# Memorandum

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| **To:** | Alison Weiss, P.Eng. | **Date:** | June 19, 2020 |
| | | **Project No.:** | 19-0107-005 |
| **From:** | Ray Offman, P.Eng.<br>Arash Kiayee, P.Eng. | **Cc:** | Ron Sorokowski, P.Eng.<br>Colin Siepman, P.Eng.<br>Lunide Milius-Alphonse, P.Eng. |
| **Re:** | Hurst Pumping Station Structural Repairs & Drainage Building Upgrades<br>Pipe Loading Assessment – Final | | |

## 1.0 INTRODUCTION AND PROJECT BACKGROUND

The City of Winnipeg (City) retained KGS Group to carry out a loading assessment of buried infrastructure during the Hurst Pumping Station Structural Repairs and Drainage Building Upgrade.

Part of the project includes replacement of the existing roofs of the Hurst Pumping Station (PS) which necessitates removal and re-installation of existing air handling units (AHU). The project also includes mitigation of sloughing soils and water infiltration into the crawl space south of the Hurst PS.

This technical memorandum presents KGS Group's evaluation of the potential impacts of the proposed construction activities on the pipes and valve chambers within the project site and provides areas of concern where the anticipated loads could have negative impacts on the buried infrastructure. We have also identified the assumed equipment required to undertake the work and we have presented the equipment restrictions that address our equipment loading and construction methodology. Nonetheless, we recommend the Contractor submit their means and methods to KGS Group before undertaking the construction activities based on the availability of the equipment and their previous experience.

## 2.0 IMPACTED BURIED INFRASTRUCTURE

The project site plan including the existing buried infrastructure and the site access is shown on Drawing 1-0650A-C0003-001. Two access routes to the site were considered, one from Hurst Way at the northwest of the site, and one from Willson Place at the southwest of the site. The selection of the site access is important as it determines which pipes could be impacted by the construction activities. The access from Willson Place was previously developed for the Wilkes Reservoir North Cell Rehabilitation Project (2015). The distance from the access gate to the Hurst PS is approximately 440 m and the route includes an enclosed laydown area pad and a gravel road until it ends at the paved road in the vicinity of the pumping station. The access from the Hurst Way is shorter (40 m) and only includes the paved road to access the pump station. In consultation with the City, the access from Hurst Way was deemed to be preferred due to the shorter length and ease of use during construction.

Based on the selected site access, the below underground pipes are anticipated to require construction equipment to pass over them during the construction activities (as presented on Drawing 1-0650A-C0003-001).

- Charleswood Feedermain, 750 mm Reinforced Concrete Water Pipe – Steel Cylinder Type, Not Prestressed, installed on the boulevard / sidewalk between the property line and back of the curb, and crossing the entrance driveway.
- Wilkes Avenue Feedermain, 900 mm Prestressed Concrete Pressure (PSC) Pipe installed on the boulevard and crossing the entrance driveway.
- Wilkes Avenue Reservoir Drainage Building Outlet Pipe, 600 mm Asbestos Cement (AC) Class II Sewer Pipe installed on the west of Hurst Pumping Station Building connecting the Drainage Lift Station to the City 1350 mm Concrete LDS.
- Wilkes Avenue Reservoir By-pass Piping, 1350 mm PSC Suction Pipe installed on the south side of the station crossing the driveway under the yard entrance gate.
- 900 mm PSC Suction Pipe on the south side of the pumping station supplying water from Wilkes Avenue Reservoir North Cell (Wilkes Avenue Reservoir No. 2) to the station crossing the gravel road.
- 900 mm PSC Interconnecting Suction Pipe running diagonally on the south side of the station.
- Two 1350 mm Steel Pipe in Concrete Suction Lines on the southwest & southeast of Hurst Pumping Station.

The City of Winnipeg provided pertinent available historical information to assist in our performance of the loading assessment. The data included record / as-built drawings, contract documents (including special provisions and general conditions), manufacturer's notes, and applicable standards at the time of various underground infrastructure construction works at the site.

To determine the pipe depths at the proposed pathway locations, the ground and invert elevations were established from survey data obtained by KGS (2019) and the City's drawings, respectively.

The reference documents that were used to assess the pipes are described in Table 1. It should be noted that where available, we used the standards and specifications that were in effect at the time of pipe installation. If no data was available, we used the first available pertinent document before or after the pipe installation.

