B-02 and B-05, they encountered existing fill soils for a depth of 1.5 ft to 17 ft. The existing fill soils “consist of elastic silt, sandy silt, silty sand, and silty gravel (MH, ML, SM, GM) with varying amounts of sand and gravel, mica, wood fragments, rock fragments, asphalt fragments, brick fragments, and crushed stone.” Schnabel also reports that they were provided “photographs from construction of the existing regulator which appeared to show excavation through shot rock fill.”

Boring B-01 and B-02 were terminated at selected depths of 16 ft and 25 ft and therefore do not identify the depth of bedrock in that area. Boring B-05, however, encountered granite at a depth of 21.5 ft.
4. FIELD OBSERVATIONS

Matthew Richie and Dan Schuetz of SGH were on site 26–27 August 2019 to perform a visual and non-destructive condition assessment of the CSO culvert. Mr. Zeke Ratcliff of Hurt & Proffitt (H&P) provided OSHA permit required confined space entry support during our visit. Access and egress to the culvert system were via the manway in the diversion dam vault (approximate station 14+60 on H&P profile drawing).

4.1 Internal Visual Condition Assessment of Culvert

We began our internal assessment at the diversion dam vault, which is the upstream terminus of our inspection scope and progressed downstream. Using a measuring wheel, we marked stationing along the tunnel wall to provide reference distance to observations recorded during our assessment. Due to irregularity in the bedrock floor of the downstream end of the culvert, we marked stationing using the culvert wall rather than the floor. Our reference starting point (0 ft) is at the downstream toe of the diversion, with distances increasing downstream in the direction of progress.

Table 3 presents a summary of our field observations. Photos of each observation referenced in the table can be found in the photographs section of this report. The general layout of the culvert within the inspection scope is described below:

- From distance 0 to 123 ft of the inspection scope, the culvert is a granite stone block arch with a 4 ft span and 7 ft rise with a concrete floor that has large exposed aggregate (Photo 2).
- At distance, 123 ft is the approximate upstream location where the culvert crosses beneath the Piedmont Flour Mill Lofts (Photo 22).
- From distance 123 to 173 ft, the culvert widens to approximately 8 ft span with an uneven, natural bedrock floor (Photo 23).
- At distance 173 ft, the culvert cross-section abruptly shifts to the left with a 2 ft offset (Photos 29 and 30).
- From 173 to 177 ft, the ceiling has a small length of brick arch supported on the granite block walls (Photo 32).
- From 178 to 220 ft, the culvert cross-section changes to rectangular cross-section with concrete wall on the left side, and granite stone wall on the right side (facing downstream). The ceiling above is exposed to the underside of the Piedmont Flour Mill Lofts. The floor in this area is a suspended concrete slab. (Photo 34).
• At distance, 220 ft is the approximate downstream location of where the culvert crosses beneath the Piedmont Flour Mill Lofts.

• From 224 to 260 ft, the cross section of the culvert changes to a 10 ft rise by 13 ft span concrete arch. This location is approximately underneath Jefferson Street (Photo 41).

• At 260 ft, the rise of the culvert abruptly drops to approximately 5 ft where the concrete arch changes to a granite stone arch (Photos 41 and 42).
  • This location is approximately where the culvert crosses underneath the railroad track.
  • This location is the approximate end of the inspection scope due to heavy sediment build up and deep water preventing inspection. Beyond this location, we visually inspected the remainder of the culvert by viewing the interior from either end.

