March 26, 2015

Toby Ressler
Seattle Parks and Recreation
800 Maynard Avenue South
Seattle, WA 98134

Re: Geotechnical Assessment (WC0197)
Lake Union Park Project
Seattle, Washington
19118-00

Dear Toby:

This letter summarizes our observations and recommendations relating to the soil and structure deformations observed at Lake Union Park. We have reviewed the design and construction documents provided to us, and visited the site several times to inspect the condition of the park. We also met with Magnusson Klemencic Associates (MKA) to specifically discuss the bridge conditions. Soil deformations have occurred across much of the site since construction of the park. Observed deformations at the site are outlined in this letter. A proposed remediation strategy is outlined for the poorly performing major site features. Figure 1 shows a map of the vicinity, and Figure 2 shows a map of the site, with locations of historical explorations.

This letter is for the exclusive use of the City of Seattle Parks and Recreation Department and its design consultants for specific application to this project and site. We completed this work in general accordance with our proposal dated January 23, 2015, and in accordance with generally accepted geotechnical engineering practices for similar work in similar localities at the time the work was performed. We make no other warranty, express or implied.

Settlement Analyses

We estimated site settlements using Settle3D (Rockscience 2014) and PLAXIS (2015), and compared the estimated values to the observed conditions. This combination allowed us to better understand the causes of past settlement and the potential for future settlement. Figure 3 shows calculated settlement contours for current conditions using soil properties from the available borings and our settlement models. Total settlement is the sum of the primary settlement due to fill placement during grading and secondary settlement from the underlying peat layers. Primary settlement, also referred to as immediate and consolidation settlement, is directly related to soil permeability and stiffness. Secondary settlement continues after primary settlement, and is usually described as a linear function of log-time.

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Given the limited soil data available, we analyzed some soil layers both with and without secondary settlement to see how much of an effect secondary settlement might have.

The contours on Figure 3 correspond well with the observed current site conditions.

Figure 4 shows predicted long-term settlement contours using the same properties and models. Based on this analysis, it appears that more than half of the total settlement expected over a period of 75 years has already occurred. Figure 5 shows three graphs of settlement along the north-south sheet pile at the section location shown on Figures 3 and 4. The deformed settlement profiles are for (1) current settlement, (2) settlement at 75 years, and (3) total settlement at 10-year time intervals.

A large amount of observed settlement was due to hog fuel replacement. To investigate the contribution of hog fuel replacement, we predicted the magnitude of settlement along the bulkhead wall using PLAXIS. The fill soil contained large amounts of clay and silt, which likely results in some long term settlement and decreased stiffness. Given the high uncertainty in the soil properties, we analyzed the Plaxis models with different fill material conditions. One model included potential for long-term settlements within fill (Figure 6). The other model assumed that fill behaves as a granular soil without long-term deformation behavior (Figure 7). Figure 8 presents the settlement over time predicted by the two PLAXIS models.

Soil explorations in the southern portion of the park encountered what was described as sawdust. Given the depth of the material below the water table, it is unlikely that the sawdust is decaying. A literature review for properties of sawdust fills found the material often exhibits fairly quick primary consolidation, with significant secondary consolidation.

In the next several sections we look at each of the major site components and recommend alternative actions to address the observed conditions.

Pedestrian Bridge

Condition and Assessment

Significant movement of the east abutment has caused the pedestrian bridge connections to displace relative to the abutments. We observed evidence of distress around the east abutment. Relative to the abutment, the walls adjacent to the abutment have settled, and the wall to the north of the abutment shows a small amount of rotation deformation. During our site observations, it was unclear whether the well has rotated east due to soil settlement or the abutment has rotated downward to the west. There are no obvious signs that the west abutment has moved; therefore, we have assumed the west abutment has remained stable. The city documented a loss of camber in the bridge, which was described as a form of distress. According to MKA, most steel bridges are designed to lose camber under

self weight. We cannot identify a settlement or rotational reason, so we have assumed the loss of camber is unrelated to any ground movements.

The ground around the east abutment has settled approximately 6 inches. Settlement around piles is a common occurrence, especially when new fill is placed on soft, compressible soils overlying very dense soils. We believe this settlement has caused significant negative skin friction on the east bridge piles. Soil settlement even less than 1/4 inch relative to a pile can cause significant negative skin friction, induced downdrag loads on the pile.

The plans call for five 18-inch closed-ended steel pipe piles filled with reinforced concrete on the east abutment. Two of those piles were designed to support downward loads and the other three were designed to take uplift loads. According to construction/driving records, 18-inch open-ended steel pipe piles were used instead. The driving records do not clearly show that a plug was formed during installation. We used this information along with available soil explorations to back-calculate vertical capacities of the piles in compression.

As stated above, negative skin friction due to settlement around the piles is significant. According to Boring B-9, there is about 60 feet of soil that imposes negative skin friction due to soft, compressible underlying soils (i.e., recent lacustrine soils and peat). The negative shaft friction has likely caused the piles supporting the abutment to settle approximately 1 to 1.5 inches. Different loading and driving conditions at each pile have likely caused differential settlement, which could be a cause for downward rotation of the east abutment.

Based on our review of the plans provided to us, our field observations, and our analyses, we believe the east bridge abutment moved westward from a combination of lateral earth pressures behind the east abutment and downward rotation.