### TABLE 1: LIST OF AVAILABLE PIPE RECORDS

| Asset | Year Installed | Reference Drawing | Reference Document | Applicable Standard | Cover (m) | Design Criteria |
|---|---|---|---|---|---|---|
| Charleswood Feedermain,<br>750 mm Reinforced Concrete Water Pipe – Steel Cylinder Type, Not Prestressed | 1960 | – Dwg. WA-18749 – 30” & 24” WM from Wilkes Ave. PS to Edgeland Blvd., Sta. 0+00 to 16+00, 1960 | Specification C.E.D. 77-59, General Conditions & Special Provisions, Supply and Delivery of 30”, 24” and 16” Water Pipe | – Alternate (3): AWWA C300-57, Reinforced-Concrete Water Pipe-Steel Cylinder Type, Not Prestressed | 2.1 @ site access driveway | – Pipe to safely withstand the full dead load of the backfill plus maximum live load equivalent to **H-20 loading** when the pipe is subjected to the internal design pressure of 150 psi, as per requirements of AWWA C-300. Depth of cover over the top of the pipe will vary from a minimum of **5 ft to 9 ft**<br>– Unit weight of backfill = 120 $lb/ft^3$ |
| Wilkes Avenue Feedermain,<br>900 mm Reinforced Concrete Water Pipe – Steel Cylinder Type, Prestressed (PSC) | 1966 | – Dwg. D-1027, Wilkes Ave. Feedermain III, As Constructed, 1967 | Specification W 11-66 - 1966, General Conditions, Installation of Wilkes Avenue Feedermain III<br>– Specification W 9-66, Contract No. 213, Specifications for Supply & Delivery of Concrete Water Pipe for Feedermains, Prestressed Concrete Pressure Pipe, 1966 | AWWA C-301-58 | 2.1 @ site access driveway | – Width of trench at 1 ft above the top of pipe to be between 12” to 24” + Pipe O.D.<br>– Soil Weight of 110 $lb/ft^3$<br>– Trench bedding factor of 1.5<br>– Min. earth cover of 9 ft<br>– $K_u$ = 0.130 in Marston’s Formula<br>– Live load **H-20 loading**<br><br>– All pipe & fittings to withstand 100 psi working |

| Asset | Year Installed | Reference Drawing | Reference Document | Applicable Standard | Cover (m) | Design Criteria |
|---|---|---|---|---|---|---|
| | | | – Design & Transient-Capacity Curves for 900 mm PSC with Cubic Parabola Design Method as per AWWA C-301-64 Appendix A | | | pressure plus 50 psi for water hammer |
| Wilkes Avenue Reservoir Drainage Building Outlet, 600 mm Asbestos Cement (AC) | 1959 | – WH5621-4, Wilkes Ave. Reservoir N0. 1 & 2, Drainage Sewer Details, 1958<br>– WH5621-6, Wilkes Ave. Reservoir N0. 1 & 2, Lift Station Details, 1958<br>– WIL- 35, Wilkes Ave. Reservoir Reconstruction, Floor Drain Piping, Misc. Details, 1980 | Specification C.E.D. 6-59, Wilkes Avenue Reservoirs No. 1 & 2 | Standard 34-GP-9M for: Pipe Asbestos Cement Sewer, Canadian General Standards Board - 1975 | 2.4 @ Drainage Lift Station, 2.8 m at Gravel Road, 3.0 @ paved access driveway in front of AHUs | – Max. clear width of trench not to be more than 2 ft greater than pipe diameter<br>– Slope = 2.0% |
| Wilkes Avenue Reservoir By-pass Piping, 1350 mm PSC | 1979 | – Dwg. D-1411, By-pass Piping, 1982 | – Special Provisions of Tender No. PD 79-178 to Construct By-pass Piping & Valve Chambers at W.D. Hurst PS & Associated Works, 1979<br>– Addendum # 1, Tender No. PD 79-162 to Supply & Deliver to the City PSC Pipe, Complete with | AWWA C301-79 – Prestressed Concrete Pressure Pipe, Steel Cylinder Type, For Water & Other Liquids | 4.8 | – All pipe & fittings to withstand 0.7 MPa (100 psi) test pressure & 0.35 MPa (50 psi) working pressure internally<br>– Trench width equal to O.D. + 0.6 m<br>– Soil Weight of 1925 kg/m$^3$ (120 lb/ft$^3$)<br>– Trench bedding factor of 1.5 |

| Asset | Year Installed | Reference Drawing | Reference Document | Applicable Standard | Cover (m) | Design Criteria |
|---|---|---|---|---|---|---|
| | | | Fittings, for By-pass Piping at W.D. Hurst PS<br>– Pipe Design Calculations for Wilkes Reservoir Reconstruction, Canron Inc. - Pipe Division, 1980<br>– Specification CW 2115, Specification for Installation of Prestressed Concrete Pressure Pipe Feedermains, 1979 | | | – Min. earth cover of 2.75 m<br>– $K_u$ = 0.110 in Marston's Formula<br>– Live load **H-20 loading** |
| Wilkes Avenue Reservoir North Cell (No. 2) Suction Line, 900 mm PSC (prestressed concrete embedded cylinder pipe w/rubber & steel joint) | 1959 | – Dwg. WH5621-25, Wilkes Ave. Reservoirs No. 1 & 2, Pipe Details for Design, 1959<br>– Dwg. B-571, Yard Piping, 1982<br>– Dwg. WH5621-19, Details of Valve Pit "C", 1959 | – Specification C.E.D. 6-59, Wilkes Avenue Reservoirs No. 1 & 2<br>– Pipe Manufacturer's Notes for Design of Yard Piping<br>– Manufacturer's Pipe Summaries for Yard Piping<br>– Pipe manufacturer's Laying Schedules for Yard Piping | AWWA C301-55T– Reinforced Concrete Water Pipe-Steel Cylinder Type, Prestressed | 5.1 | – Section XV of Dwg. WH5621-25<br>– Live load **H-15 loading**<br>– Total Pressure incl. Water Hammer = 100 psi<br>– Depth of Cover over Top of Pipe = 18.5 ft (5.6 m) of Earth |
| 900 mm PSC Interconnecting Suction Line<br>(prestressed concrete embedded cylinder pipe w/rubber & steel joint) | 1959 | – Dwg. WH5621-25, Wilkes Ave. Reservoirs No. 1 & 2, Pipe Details for Design, 1959<br>– Dwg. D-1412, Valve Chamber No. 1, Mechanical, 1980 | | | 4.9 | – Section XV of Dwg. WH5621-25 (assumed)<br>– Live load **H-15 loading**<br>– Total Pressure incl. Water Hammer = 100 psi<br>– Depth of Cover over Top of Pipe = 16.5 ft (5.0 m) of Earth |