Table 3 –Summary of Field Observation

<table>
<thead>
<tr>
<th>Distance (ft)</th>
<th>Location</th>
<th>Observation</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Floor</td>
<td>Downstream toe of diversion dam, 7 ft rise by 4 ft span stone arch culvert with concrete floor.</td>
<td>1 and 2</td>
</tr>
<tr>
<td>1</td>
<td>Floor</td>
<td>8 in. dia. spall with granite block visible below.</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Crown</td>
<td>Curtain to reduce odor to Mill Building.</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>Right side wall, 5 ft</td>
<td>12 in. dia. terracotta inlet pipe (1 in. wall thickness). Pipe is completely plugged with sediment and stone.</td>
<td>5</td>
</tr>
<tr>
<td>18</td>
<td>Crown 12:00</td>
<td>Displaced 4 ft long keystone in crown. Stone is vertically displaced 6 in. at upstream end and 14 in. on downstream.</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>Floor</td>
<td>ADS Flow meter on floor.</td>
<td>-</td>
</tr>
<tr>
<td>27 to 33</td>
<td>Floor, right side</td>
<td>Large spall 4 ft long x 2 ft wide, up to 10 in. deep, with granite block visible below. Some undermining/washout under block wall.</td>
<td>7 and 8</td>
</tr>
<tr>
<td>32 to 38</td>
<td>10:00 to 11:30, left side</td>
<td>Large 5 ft long x 2 ft high concrete patch area. Concrete is stable and intact but soft and friable, deterioration.</td>
<td>9</td>
</tr>
<tr>
<td>Various</td>
<td>Typical</td>
<td>Typical condition throughout tunnel: Missing mortar from between stones with missing length ranging from 6 in. to 18 in. long, and depth varying from partial depth to full depth of block. Remaining mortar is soft and friable in many locations. Several locations of loose mortar between stones. Water infiltration from mortar joints at several locations.</td>
<td>10 – 12</td>
</tr>
<tr>
<td>58 to 64</td>
<td>1:00</td>
<td>Mortar missing around 1/3 of stone block at 1:00.</td>
<td>13</td>
</tr>
<tr>
<td>68 to 73</td>
<td>Floor, right side</td>
<td>Large spall in floor 5 ft x 1 ft, missing mortar on upstream side of first course wall block.</td>
<td>14</td>
</tr>
<tr>
<td>80</td>
<td>5.5 ft, right side</td>
<td>12 in. dia. terracotta inlet pipe (1 in. wall thickness). Several displaced joints.</td>
<td>15</td>
</tr>
<tr>
<td>83 to 89</td>
<td>Floor</td>
<td>Large spall in floor, full width of tunnel. Length of spalled area varies 1 to 5 ft.</td>
<td>16</td>
</tr>
<tr>
<td>89</td>
<td>5 ft, left side</td>
<td>12 in. diameter terracotta inlet pipe (1 in. wall thickness). Several displaced joints. Large displacement in 4th joint, possible soil infiltration through joint.</td>
<td>17</td>
</tr>
<tr>
<td>Distance(ft)</td>
<td>Location</td>
<td>Observation</td>
<td>Photo</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>95 to 99</td>
<td>Floor</td>
<td>Large spall full width of floor with undermining/washout up to 18 in. deep.</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Floor</td>
<td>Crack in floor full width, likely associated with adjacent spall.</td>
<td></td>
</tr>
<tr>
<td>120 to 122</td>
<td>Floor, right side</td>
<td>Large spall in floor, right side 2 ft L x 3 ft W. Undermining/washout with exposed stone underneath.</td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>Floor</td>
<td>End of concrete floor drop off to bedrock floor. Cross-section widens to approximately 8 ft.</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>5 ft, right side</td>
<td>4 in. dia. clay pipe, visible soil infiltration through joints.</td>
<td></td>
</tr>
<tr>
<td>133</td>
<td>Left side</td>
<td>Bottom three courses of block are not fully supported (overhang) and have open joints, missing mortar, and signs of movement/rotation.</td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>Bottom of wall, left side</td>
<td>Water infiltration from under wall, some undermining/washout from under bottom course of block.</td>
<td></td>
</tr>
<tr>
<td>173</td>
<td>Cross-section change</td>
<td>End of 8 ft wide section. Cross-section widens and is offset by approximately 2 ft to the right. Right side of wall that extend into the cross-section and has missing mortar and wide joints.</td>
<td></td>
</tr>
<tr>
<td>173</td>
<td>12:30</td>
<td>12 in. dia. terracotta inlet pipe (1 in. wall thickness). Small diameter steel pipe with debris visible inside.</td>
<td></td>
</tr>
<tr>
<td>173 to 175</td>
<td>10:00 to 2:00 (ceiling)</td>
<td>2 ft wide section of brick arch. Downstream end of brick arch has separate horizontal wythe of brick that appears unsupported.</td>
<td></td>
</tr>
<tr>
<td>178</td>
<td>Wall left side</td>
<td>Start of reinforced concrete wall on left side. Hammer sounding did not identify any delamination between the concrete cover and rebar.</td>
<td></td>
</tr>
<tr>
<td>180 to 223.5</td>
<td>Floor</td>
<td>Start of concrete floor slab. Hammer sounding did not identify any delamination between the concrete cover and rebar.</td>
<td></td>
</tr>
<tr>
<td>177</td>
<td>Wall right side</td>
<td>6 in. dia. metal elbow tuned downstream.</td>
<td></td>
</tr>
<tr>
<td>177</td>
<td>Ceiling</td>
<td>6 in. dia. PVC extending into tunnel from cutout in Mill Building crawl space above.</td>
<td></td>
</tr>
<tr>
<td>178 to 187</td>
<td>Ceiling</td>
<td>Corroded metal deck overhead.</td>
<td></td>
</tr>
<tr>
<td>178 to 223.5</td>
<td>Ceiling</td>
<td>Corroded structural steel members running longitudinally along left side.</td>
<td></td>
</tr>
<tr>
<td>178 to 206</td>
<td>Ceiling</td>
<td>Charred wood members overhead, remnants of deteriorated wooden joists (appear abandoned, non-structural).</td>
<td></td>
</tr>
<tr>
<td>204 to 220</td>
<td>Wall right side</td>
<td>Upper 2 ft of wall has exposed brick above stone wall.</td>
<td></td>
</tr>
<tr>
<td>224</td>
<td>Ceiling</td>
<td>Concrete arch with large stone aggregate. Arch ceiling is approximately 18 in. lower than upstream ceiling. Arch has cold joints with large aggregate visible, up to 4 in. long. Hammer sounding did not identify any delamination between the concrete cover and rebar.</td>
<td></td>
</tr>
<tr>
<td>220 to 223</td>
<td>Wall, right side, 3 to 7 ft</td>
<td>Missing granite blocks in wall.</td>
<td></td>
</tr>
<tr>
<td>224 to 260</td>
<td>Cross-section change</td>
<td>Reinforced concrete arch, 10 ft span x 13 ft rise.</td>
<td></td>
</tr>
<tr>
<td>Distance&lt;sup&gt;(1)&lt;/sup&gt; (ft)</td>
<td>Location&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>Observation</td>
<td>Photo</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>260 to Outfall interior</td>
<td>Culvert interior</td>
<td>End of scope of interior inspection. Limited inspection from 260 ft and outfall end. No distress observed.</td>
<td>42</td>
</tr>
<tr>
<td>Outfall</td>
<td>Culvert interior</td>
<td>Limited inspection from outfall end. No distress observed. Outfall and final portion of appear to be culvert are precast three-sided box culvert with attached precast headwall and wingwalls. Invert obscured by river sediment and water.</td>
<td>43 and 44</td>
</tr>
</tbody>
</table>

1. Yellow shaded cells indicate location is within the proposed CSO 56 improvements will replace approximately 50 ft of the stone arch culvert downstream from the existing CSO vault.
2. Distance measured along bottom of wall from toe of diversion dam to downstream location of interest.
3. Left/right and clock positions measured facing downstream.