| Asset | Year Installed | Reference Drawing | Reference Document | Applicable Standard | Cover (m) | Design Criteria |
|---|---|---|---|---|---|---|
| 1350 mm Steel Pipe in Concrete, Suction Lines on the Southwest & Southeast of Hurst Pumping Station | ~ 1960 | – Dwg. WH5622-18, Wilkes Ave. Pumping Station, Site Plan Showing Pipe Layout, 1960<br>– Dwg. WH5621-25, Wilkes Ave. Reservoirs No. 1 & 2, Pipe Details for Design, 1959<br>Shop Drawings, Manitoba Bridge & Engineering Works Limited, 1958 | Specification C.E.D. 74-59, General Conditions and Special Provisions for Supply and Construction of Wilkes Avenue Pumping Station and Reservoir Building Superstructure, 1959 | AWWA C201 | 4.5 @ 54”×54”×54”×36” Cross on Southwest & 4.4 @ Southwest of Building<br>4.8 @ 54”×54”×36” Tee on Southeast & 4.5 @ Southeast of Building | – Working Pressure including Water Hammer = 75 psi<br>– Wall Thickness = 0.375”<br>– The use of trenching machinery or hand methods shall be acceptable except that all excavations within six (6) feet of an existing utility must be done as hand work unless written permission has been obtained from the Engineer. |

# 3.0 PROPOSED CONSTRUCTION ACTIVITIES

The construction activities at the site require using heavy machinery that could impact the existing pipes and valve chambers within the site. They include:

- Removal and re-installation of existing Air Handling Units to implement upgrades on the roof of the pump station building.
- Crawl space modification including excavation and temporary shoring on the south side to facilitate installation of new grade beams.

The size of the equipment has been selected in such a way that the load on each pipe does not exceed its allowable load, where possible. We contacted Able Crane Services Limited and Subterranean (Manitoba) Limited to obtain information on the size of equipment that could be used for lifting the air handling units and temporary shoring, respectively. List of anticipated equipment that could be used during construction to implement the above activities is provided in Table 2. The list is by no means exhaustive and the Contractor is required to submit their equipment to perform the work for approval. Details as to how this information is incorporated into our analysis will be discussed in the following sections. It should be noted that only certain pipes will be impacted by each construction activity based on the strategy adopted and the equipment used.

TABLE 2: EQUIPMENT USED DURING CONSTRUCTION

| Equipment | Model | Max. Weight (Operating + Load) *(kg)* | No. of Axles | Axle / Track Load (kg) |
|---|---|---|---|---|
| Skid Steer Loader | CAT 262D | 5,000 | 2 | 2,500 |
| Hydraulic Excavator | Komatsu PC55MR-5 | 6,000 | 2 Tracks | 3,000 |
| Rotary Drill Rig | Sub-Tec 06-04 | 7,000 | 2 Tracks | 3,500 |
| Articulated Boom Lift | Genie Z-34/22 IC | 5,000 | 2 | 2,500 |
| Concrete Pump Truck | N/A | 11,000 | 3 | 3,667 |
| Concrete Mixer Truck (6 $m^3$) | N/A | 27,000 | 3 | 9,000 |
| Crane | AC 140 | 49,940 | 5 | 9,988 |
| Crane + Counterweight | AC 140 + 86 KIP Counterweight | 49,940 + 39,000 = 92,940 | N/A | N/A |

## 3.1 Removal and Re-installation of Air Handling Units

There are two air handling units on the Hurst PS building roof which are to be removed by a crane before replacement of the roof. The units will be stored at the designated location shown on the drawings (as stipulated by the City) adjacent to the PRV Chamber and will be re-installed on the roof upon completion of the roofing. KGS consulted Able Crane Services Limited to submit a lifting plan and size a crane to perform the task. The factors that affected the size of the crane were as follows:

- Weight of the AHUs: each unit weighs 3.5 tonnes.
- Height of the Hurst PS building: 5 m.
- Position of the crane: To maintain maximum feasible clearance from the building to protect existing underground pipes.

The selected crane and the conditions under which the crane will hoist the AHUs are described in Table 3 and Table 4.

**TABLE 3: CRANE INFORMATION**

| | |
|---|---|
| Crane Manufacturer | TEREX \| DEMAG |
| Crane Model | AC 140 \| All Terrain Crane – 170 t Lifting Capacity |
| Main Boom Length | 47.2 m (154.9 ‘) |
| Main Boom Angle | 28.7° |
| Position of Outriggers | Full Extension (100%) |
| Outrigger Length | 8.2 m |
| Outrigger Width | 7.5 m |
| Outrigger Pads | Steel, 1.2 m x 2.4 m x 0.13 m (4’ x 8’ x 5”) |
| Counterweight | 86 kip (86,000 lb) |
| Lift Radius at 360° | 40 m (131’) |
| Crane Capacity at 40 m (131’) Lift Radius | 5,400 kg (11,900 lb) |
| Axle Load with 8,000 kg (17,650 lb) Counterweight | 12,000 kg (26,500 lb) |
| Axles | 5 × 12,000 kg (26,500 lb) |

**TABLE 4: CRANE WEIGHTS**

| | | |
|---|---|---|
| Carrier | 25,100 kg | 55,336 lb |
| Superstructure | 9,200 kg | 20,283 lb |
| HA Boom (Foot Weight) | 9,790 kg | 21,583 lb |
| HA Boom (Head Weight) | 5,850 kg | 12,897 lb |
| Counterweight | 39,000 kg | 85,980 lb |
| Net Load Weight (including AHU & Rigging) | 4,000 kg | 8,817 lb |
| **Total Weight** | **92,940 kg** | **204,896 lb** |

Able Crane provided the ground bearing pressure at 90° swing angle as well as 47° critical angle, as shown below on Figure 1. The lifting plan supplied by Able Crane is provided in Appendix B.

Pipes that will be traversed by this work include the Charleswood Feedermain (750 mm RC), the Wilkes Avenue Feedermain (900 mm PSC), and the Wilkes Avenue Reservoir Drainage Building Outlet sewer (600 mm AC). Traveling of the crane over or adjacent to the pipes is not expected to cause the feedermains to be subjected to load concentrations in excess of their original design loads (H-20 Highway Loading) as the crane axle load is less than the design axle load of 32,000 lb as per the American Association of State Highway Officials (AASHTO) H-20 loading criteria.

The situation that causes concern is when the crane hoists the AHU from the roof and moves it to the designated area for storage. To minimize the impacts of crane load on the underground pipes, its sitting position will be restricted to a 20 m by 9 m area, maintaining 3 m clearance from outside wall of the 600 mm asbestos-cement pipe (as shown on the Drawing 1-0650A-C0003-001). We identified the existing loads (see section 4.3.3) and provided recommendation for their protection during design. A complete loading assessment was undertaken for the anticipated loads on the 600 mm Class II AC drainage pipe.

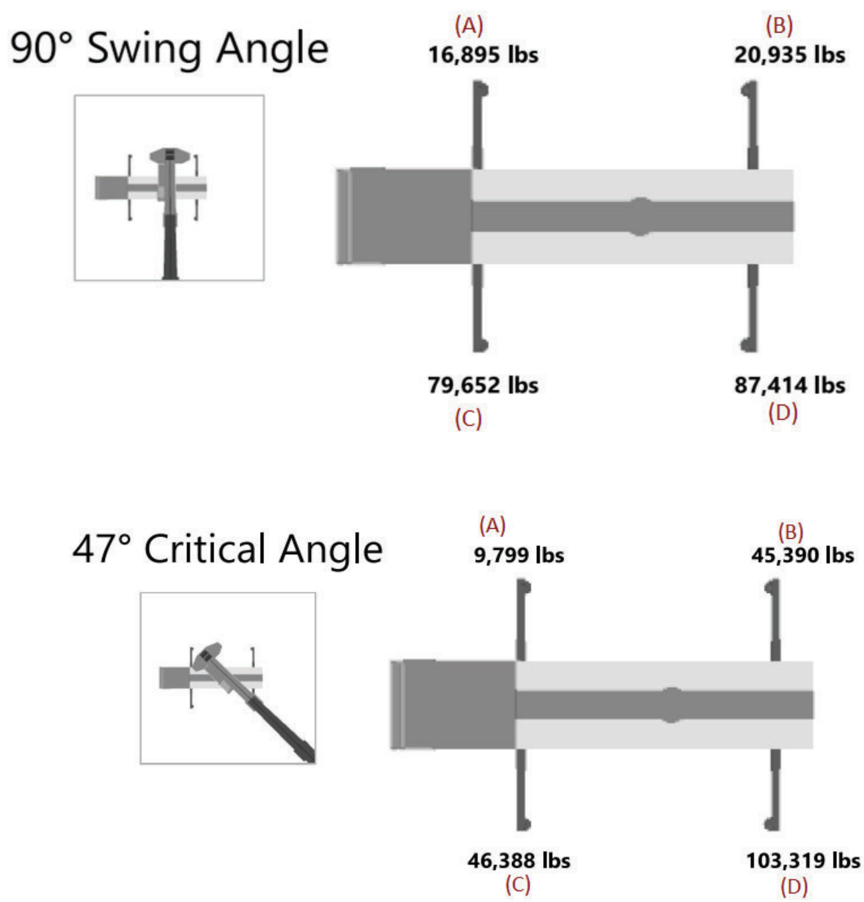


FIGURE 1: GROUND BEARING PRESSURES UNDER OUTRIGGERS

## 3.2 Crawl Space Modifications

To prevent soils sloughing and water infiltration into the crawl space along the south side of the pumping station building, modifications to the crawl space will be required. The construction activities include excavating a 2.5 m wide trench adjacent to the south side of the building. In the areas in proximity to the existing cooling tower, temporary shoring will be required to protect the infrastructure. In addition, a concrete mixer truck and a concrete pump truck will be required to supply material for the concrete works. To increase the safety of the underground infrastructure, the concrete mixer truck and the concrete pump truck are required to be parked on the designated area west of the pumping station building. The Rotary Drill Rig will then be the heaviest equipment with the highest surface stress entering the fenced area (yard) and has the governing load for the loading assessment.