### 4.2 Hammer Sounding

We performed hammer sounding of the reinforced concrete wall and floor slab between distance 178 ft to 223 ft. Hammer sounding is a technique whereby tapping or dragging a hammer across the surface of reinforced concrete can be used to detect pitch changes in the sound of the hammer strike. Areas that sound distinctly hollow compared to the surrounding concrete are typically initiative of delamination between the concrete cover and the reinforcing bars. This technique can further be used to identify weak or degraded concrete. We did not identify any hollow sounding areas, nor did we find areas of degraded concrete. Concrete appeared and sounded generally competent and in good structural condition.

### 4.3 Ground Penetrating Radar

We performed Ground-Penetrating Radar (GPR) scanning in a targeted capacity to evaluate thickness and condition of the granite arch blocks and reinforced concrete sections of the tunnel (Photo 45). We used a GSSI-3000 GPR unit coupled with two different antennae, a 1.5 GHz antenna (relatively high resolution and a typical signal penetration depth of 12 to 18 in.) and a 900 MHz antenna (relatively low resolution and a typical signal penetration depth of 24 to 36 in.), to scan the stone and concrete elements.

GPR systems operate by sending a pulse of energy into a material and recording the amplitude and time required for the return of any reflected signal. The energy pulse signal is sent and received from an antenna placed against the surface. Reflections are produced whenever the energy pulse crosses a boundary with a different density material. The amplitude of the reflected signal is determined by the contrast in material densities across the boundary. The amplitude of the reflection is determined by the contrast in the electrical conduction properties of the two materials and is affected by the moisture within the materials.
Correlation of the time-depth relationship requires confirmation by physical measurements obtained via sample openings or direct thickness measurements where both sides of the scanned element are visible. For our investigation, we were able to find several locations where full granite block thickness measurements could be made to confirm the time-depth relationship. The accuracy of the determination of the locations of reflection depends largely on the smoothness of the contact surface.\(^3\)

We performed GPR scanning of individual granite blocks at locations to determine approximate thickness and, to the extent possible, to determine likelihood of the presence of void space behind the stones. We selected scanning locations based on observed spalling and distress identified in the floor and/or undermining of the granite block at the base course. At each location, we scanned multiple stones along the length and height of the wall in the vicinity of the spalling. We reviewed the collected GPR data from the granite stones and determined the following:

- Estimated stone thicknesses from GPR scanning range from 11 to 30 in., with most of the stones thickness in the range of 15 to 24 in.
- The back sides of the stones are rough, and the thickness of an individual stone can vary by 6 in. or more along its length.
- GPR scans indicate possible voids near the bottom course of stones where spalling and undermining in the floor is present. Voids appear most prominent (largest) near the bottom course of stone and dissipate at higher stone courses.

We also performed GPR scans along the concrete sections of the culvert. We reviewed the collected GPR data at the concrete areas and determined the following:

- We did not identify any steel reinforcing within concrete wall located at distance 178 to 223.5 ft. The thickness of the wall is 24.5 in. The wall is either unreinforced or has very little reinforcement. Some embedded reinforcement or metal appears to be present at about 10 in. deep from the inside face, but could not be confirmed.
- Concrete arch section located at distance 220 to 223 ft thickness at the center is 20 in. based on physical measurement and confirmed by GPR scan.
- The concrete floor slab at distance 180 to 223.5 ft is reinforced with closely spaced reinforcing bars near the surface. The thickness, based on physical measurements of the slab edge, is about 6 in.

\(^3\) By its nature, there are other limitations to the accuracy of the GPR equipment due to the potential interference and imperfections. For example, near surface, closely-spaced reinforcement or welded wire mesh would prevent GPR signals from penetrating into the depth of the concrete body, though not applicable to granite scanning.
• The concrete infill at distance 32 to 38 ft is reinforced in both directions. Anchorage of the reinforcement could not be determined; however, the patch was stable. The thickness could not be determined.

4.4 External Condition Assessment of Culvert and Piedmont Flour Mill Lofts

We performed an external walkdown of the accessible public spaces at the ground surface immediately above the culvert to look for visual indications of subsidence, instability, or ground movement that may indicate loss of backfill support around the culvert. Our evaluation included visual assessment of the paved parking surface behind the Piedmont Flour Mill Lofts building, the area around the building, Jefferson Street roadway, and the CSX railroad crossings. We noted the following:

• We did not observe any signs of subsidence in the ground surface above the culvert.
• We did not observe any indications of excessive pavement cracking above the culvert.
• During our inspection we encountered a CSX maintenance crew performing welding work on the rails near the Piedmont Flour Mill. We asked the crew about their experience in the area and if they knew of any reported subsidence at that location reported by rail operators. They informed us that, to their knowledge, there had not been any subsidence reported in the vicinity of the culvert.

We also performed a limited interior and exterior structural condition assessment of the Piedmont Flour Mill Lofts. The purpose of our assessment was to evaluate the structure for indication of building settlement that may be related to the culvert below. Our exterior assessment of the Piedmont Four Mill Lofts structure was limited to visible portions of the exterior facade and surrounding property. Our interior access was limited to a crawl space under the first floor of the building, with portions directly above the ceiling of the culvert.

We made the following observations about the building exterior:

• The rear (west) face of the building appears to have undergone multiple iterations of brickwork maintenance and repair, evidenced by mismatched brickwork and patching (Photo 46). We observed prevalent cracking of both the brick and mortar with cracking primarily around window lintels (Photos 47 and 48).
• The front (east) face of the building is generally in fair condition with little to no cracking in the brick or mortar (Photo 49).
• The brick facade of the building is supported on granite block foundation walls which were visible. The granite blocks and mortar joints are in fair condition, with no indications of cracking, movement, or settlement of the foundation walls (Photo 50).
We made the following observations about the building interior crawl space:

- The crawl space is accessed by a small 2 ft by 2 ft opening in the basement of the Mill building. The interior of the crawl space is approximately 36 ft by 40 ft with a height of 3 ft. The floor of the crawl space is concrete, and the ceiling is made up of the floor joist and subfloor of the first floor. The concrete floor appears to span across the top of the concrete wall on the left side of the culvert, and supported on the right side at the top of the stone block wall.