The pipes for which the loading assessment were carried out are as follows:

- Wilkes Avenue Reservoir By-pass Piping (1350 mm PSC) at the yard entrance gate.
- Wilkes Avenue Reservoir Drainage Building Outlet pipe (600 mm AC) at the gravel road crossing.
- Wilkes Avenue Reservoir North Cell (No. 2) suction line (900 mm PSC) at the gravel road crossing.
- Interconnecting suction line (900 mm PSC) under the grassed area south of the pumping station building.
- 1350 mm Steel Pipe in Concrete Suction Lines on the southwest & southeast of Hurst Pumping Station.

# 4.0 PIPE LOADING ASSESSMENT

## 4.1 Methodology

Two different methods were used for loading assessment of the pipes based on the availability of their design live loads (as a threshold) at the time of installation.

- For pipes with available design live loads, we first calculated the proposed live loads imposed from the new equipment on the pipes. Then, we compared the two numbers to determine if the proposed live load exceeds the original design live load. All water pipes at the site fell into this category. The 750 mm RC Charleswood Feedermain, 900 mm PSC Wilkes Avenue Feedermain, and the 1350 mm PSC Wilkes Avenue Reservoir By-pass were designed to withstand the maximum live loads equivalent to AASHTO H-20 loading. The water pipes installed in the yard including 900 mm PSC Wilkes Avenue Reservoir North Cell and the 900 mm PSC interconnecting suction lines were designed to withstand the maximum live loads equivalent to AASHTO H-15 loading. Additionally, the pipes for which the combined internal-external loading analysis was available were double-checked using their current internal and external loads (i.e. Wilkes Ave. FM & Wilkes Ave. By-pass). The external loads on the pipe included backfill loads (calculated using Marston Load Calculations in Trench Condition) and the proposed live loads.

- For the pipe with unknown design live load – i.e. 600 mm Asbestos-Cement Pipe, we calculated the external loads using the same approach. Then, we compared the external load with the crushing strength of the pipe to determine if it could withstand the proposed loads.

## 4.2 Assumptions

To estimate the live load from the equipment, the following assumptions were made.

- For wheeled machines, tire loads were assumed to be effective as point loads and the total loads were equally distributed on all tires.
- For tracked machines, loads were assumed to be effective as strip load equally distributed on two tracks.
- Boussinesq's Equation was used to determine stresses at any point P at a depth z because of a surface point load.
- A Factor of Safety of 1.14 was applied to the mass of all equipment.

## 4.3 Pipe Loading Assessment

### 4.3.1 PIPE IMPACTED BY REMOVAL AND RE-INSTALLATION OF AIR HANDLING UNITS

The critical condition for each pipe under which it could be impacted the most by the live load is based on the equipment weight and the load distribution on its axles / tracks. The Charleswood and Wilkes feedermains will be impacted by the equipment traversing them. The two heaviest pieces of equipment imposing stress on these pipes are the crane and 6 $m^3$ concrete mixer truck. Due to the shorter distance between the rear axles of the concrete mixer truck compared to the crane (1 m vs. 1.65 m), it will impose a higher stress on the feedermains and therefore will be used for the loading assessment. We also assumed that the required counterweight will be delivered to the site using flatbed trucks in two parts, therefore, its weight will not exceed that of the concrete mixer truck or the crane.

The additional load from the AC 140 Crane and the 6 $m^3$ concrete mixer truck while passing the feedermains is provided in Table 5. For comparison, the feedermains were originally designed based on the H-20 design highway loading of 32,000 lb on the rear axle, corresponding to the uniform lane loading of 640 lb/ft of lane load.

### TABLE 5: ADDITIONAL LOAD (STRESS) FROM CONCRETE MIXER TRUCK & CRANE ON CHARLESWOOD & WILKES AVE. FEEDERMAINS

| Description | Unit | Charleswood Feedermain 750 mm RC, 2.1 m Cover | Wilkes Ave. Feedermain 900 mm PSC, 2.1 m Cover |
|---|---|---|---|
| AC 140 Crane | kPa | 9.9 | 9.9 |
| | $lb/ft^2$ | 206 | 206 |
| | lb/ft | 508 | 609 |
| 6 $m^3$ Concrete Mixer Truck | kPa | 10.0 | 10.0 |
| | $lb/ft^2$ | 208 | 208 |
| | lb/ft | **513** | **616** |
| Design Uniform Lane Load | lb/ft | ***640*** | ***640*** |

As the original design combined internal-external loading analysis was available for the Wilkes Avenue Feedermain, we also double-checked its load capacity using the current dead and proposed live loads. The load analysis of the pipes is provided in Table 6. Because applying the proposed live load from the Concrete Mixer Truck does not exceed the pipe maximum allowable load ratio $((W_D + W_L) / (W_{.001} \times L_F) = 0.47 < \text{Max. } 0.88)$, the pipe is expected to withstand the load.