- The south side of the crawl space is approximately over the top of the culvert (coincident with distance 173 to 209 ft inside the culvert).

- There is a 2 ft by 2 ft penetration in the floor of the crawl space that opens to the culvert below (distance 177 ft inside culvert). The floor penetration has a 6 in. dia. PVC drain pipe extending into culvert (Photo 33). Within the wall penetration for the horizontal section of white PVC pipe in Photo 33, we noted that there are at least two wythes\(^4\) of brick. There is also a 6 in. dia. metal pipe with a 90° elbow downturned into the culvert below.

- The wooden floor joists of the Mill Lofts are in good condition, but are anchored to the unsupported wythe of brick shown in Photos 32 and 33, and may be structurally unstable.

4.5 Outfall

We visually inspected the outfall of the culvert from the banks of the James River. The outfall, which includes the final 50 to 60 ft of the culvert, appears to be precast concrete segments of rectangular box culvert. We did not observe any cracking in the outfall concrete, and the wingwalls and headwall appeared stable with no signs of movement or rotation. The invert of the culvert and wingwall foundations were underwater and buried under sediment; therefore, we were unable to inspect them at the time of our visit.

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\(^4\) Masonry units are placed in wythes and courses. Wythes are the continuous vertical sections of the wall. The number of wythes determines the wall thickness. Course refers to the layer of units running horizontally. The number of courses determines the height of the wall.
5. DISCUSSION

5.1 Condition of Granite Stone Block Masonry

The stone arch tunnel makes up the first 178 ft of the inspection scope, which includes approximately 50 ft underneath the Piedmont Flour Mill Lofts. This portion of the tunnel consists of granite block masonry with mortared joints and concrete floor. Based on our internal inspection, the masonry units are in “fair” condition with very little degradation, cracking, or damage. Additionally, the section beyond 260 ft to the outfall is also granite stone block arch. We were limited in our ability to inspect this location, but for the areas we observed, the masonry units are in “fair” condition with very little degradation, cracking, or damage.

Movement of Granite Stone Blocks (Distance 18 ft and 133 ft).

We did not observe any indications of settlement, or global movement. The culvert is stable in terms of global section stability; however, we did observe several instances of instability and movement of individual granite blocks. At distance 18 ft, there is a single dislodged block in the crown of the culvert that has become vertically displaced 6 in. at upstream end and 14 in. on downstream. This displaced stone is within the area of the proposed new CSO regulator structure and will be replaced during construction; therefore we have excluded this location from our condition rating. We understand that the new regulator construction is expected within the next twelve months. If construction is delayed beyond twelve months, consider providing temporary structural support at the location. Additionally, at distance 133 ft, the bottom three courses of granite block are not fully supported and show signs of movement and rotation due to lack of support and missing joint mortar (Photos 25 and 26). This location should be repaired by restoring the blocks to their original position and proving support below their overhang.

5.2 Condition of Joint Mortar

The joint mortar between the granite stone blocks is in “poor” condition and in need of repair. The joint mortar is characterized by extensive areas of missing and deteriorated mortar, typical throughout the stone arch section of culvert. Missing mortar from between stones with missing length ranging from 6 in. to 18 in. long, and depth varying from partial depth to full depth of block. Remaining mortar is soft and friable in many locations. We also observed several locations of loose mortar between stones.

We noted water infiltration from between mortar joints at several locations throughout the length of the culvert. Joints are not intended to be fully watertight, and some water infiltration is expected
given the type of construction and age of the structure. We did not see any signs of soil infiltration during our inspection.

Joint mortar in poor condition can lead to global instability and eventual collapse of the culvert. We recommend that the joint mortar be repointed within the next 3 – 5 yrs. Prior to selection of mortar for repointing, we recommend mortar sampling for petrographic analysis. Collect mortar samples and perform laboratory tests and petrographic examinations to identify potential causes of the observed degradation, and effects on durability and remaining strength. Results of laboratory and petrographic examination will be used to determine the full scope of mortar repointing and will help inform selection of repair mortar.

5.3 Condition of Culvert Beneath Piedmont Flour Mill Lofts

The culvert beneath the Piedmont Flour Mill Lofts starts at around distance 123 to 220 ft. Between distance 123 ft and 178 ft, the culvert is 8 ft wide stone arch, with uneven bedrock floor. From 178 to 220 ft, the culvert cross section changes to rectangular cross section with concrete wall on the left side, and granite stone wall on the right side (facing downstream). The stone wall of the culvert from distance 204 to 220 ft appears to be a shared foundation support for the Piedmont Flour Mill Lofts, which can be seen in the upper portion of Photo 38. From inside the culvert, we could not definitely determine what portions of the Mill Lofts structure were supported by the concrete wall. A gap between the top of the wall and soffit of the concrete slab (floor of crawl space) indicates that the slab may not be support by the top of the concrete wall. Our assessment indicates that the concrete slab is supported at the top of the brick above the stone block wall on the right side of the culvert.

_Deteriorated Overhead Structure (Distance 178 to 223 ft)_.

Portions of the ceiling along distance 178 to 223 ft, directly below the Mill Lofts, include charred wood joists (presumably from a previous fire), and corroded steel girders which appear to be non-structural. These charred and corroded beams appear to be abandoned and left in place, likely from construction done during the Loft conversion or other renovation work. The beams and structure in this area are unstable and on the verge collapse. Structural drawings for the Piedmont Flour Mill Lofts were not available for our review, however, our observations suggest that these are non-structural due to the presence of concrete slabs in the crawl space above this location. While the abandoned beams may not present a structural concern, they are currently unstable and pose a safety threat from collapse. Collapsed debris inside the culvert can also result in
blockage, reducing or preventing flow through the culvert, and causing backup and potential flooding.

**Unsupported Brick Wythe (Distance 175 ft).**
The brickwork in the ceiling area of the culvert at distance 175 ft appears to have an unsupported wythe of brick spanning the width of the tunnel (Photo 32). This location coincides with the foundation wall of the Mill Lofts at the upstream end of the crawl space. We examined this area from inside the Mill Loft crawl space and noted that the wooden floor joists are anchored to this same unsupported brickwork. Photo 32 shows a view of the unsupported brick work visible in the culvert, and Photo 33 shows the same wythe of brick from inside the Mill Lofts crawl space (note wooden joists at top of photo). Within the wall penetration for the horizontal section of white PVC pipe in Photo 33, we noted that there are at least two wythes of brick. Likely, the bond between wythes is providing the means of transferring vertical loads on the wall. Drawings of the Mill Lofts were not available for our review; therefore, we do not know the structural loading demand on the brick wall. We recommend that Piedmont Flour Mill Lofts consult with their structural engineer of record to confirm the structural adequacy of the brickwork and wooden floor joists.

**Crawl Space Ceiling Penetration (Distance 177 ft).**
The culvert ceiling in this area also has direct access into Mill Lofts crawl space through a 2 ft by 2 ft penetration (Photo 35). This penetration, seemingly made for a PVC drain pipe from the Mill Lofts, lacks any controls to regulate hazardous gas or odors that may emanate from the culvert during sanitary sewer overflow events. We recommend discussing this matter with the owner of the Mill Lofts and consider constructing a seal around the PVC drain.

**Access between Culvert and Underside of Piedmont Flour Mill Lofts.**
The concrete floor slab between distance 180 to 223.5 ft is suspended above the ground and has access under the Piedmont Flour Mill Lofts at the downstream end. We briefly explored the area under the slab and noted that the underside of the slab has direct access to portions of the Mill Lofts. The area has exposed building structure and what appears to be abandoned steel penstock and turbine left over from the original Flour Mill. The sequence of Photos 52 – 55 illustrate this area.

During high flow events, the combined sewer overflow has potential to backup into the space under the Mill building. Exposure to combined sewer overflow may have negative implications for the Mill Lofts structure. The presence of hydrogen sulfide gas, which is prevalent in sanitary
sewage, can lead to sulfide corrosion causing premature degradation of concrete and steel members. We recommend reviewing the condition and function of the access to determine if it can be closed to prevent combined sewage and/or gases from entering the Mill building foundation area.

Effects of Culvert on Piedmont Flour Mill Lofts.
Our exterior evaluation of the Piedmont Mill Lofts indicated some cracking in the brick facade on the west face of the building. Given the age, changes in use, structural renovations, and modifications to the structure throughout its history, cracking and deterioration of the brick and mortar is not uncommon. The pattern of cracking and relatively stable, uncracked condition of the granite block foundation of the building do not suggest settlement due to culvert movement. The culvert directly below the Piedmont Mill Lofts is founded on stable bedrock; therefore, settlement of the culvert due to consolidation of foundation soils is not expected. However, loss of backfill around the culvert can lead to instability in the foundation soil around the Piedmont Flour Mill Lofts. Our internal inspection of the culvert did not find any signs of global deformation or movement of the culvert that would suggest implication to the Piedmont Flour Mill Lofts. Further, our external ground level inspection did not identify any subsidence or pavement distress that would indicate loss of backfill in the vicinity of the culvert.

We did not see evidence of significant instability in the culvert or the soil around the culvert. The missing joint mortar and floor spalls provide direct pathways for groundwater to flow into the culvert and carry backfill from around the culvert. Our GPR survey indicated the possible existence of voids spaces behind the bottom course of stone block at the floor spalls. We provide additional discussion of these potential void spaces in the Section 4.4 Condition of Concrete Floor and Foundation. We recommend further exploration of the potential void spaces identified during our GPR survey.

5.4 Condition of Concrete Floor and Foundation of Culvert
Foundations for the tunnel were not directly visible for the first 123 ft of the inspection scope. The concrete floor within the first 123 ft of the inspection scope is in “poor” condition and in need of repair, characterized by large spalls, washout, and undermining of the floor and bottom course of granite block. GPR scans indicate potential voids behind the bottom course of granite blocks at locations of floor spalls. Voids spaces behind the wall may be a result of backfill infiltration and washout related to the floor spalls. Alternatively, the GPR signal may be indicating void spaces due to the presence of rubble fill (i.e., the rock, brick wood fragments reported by Schnabel). The
debris-filled clay pipe inlet in Photo 8 indicates that the fill around the culvert may include areas of large stone/rubble fill. This was identified by Schnabel’s geotechnical report in Boring B-02 and B-05 and would also be consistent with construction practices contemporary with the culvert installation. We note that shot rock (also referred to as riprap) reportedly seen by Schnabel in the existing regulator excavation is commonly 4 in. to 9 in. diameter, although Schnabel did not report a size. Rock of this size often leaves relatively large voids spaces between stones, which may have influenced the GPR results. If washout has occurred between the large diameter rubble, over time finer or smaller diameter particles will migrate to fill the remaining voids spaces between larger fill. This can result in movement of the surrounding soils and subsidence at the ground surface, producing instability for nearby structures.

We recommend that Phase 2 of this project include evaluation of the presence of voids. Evaluation of voids can be performed at the time of mortar repointing by removing sections of mortar (while supporting the granite blocks) and inspecting behind the stone using probes and/or borescope inspection camera. If voids are detected, they should be filled under carefully controlled conditions using injectable grout or foam appropriate for such applications.