### TABLE 6: LOAD ANALYSIS OF WILKES AVENUE FEEDERMAIN IMPACTED BY REMOVAL & RE-INSTALLATION OF AIR HANDLING UNITS

| Parameter | Desc. | Unit | Wilkes Ave. Feedermain, 900 mm PSC, 2.1 m Cover | Comment |
|---|---|---|---|---|
| **Design Data** | | | | |
| $P_0$ | Internal Pressure required to overcome all compression in the core concrete, exclusive of the effect of external load | psi | 160 | |
| $W_{.001}$ | Three-edge bearing load producing incipient cracking in the core, with no internal pressure | lb/ft | 6800 | $W_0/0.9$ |
| $P_W$ | Working Pressure | psi | 100 | |
| $P_{WH}$ | Max Surge Pressure Allowance | psi | 50 | |
| I.D. | Inside Diameter | inch | 36 | |
| O.D. | Outside Diameter | inch | 44 | |
| $B_D$ | Trench Width | ft | 5.7 | O.D. Pipe + 2 ft |
| w | Unit Weight of Backfill | $lb/ft^3$ | 120 | |

| Parameter | Desc. | Unit | Wilkes Ave. Feedermain, 900 mm PSC, 2.1 m Cover | Comment |
|---|---|---|---|---|
| $L_F$ | Load Factor for Bedding | N/A | 1.5 | |
| Design Live Load | Category | | H-20 | |
| | Uniform Lane Load | lb/ft | 640 | |
| H | Depth of Fill | ft | 6.9 | |
| $K_u$ (or $K_\mu$) | Soil Properties | N/A | 0.11 | $K_\mu = K_{\mu'}$ |
| **External Load Calculations** | | | | |
| $C_D$ | Load Coefficient | N/A | 1.06 | $C_D = (1-e^{-2K\mu'(H/BD)})/2K_{\mu'}$ |
| $W_D$ | Dead Load | lb/ft | 4133 | $W_D = C_D \times w \times B_D^2$ |
| $W_L$ | Live Load | lb/ft | 616 | |
| **Combined Analysis** | | | | |
| $P_W/P_0$ | | N/A | 0.63 | |
| $W_D/ (W_{.001} \times L_F)$ | | N/A | 0.41<br>Max 0.64 | See Appendix C |
| $(P_W+P_{WH}) / P_0$ | | N/A | 0.94 | |
| $W_D/ (W_{.001} \times L_F)$ | | N/A | 0.41<br>Max 0.74 | See Appendix C |
| $P_W/P_0$ | | N/A | 0.63 | |
| $(W_D + W_L) / (W_{.001} \times L_F)$ | | N/A | 0.47<br>Max 0.88 | See Appendix C |

The 600 mm Class II (2400) sewer pipe will be impacted by the weight of the crane plus counterweight sitting on the four outriggers parallel to the pipe. The additional (live) loads from the two critical ground bearing pressures under outriggers at 90° swing angle and 47° critical angle (see Figure 1) are provided in Table 7.

### TABLE 7: ADDITIONAL LOAD (STRESS) FROM CRANE OUTRIGGERS

| Condition | Unit | Wilkes Avenue Reservoir Drainage Building Outlet, 600 mm AC Class II (2400) Sewer, 3 m Cover |
|---|---|---|
| 47° Critical Angle | kPa | 3.0 |
| | $lb/ft^2$ | 63 |
| | lb/ft | **125** |
| 90° Swing Angle | kPa | 2.6 |
| | $lb/ft^2$ | 54 |
| | lb/ft | 107 |

Since the crane under 47° Critical Angle imposes more stress to the pipe, the higher load of 125 lb/ft was used in the loading assessment. The pipe loading assessment calculations are summarized in Table 8.

### TABLE 8: LOAD ANALYSIS OF WILKES AVENUE RESERVOIR DRAINAGE BUILDING OUTLET IMPACTED BY REMOVAL & RE-INSTALLATION OF AIR HANDLING UNITS

| Parameter | Desc. | Unit | Wilkes Avenue Reservoir Drainage Building Outlet, 600 mm AC Class II (2400) Sewer, 3 m Cover | Comment |
|---|---|---|---|---|
| **Design Data** | | | | |
| I.D. | Inside Diameter | inch | 24.05 | |
| O.D. | Outside Diameter | inch | 25.67 | |
| Crushing Strength | Per ASTM Three-Edge Bearing Method | lb/ft | 2400 | |
| $B_D$ | Trench Width | ft | 4.14 | O.D. Pipe + 2 ft |
| w | Unit Weight of Backfill | $lb/ft^3$ | 120 | |
| $L_F$ | Load Factor for Bedding | N/A | 1.5 | |
| H | Depth of Fill | ft | 9.8 | |
| $K_u$ (or $K_\mu$) | Soil Properties | N/A | 0.11 | $K_\mu = K_{\mu'}$ |
| **External Load Calculations** | | | | |
| $C_D$ | Load Coefficient | N/A | 1.85 | $C_D = (1-e^{-2K\mu'(H/BD)})/2K_{\mu'}$ |
| $W_D$ | Dead Load | lb/ft | 3805 | $C_D \times w \times B_D^2$ |
| $W_L$ | Live Load | lb/ft | 125 | See Table 7 |
| $(W_D+W_L)/1.5$ | | lb/ft | **2620** | |
| $W_D/1.5$ | | lb/ft | 2537 | |
| $W_L/W_D$ | Proposed Live Load / Existing Dead Load | % | 3 | |

As the estimated external load of 2,620 lb/ft (resulting from the total soil pressure on top of the pipe and the crane live loads) exceeds the pipe crushing strength of 2,400 lb/ft, the pipe would be susceptible to damage. The proposed live load may exceed the total load on the pipe by 3%.