The remainder of the culvert from 123 ft to the outfall appears to be founded on stable bedrock. In many locations the granite block has been fitted to the uneven surface of the bedrock; however, we did not observe any instability of the walls or bottom course of granite block.

5.5 Condition of Outfall

The outfall is in fair to good condition, based on our limited access for inspection which we visually inspected from the banks of the James River. We did not observe any distress in the visible portions of the culvert or the wingwalls.

5.6 Condition of Inlet Pipes in Culvert

We observed several inlets pipes that drain into the culvert. Most inlet pipes are 12 in. dia. terracotta pipe. These inlet pipes are in poor condition and typically have open joints, some with vertical displacement and evidence of soil infiltration (Photos 8, 15, 17, 24, and 31). Soil infiltration through open joints can cause debris accumulation and blockage of flow. Advancement of this condition can lead loss of backfill support to the inlet pipe and culvert, with eventual collapse. This can also cause settlement of the ground surface above the pipe creating instability in surrounding structures (i.e., differential settlement, cracking) and damage to pavement.
We recommend that these inlet pipes be inspected using remote video inspection. For areas with open joints, we recommend repairing the joints, relining the pipe, or replacement. If the inlet pipes are abandoned, they should be sealed at their ends and filled with concrete to prevent further degradation.
6. CONCLUSIONS

Based on the results our internal and external condition assessment of the Horseford Culvert, we conclude the following:

- The granite stone block masonry within the first 178 ft of the inspection scope is in “fair” condition with very little degradation, cracking or damage. There are two locations with local instability of individual stone blocks:
  - Distance 18 ft: A single dislodged block in the crown of the culvert. We understand this stone is within the area of the proposed new CSO regulator structure, and will be replaced during construction.
  - Distance 133 ft: The bottom three courses of granite block are not fully supported and show signs of movement and rotation due to lack of support and missing joint mortar. This location should be repaired.

- The joint mortar between the granite stone blocks is in “poor” condition with extensive areas of missing and deteriorated mortar, typical throughout the stone arch section of culvert. The poor condition joint mortar can lead to instability and should be repaired.

- The inlet pipes that drain into the culvert typically have open joints, with some vertical displacement, and evidence of soil infiltration. Soil infiltration can cause loss of backfill support to the inlet pipe and culvert causing instability to the inlet pipe, the culvert, and/or surrounding structures.

- For the portion of the culvert directly below the Mill Lofts, there are several areas of concern:
  - Distance 175 ft: The brickwork in the ceiling area of the culvert at this location has an unsupported wythe of brick spanning the width of the tunnel. Examination of this area inside the Mill building crawl space shows that the wooden floor joists are anchored to this same unsupported brickwork. This condition appears to be structurally unstable.
  - Distance 177 ft: The culvert ceiling at this location has a 2 ft by 2 ft penetration that opens into a crawl space under the first floor of the Mill building. This penetration lacks any controls to regulate hazardous gas or odors that may emanate from the culvert during sanitary sewer overflow events.
  - Distance 178 to 223 ft: The ceiling in this area contains charred wood joists and corroded steel girders, which appear to be non-structural and abandoned during prior construction related to the Mill Lofts. The beams appear to be unstable and pose a safety threat from collapse. Collapsed debris inside the culvert can also result in blockage, reducing, or preventing flow through the culvert and causing backup and potential flooding.
  - Distance 180 to 223.5 ft: The suspended concrete floor slab in this area has access under the Mill building at the downstream end. During high flow events, the combined sewer overflow has potential to backup into the space under the Mill building. Exposure to combined sewer overflow may have negative implications for the Mill Lofts structure due to potential corrosion from hydrogen sulfide gas produced by sewage overflows.
Regarding the culvert floor and foundation, we noted the following concerns:

- Distance 0 to 123 ft: The concrete floor is in “poor” condition and in need of repair, characterized by large spalls, washout, and undermining of the floor and bottom course of granite block. GPR scans indicate potential voids behind the bottom course of granite blocks at locations of floor spalls. Spalling in the concrete floor of the culvert is an initiation point for continued degradation in the form of erosion and undermining of the granite block walls. Undermining can cause instability of the arch and should be repaired.

- The remainder of the culvert from 123 ft to the outfall appears to be founded on stable bedrock. In many locations the granite block has been fitted to the uneven surface of the bedrock; however, we did not observe any instability of the walls or bottom course of granite block.

- There is no evidence of settlement of the Piedmont Mill Lofts building due to distress to the culvert.

- The outfall is in fair to good condition, based on our limited access for inspection, with no evidence of distress in the visible portions of the culvert or the wingwalls.
7. RECOMMENDATIONS

As outlined in Section 1.2 of this report, the approach to improvements to the Horseford Culvert consist of three phases. Phase 1, presented in this report, detailed the finding of our field assessment of the Horseford Culvert and Piedmont Flour Mill Building. Phase 2 was envisioned to consist of a preliminary engineering report presenting and evaluating improvement options, and identifying the need for any further analysis or sample. Our assessment indicates that there are no significant structural issues that require finite element analysis, and improvement options are relatively straight-forward to the extent that Phase 2 and Phase 3 can be combined to complete a preliminary material sampling and void evaluation and then move directly to design of improvements. We make the following recommendations for Phase 2 of this work:

Phase 2A: Material Sampling and Void Evaluation

Our investigation revealed two issues that require further evaluation and material sampling: (1) GPR indicates potential voids behind the bottom course of granite blocks at locations of floor spalls; (2) the joint mortar between the granite stone blocks is in “poor” condition with extensive areas of missing and deteriorated mortar. In order to prepare appropriate improvements, we recommend the following tasks as an initial part of the Phase 2 scope:

- **Mortar Sampling**: Collect mortar samples and perform laboratory tests and petrographic examinations to identify potential causes of the observed degradation and effects on durability and remaining strength. Results of laboratory and petrographic examination will be used to determine the full scope of mortar repointing and will help inform selection of repair mortar.
  - We recommend that removal of mortar be performed by a local contractor with direction from SGH. Petrographic examination can be conducted by our laboratory staff in our facility in Waltham, Massachusetts.

- **Void Evaluation**: Perform a targeted internal investigation of the potential void areas identified behind the bottom course of granite blocks at locations of floor spalls. Evaluation of voids can be performed at the time of mortar repointing by preparing exploratory openings by removing sections of mortar (while supporting the granite blocks) and inspecting behind the stone using probes and/or borescope inspection camera. If voids are detected, they can be filled under carefully controlled conditions using injectable grout or foam appropriate for such applications.
  - We recommend that this work be conducted concurrent with material sampling. SGH can perform the probing and borescope inspection, but we recommend that a local contractor assist with making exploratory openings and restoring them after work is completed.

Upon request, we will issue a proposal for this work.
Phase 2B: Design of Improvements

We have identified the need for improvements to the Horseford Culvert at several locations. Phase 2B will include the preparation of conceptual repair options to be presented to the City of Lynchburg and will include a high-level cost estimate for the work presented. Phase 2B will detail the following recommended improvements:

- Plan to repoint the mortar between the granite blocks throughout the culvert within the next 3 to 5 yrs. Prior to selection of mortar for repointing, we recommend mortar sampling as part of Phase 2 of this project. Results of the Phase 2A laboratory and petrographic examination will be used to determine the full scope of mortar repointing and will help inform selection of repair mortar.

- Repair the spalls in the concrete floor of the culvert between distance 0 and 123 ft. Repair design will take into consideration the results of the void evaluation and address any needs for void remediation.

- At the time of repairs, consider installing transitions across locations of discontinuities in the culvert. Locations include:
  - Distance 123 ft: The end of the concrete floor, drop off to bedrock floor. Cross section widens to approximately 8 ft.
  - Distance 173 ft: The end of 8 ft wide section. Cross section widens and is offset by approximately 2 ft to the right. Right side of wall that extend into the cross section and has missing mortar and wide joints.
  - Distance 178 ft: Start of reinforced concrete wall on left side.
  - Distance 223.5 ft: End of suspended concrete slab with 5 ft drop-off to ground below.

- Perform an inspection of the inlet pipes that drain into the culvert. If inlets pipes are abandoned, they should be sealed at their ends filled with concrete. If inlet pipes are active, they should be inspected and repaired at locations with open joints. This work may be performed by the City of Lynchburg or their contractor and does not require design by SGH.

Our investigation identified some concerns with the Piedmont Flour Mill Building, which we present below. Given that the Mill Building Design is not owned by the City, recommendations listed below will first require discussion with the City of Lynchburg to identify the appropriate course of action. We recommend a teleconference to discuss options and approach before proceeding with selection or design of improvements. Once selected, improvement will be design in Phase 2B, including a high-level cost estimate of the proposed repair work:

- Consider sharing our observations of the wooden floor joists anchored to the unsupported wythe of brick shown in Photos 32 and 33 with the owners of the Piedmont Flour Mill Lofts. We recommend that Piedmont Flour Mill Lofts consult with their structural
engineer of record to confirm the structural adequacy of the brickwork and wooden floor joists.

- Consider demolition and removal of the charred wooden structure and corroded steel beams in the ceiling along distance 178 to 223 ft. Structural drawings for the Piedmont Mill Lofts were not available for our review; however, our observations suggest that the corroded and charred members are non-structural remnants from the Lofts renovations. While these may not present a structural concern, they are currently unstable and pose a safety threat from collapse. Collapsed debris inside the culvert can result in blockage, reducing, or preventing flow through the culvert and causing backup and potential flooding.

- Consider sealing the 2 ft by 2 ft penetration to the crawl space to regulate hazardous gas or odors that may emanate from the culvert during sanitary sewer overflow events.

- Evaluate the need to isolate the culvert flow from the area under Piedmont Mill Lofts, where there is direct access for flow under the suspended concrete slab in the vicinity of distance 180 to 223.5 ft. If necessary, design supplemental structure to isolate culvert flow.
Photo 1
Upstream end of inspection scope at concrete diversion dam.
View: Upstream

Photo 2
7 rise by 4 ft span stone arch culvert with concrete floor.
View: Downstream
Photo 3

Missing mortar from between stones. Remaining mortar is soft and friable in many locations.

Typical condition, various locations.

Photo 4

Missing mortar from between stones with varying length and depth of missing mortar. Remaining mortar is soft and friable in many locations. Water infiltration on face of stone

Typical condition, various locations.
Photo 5
Loose and missing mortar.

Typical condition, various locations.

Photo 6
8 in. diameter spall with granite block visible below.

View: Floor
**Photo 7**
Odor control curtain at start of inspection.
View: Downstream

**Photo 8**
12 in. diameter terra-cotta inlet pipe (1 in. wall thickness). Pipe is completed plugged with sediment and stone.
View: Right side wall
Photo 9
Displaced 4 ft long keystone in crown. Stone is vertically displaced 6 in. at upstream end and 14 in. on downstream.
View: Downstream

Photo 10
Large spall 4 ft long x 2 ft wide, up to 10 in. deep, with granite block visible below.
View: Floor, right side
Photo 11
Undermining/washout of fill material from under granite block wall at spall in floor.
View: Floor, right side

Photo 12
Large 5 ft long x 2 ft high concrete patch area. Concrete is stable and intact but soft and friable, deterioration.
View: Downstream
Photo 13

Mortar missing around 1/3 of stone block @ 1:00

View: Ceiling, right side

Photo 14

Large spall in floor 5 ft x 1 ft, missing mortar on upstream side of first course wall block.