To mitigate the risks associated with this pipe, we have included the following measures into the construction tender as follows.

- Multiple inspection of the sewer to be conducted during construction to look for potential impacts on the pipe. Inspections include once prior to and once after the removal of Air Handling Units, and once prior to the substantial performance of the project.
- Localized sewer repair pricing should impact be identified during construction.
- A working area for the crane, concrete mixer truck and the concrete pump truck with 3 m separation from outside of the pipe was designated.

#### 4.3.2 PIPES IMPACTED BY CRAWL SPACE MODIFICATION WORK

The weight of the Sub-Tec 06-04 Rotary Drill Rig for installation of the temporary shoring wall to protect the cooling tower during construction is estimated at 7,000 kg (approximately 15,400 lb) imposed on two tracks. The additional load from this machine while passing the yard piping impacted by the construction activities is provided in Table 9. For comparison, all yard piping was originally designed based on the H-15 design highway loading of 24,000 lb on the rear axle, corresponding to the uniform lane loading 480 lb/ft of lane load. The Wilkes Avenue Reservoir By-pass Piping was also designed based on the H-20 design highway loading of 32,000 lb on the rear axle, corresponding to the uniform lane loading of 640 lb/ft of lane load.

TABLE 9: ADDITIONAL LOAD (STRESS) FROM ROTARY DRILL RIG ON YARD PIPING

| Description | Unit | Wilkes Ave. Reservoir By-pass Piping, 1350 mm PSC, 4.8 m Cover | Wilkes Ave. Reservoir Drainage Building Outlet, 600 mm AC, 2.8 m Cover | Wilkes Ave. Reservoir North Cell (No. 2) Suction Line, 900 mm PSC, 5.1 m Cover | Interconnecting Suction Line, 900 mm PSC, 4.9 m Cover |
|---|---|---|---|---|---|
| Rotary Drill Rig | kPa | 4.6 | 7.2 | 4.4 | 4.5 |
| | $lb/ft^2$ | 97 | 151 | 91 | 95 |
| | lb/ft | **427** | **298** | **270** | **280** |
| Design Uniform Lane Load | lb/ft | ***640*** | ***N/A*** | ***480*** | ***480*** |

As the original design combined internal-external loading analysis was available for the Wilkes Avenue Reservoir By-pass piping, we also double-checked its load capacity using the current dead and proposed live loads. The load analysis of the pipes is provided in Table 10. Because applying the proposed live load from the Rotary Drill Rig does not exceed the pipe maximum allowable load ratio $((W_D + W_L) / (W_{.001} \times L_F) = 0.73 < \text{Max. } 0.87)$, the pipe is expected to withstand the applied load from the drill rig.

## TABLE 10: LOAD ANALYSIS OF WILKES AVENUE BY-PASS PIPING IMPACTED BY CRAWL SPACE MODIFICATION WORK

| Parameter | Desc. | Unit | Wilkes Ave. Reservoir By-pass Piping, 1350 mm PSC, 4.8 m Cover | Comment |
|---|---|---|---|---|
| **Design Data** | | | | |
| $P_0$ | Internal Pressure required to overcome all compression in the core concrete, exclusive of the effect of external load | psi | 150 | |
| $W_0$ | 0.9 of the three-edge bearing load producing incipient cracking in the core, with no internal pressure | lb/ft | 10395 | |
| $P_T$ | Test Pressure | psi | 100 | |
| $P_W$ | Working Pressure | psi | 50 | |
| $P_{WH}$ | Max Surge Pressure Allowance | psi | 20 | |
| $B_D$ | Trench Width | ft | 7.2 | O.D. Pipe + 2 ft |
| w | Unit Weight of Backfill | $lb/ft^3$ | 120 | |
| $L_F$ | Load Factor for Bedding | N/A | 1.5 | |
| Design Live Load | Category | | H-20 - S16 | |
| | Uniform Load | lb/ft | 640 | |
| H | Depth of Fill | ft | 15.7 | |
| $K_u$ (or $K_\mu$) | Soil Properties | N/A | 0.11 | $K_\mu = K_{\mu'}$ |
| **External Load Calculations** | | | | |
| $C_D$ | Load Coefficient | N/A | 1.73 | $C_D = (1-e^{-2K\mu'(H/BD)})/2K_{\mu'}$ |
| $W_D$ | Dead Load | lb/ft | 10762 | $W_D = C_D \times w \times B_D^2$ |
| $W_L$ | Live Load | lb/ft | 640 | See Table 5 |
| **Combined Analysis** | | | | |
| $P_W/P_0$ | | N/A | 0.33 | |
| $W_D/ (W_0 \times L_F)$ | | N/A | 0.69<br>Max 0.87 | See Appendix C |
| $(P_W+P_{WH})/P_0$ | | N/A | 0.47 | |
| $W_D/ (W_0 \times L_F)$ | | N/A | 0.69<br>Max 1.02 | See Appendix C |

| Parameter | Desc. | Unit | Wilkes Ave. Reservoir By-pass Piping, 1350 mm PSC, 4.8 m Cover | Comment |
|---|---|---|---|---|
| $P_W/P_0$ | | N/A | 0.33 | |
| $(W_D + W_L)/ (W_0 \times L_F)$ | | N/A | 0.73<br>Max 0.87 | |
| $W_L/W_D$ | Proposed Live Load / Existing Dead Load | % | 6 | |

The impact of the Sub-Tec 06-04 Rotary Drill Rig crossing the Wilkes Avenue Reservoir Drainage Building Outlet as well as the existing dead load on the pipe is provided in Table 11.