View: Downstream
Photo 15

12 in. diameter terra-cotta inlet pipe (1 in. wall thickness). Several displaced joints.

View: Wall, right side

Photo 16

Large spall in floor, full width of tunnel. Length of spalled area varies 1 ft to 5 ft.

View: Downstream
Photo 17

12 in. diameter terra-cotta inlet pipe (1 in. wall thickness). Several displaced joints. Large displacement in fourth joint with possible soil infiltration.

View: Wall, left side

Photo 18

Large spall full width of floor with undermining/washout up to 18 in. deep.

View: Downstream
Photo 19
Spall in tunnel floor with undermining/washout up to 18 in. deep.

View: Downstream

Photo 20
Crack in floor full width, likely associated with adjacent spall.

View: Downstream
Photo 21
Large spall in floor, right side 2 ft L x 3 ft W undermining and/or washout with exposed stone underneath.

View: Downstream

Photo 22
End concrete floor, drop off to bedrock floor. Cross section widens to approximately 8 ft.

View: Downstream
Photo 23
Upstream view showing end concrete floor, drop off to uneven bedrock floor and widened cross section.
View: Upstream

Photo 24
4 in. diameter clay pipe, visible soil infiltration through joints.
View: Wall, right side
Photo 25

Bottom three courses of block are not fully supported and have open joints, missing mortar, and signs of movement.

View: Upstream

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Photo 26

Bottom three courses of block are not fully supported and have open joints, missing mortar, and signs of movement.

View: Wall, left side
Photo 27

Water infiltration from under wall, some undermining/washout from under bottom course of block.

View: Wall, left side

Photo 28

View under bottom course of block showing undermining/washout and water infiltration.

View: Wall, left side
Photo 29

End of 8 ft wide section. Cross section widens and is offset by approximately 2 ft to the right (arrow). Right side of wall that extend into the cross section and has missing mortar and wide joints (close-up next photo).

View: Downstream

Photo 30

Offset in cross section, approximately 2 ft to the right. Offset section has missing mortar between blocks and wide joints.

View: Downstream
Photo 31

12 in. diameter terra-cotta inlet pipe (1 in. wall thickness). Small diameter steel pipe with debris visible inside.

View: Ceiling

Photo 32

2 ft wide section of brick arch. Downstream end of brick arch has separate horizontal wythe of brick that appears unsupported (arrow).

View: Upstream
Photo 33

View from inside Mill Loft crawl space showing area directly above Photo 32. Note wooden floor joists in top of photo are anchored into unsupported brick shown in previous photo.

View: Upstream

Photo 34

Start of reinforced concrete wall on left side and concrete floor slab. Right side wall is granite block.

View: Downstream
**Photo 35**

6 in. diameter metal elbow (arrow) tuned downstream and 6 in. diameter PVC extending into tunnel from 2 ft x 2 ft cutout in Mill Building crawl space above.

View: Ceiling, facing upstream

**Photo 36**

Corroded metal deck overhead.

View: Ceiling, facing upstream
Photo 37
Charred wood members overhead, remnants of wooden joist completely deteriorated. Corroded steel girder (arrow). Members appear abandoned in place and non-structural, but may present a safety hazard from unstable falling debris.

Photo 38
Exposed brick foundation of Mill Building at top of tunnel wall.

View: Downstream
Photo 39
Section of concrete arch with large stone aggregate. Arch ceiling is approximately 18 in. lower than upstream ceiling. Arrow shows cold joint with large aggregate up to 4 in. long.
View: Downstream

Photo 40
Stone blocks missing from right side wall.
View: Downstream
Photo 41

Reinforced concrete arch under Jefferson Street. Arch has 10 ft span x 13 ft rise.

View: Downstream

Photo 42

View looking downstream towards outfall to James River. This section inaccessible due to heavy sedimentation and deep water.

View: Downstream
Photo 43
Culvert outfall viewed from bank of James River.
View: Upstream

Photo 44
Culvert outfall viewed from bank of James River. Outfall and final portion of appear to be culvert are precast three-sided box culvert with attached precast headwall and wingwalls. Invert obscured by river sediment and water.
View: Upstream
Photo 45

GPR scanning of granite block.

Photo 46

Rear (west) face of Piedmont Flour Mill Lofts. Mismatched brick color indicates repair and/or rework of the facade.
Photo 47
Cracking above window lintel, rear (west) face of building. Typical condition.

Photo 48
Cracking above window lintel, rear (west) face of building. Typical condition.
Photo 49

Front face of building along Jefferson Street is generally in fair to good condition with little to no cracking in the brick or mortar.

Photo 50

No indications of cracking, movement, or settlement of the granite block foundation walls.
Photo 51
Access location to crawl space under first floor of Piedmont Mill Lofts.

Photo 52
Photo taken at downstream end of concrete floor slab, looking upstream. Arrow indicates open space under suspended slab.
Photo 53
Area under concrete floor slab. Arrow indicates direction of next photo.
View: Upstream

Photo 54
Photo taken from area under Mill building North of the culvert. Photo shows abandoned steel penstock and turbine left over from the original Flour Mill.
View: Upstream
Photo 55

Photo taken from area under Mill building North of the culvert. Top of photo show soffit of first floor. Left side of photo is the backside of the concrete culvert wall.

View: Upstream
PROPOSED REGULATOR SECTION VIEWS

SCALE: 1" = 20'

CITY OF LYNCHBURG, VIRGINIA
DEPT. OF WATER RESOURCES
CSO 56 BASIS OF DESIGN REPORT
JANUARY 24, 2019