TABLE 11: LOAD ANALYSIS OF WILKES AVENUE RESERVOIR DRAINAGE BUILDING OUTLET IMPACTED BY CRAWL SPACE MODIFICATION WORK

| Parameter | Desc. | Unit | 600 mm AC Class II (2400) Sewer | Comment |
|---|---|---|---|---|
| **Design Data** | | | | |
| I.D. | Inside Diameter | inch | 24.05 | |
| O.D. | Outside Diameter | inch | 25.67 | |
| Crushing Strength | Per ASTM Three-Edge Bearing Method | lb/ft | 2400 | |
| $B_D$ | Trench Width | ft | 4.14 | O.D. Pipe + 2 ft |
| w | Unit Weight of Backfill | $lb/ft^3$ | 120 | |
| $L_F$ | Load Factor for Bedding | N/A | 1.5 | |
| H | Depth of Fill | ft | 9.2 | |
| $K_u$ (or $K_\mu$) | Soil Properties | N/A | 0.11 | $K_\mu = K_{\mu'}$ |
| **External Load Calculations** | | | | |
| $C_D$ | Load Coefficient | N/A | 1.76 | $C_D = (1-e^{-2K\mu'(H/BD)})/2K_{\mu'}$ |
| $W_D$ | Dead Load | lb/ft | 3620 | $C_D \times w \times B_D^2$ |
| $W_L$ | Live Load | lb/ft | 298 | See Table 5 |
| $(W_D+W_L)/1.5$ | | lb/ft | **2612** | |
| $W_D/1.5$ | | lb/ft | 2413 | |
| $W_L/W_D$ | Proposed Live Load / Existing Dead Load | % | 8 | |

As the estimated external load of 2,612 lb/ft (resulting from the total soil pressure on top of the pipe and the drill rig traversing the pipe) exceeds the pipe crushing strength of 2,400 lb/ft, the pipe would be susceptible to damage. The proposed live load may exceed the total load on the pipe by 8%.

We also analyzed the impact of the proposed live load on the pipe if two steel road plates were to be used under the rotary drill rig tracks. Each steel road plate was assumed to be 5’×10’×1” with a mass of 2,042 pounds. The stress imposed on the 600 AC pipe at the gravel road while the rotary drill rig crossing the steel road plates (one under each track) was estimated at 255 lb/ft Comparing the live loads on the pipe with and without using the steel road plates shows that using the steel road plate to distribute the load does not noticeably improve the situation as the pipe is already overloaded by its dead load.

To mitigate the risks associated with this pipe, we have included the following measures into the construction tender as follows.

- Multiple inspection of the sewer to be conducted during construction to look for potential impacts on the pipe.
- Localized sewer repair pricing should impact be identified during construction.

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

Several findings have resulted from this study. They include the following:

- All assessed water pipes including the Charleswood Feedermain 750 mm RC), the Wilkes Avenue Feedermain (900 mm PSC), the Wilkes Avenue Reservoir By-pass Piping (1350 mm PSC), the Wilkes Avenue Reservoir North Cell (No. 2) Suction Line (900 mm PSC) and the Interconnecting Suction Line (900 mm PSC) can withstand the live loads resulting from the construction activities providing the selected equipment is similar to the allowable equipment identified in this report.
- The Wilkes Avenue Reservoir Drainage Building Outlet pipe (600 mm AC Class II Sewer) could be impacted by the construction activities as the pipe is overloaded based on its classification. However, the risk will be mitigated by conducting inspections and performing point repairs as required.
- During the crane operation at the site, it is critical to maintain a minimum 3 m offset from the edge of the Wilkes Avenue Reservoir Drainage Building Outlet pipe to mitigate the risk of overloading the pipe. Steel plates shall be used under the outriggers.
- Protection of valve chambers by installation of temporary snow fences is recommended. The contractor is advised to adhere to the area restrictions shown on the Drawing 1-0650A-C0003-001.
- No vehicle is permitted within 2 m of the two 1350 Steel Pipes in Concrete Suction Lines on the southwest & southeast of Hurst Pumping Station.
- All excavations within two (2.0) meters of an existing utility must be done as hand work.
- The equipment to undertake the work was selected based on KGS previous experience of similar projects and after consultation with contractors. However, each Contractor may choose to use alternate means and methods based on the availability of the equipment and their previous experience. The Contractor shall submit their means and methods of undertaking the work to the Contract Administrator for approval before commencement of each activity.

- The Contractor shall select each piece of equipment to undertake the work in such a way that they meet the design loading criteria stated in Table 1. The Contractor shall also verify that the equipment will not impose more stress on the piping than the loading thresholds. If the load of a selected piece of equipment exceeds the loading threshold, the Contractor shall provide their specific means and methods validating the piping will not be impacted.

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