Remediation Alternatives

We recommend the following actions to allow the bridge to reopen:

1) Decrease lateral earth loads behind the abutment by locally replacing approximately 4 feet of the backfill material with Geofoam along the entire east abutment surface. Extend this replacement to about 10 feet behind the abutment.
2) Modify the west abutment connections to allow continuing deformation of the bridge, after the bridge is reset at each abutment.
3) Alternatively to Step 1, unload the abutment and the pond area by replacing fill with lightweight fill, temporarily fixing the pond settlement issue as well (see subsequent discussion). We recommend an excavation and replacement plan that results in a net decrease in vertical stress from the prior construction of the park. To complete this, we recommend excavating the fill and replacing it with

Geofoam at least 4 feet beneath the existing subgrade and required soil cap within a radius of 35 feet from the bridge up to the shoreline, or the extent of area that was backfilled for the park.

4) If after these steps the problems persist, a more aggressive repair would include structural adjustments to the east abutment by installing either battered piles in front of the abutment or a deadman system. This system could be complicated, but MKA confirmed this option is designable.

All possible options will require readjusting the bridge and reconnecting it to the abutments. The most simple and cost-effective measure is to readjust the bridge, mitigate the lateral earth pressures behind the east abutment, and monitor the bridge and surrounding area for further deformation. Our analyses show that most of the post-construction settlement has already occurred, but we recommend periodically surveying and monitoring the movement according to recommendations in this report.

Bulkhead Wall

Condition and Assessment

The concrete bulkhead wall between the pedestrian bridge and the sheet piled bulkhead shows apparent differential movement of about 4 to 6 inches downward from south to north. The bulkhead is pile-supported. At the south connection to the pedestrian bridge there appears to be differential movement of 1 to 2 inches. At the north connection to the sheet piled bulkhead, the concrete grade beam has settled about 6 inches relative to the sheet piled bulkhead. The ground around the supporting pile at the north end has settled and one of the supporting piles is clearly exposed.

At this time it is unclear how the bulkhead wall separated from the sheet piled bulkhead and the pedestrian bridge abutment. One possible cause could be the settlement of the soil behind the bulkhead wall and the resulting negative skin friction. As the soil settled the wall could have rotated, causing the bulkhead wall to disconnect from the other structures. Another possible explanation is that the bridge abutment rotated and translated, as explained in the previous section of this letter.

Remediation Alternatives

Since most of settlement has likely already occurred, we recommend providing the needed architectural fixes, letting the wall continue to move, and continually monitoring the movement/rotation of the bulkhead wall. Monitoring methods are discussed later in this report.

Sheet Piled Bulkhead

Condition and Assessment

While settlement in the grass and on the sidewalks behind the wall on the west side initially caused concern, significant distress at the western sheet piled bulkhead was not evident when we visited the site on February 13, 2015, to inspect the bulkhead movement and settlement under the board walk. We

observed 3 to 4 inches of settlement of the gravel backfill, but no significant movement near the sheet piled bulkhead. Visually, the sheet piled bulkhead showed no evidence of local movement. We believe that the sheet piled bulkhead is performing as designed.

Remediation Alternatives

No remedial actions are required for the sheet piled bulkhead.

Pond and Other Distress Issues

Condition and Assessment

The pond is apparently supported on a prepared subgrade on Geofoam blocks. The west side of the pond has settled about 3 inches more than the east side, raising concerns about overtopping of the water. In addition there is now a gap of about 1 inch between the retaining wall supporting the pond and the sidewalk. This connection was initially caulked, but now all the caulking has pulled away. The tilting of the pond and differential settlement around it indicates the highly variable subsurface and loading conditions.

We noticed other areas of settlement across the park, including uneven sidewalks and low spots in the grass. The calculated settlement shown on Figure 3 is consistent with what we observed on site. This shows that the main cause of settlement is consolidation in the soft soils after site grading.

Subsurface conditions across the pond structure, combined with the nearby fill placement, are likely the reason for differential settlement of the pond and across the site.

Pond Remediation Alternatives

We believe most of the settlement has already occurred. However, maintenance and regrading will be required to maintain appearance and proper drainage. Over time, the need will decrease, as settlements decrease. To specifically address the pond differential, we recommend excavating around the side of the pond and placing lightweight fill within a radius of 40 feet from the pond's edge and to the edge of the Lake Union shoreline. The recommended depth of excavation is the same as that for the bridge abutment. The excavation and fill placement can be done during the east abutment backfill replacement, as described previously. Mitigation of future settlements in other areas of the park can be completed in a similar manner, if desired.

General Park Remediation Alternatives

As stated above, most of the settlement has already occurred. We believe that maintenance and regrading will be required regularly. Over time, the need will decrease as settlements decrease. Much of the area can be addressed over time with architectural fixes, such as fixing cracks and leveling sidewalks,

leveling benches, and minor regrading. These steps would likely need to occur multiple times in the future. A more long-term fix would be excavation and replacement with lightweight fill, as described for the east abutment and pond.

Remediation of settlement along the shoreline relative to the piles and walls can be addressed by backfilling around the distressed areas. This would be done mostly as an architectural fix, and should be completed by placing as little fill as needed to return the shoreline to the original elevation relative to the piles and walls.

Monitoring Recommendations

While we have gained information, uncertainty remains about the actual source and magnitude of many of the deformations. To better define the ongoing deformations and identify areas deserving additional remediation, several monitoring methods should be installed or completed for a period of 6 to 12 months. Many of the recommended methods can be inexpensively automated for increased data resolution and long-term cost savings. We recommend:

- Installing a multipoint borehole extensometer in the hog fuel replacement area and between the pond and bridge. Extensometers provide highly accurate settlement points within the soil profile, identifying the sources of deformation.
- Installing tilt meters on each abutment and bulkhead wall. Tilt meters provide sensitive rotation monitoring of each structure.
- Installing an inclinometer behind the sheet pile bulkead. While automated monitoring is possible, it is expensive, and we therefore recommend manual readings.
- Installing and observing several surface settlement points around the park. Deformation at these points should be monitored by optical surveying methods. Automated monitoring may be less expensive and more accurate in the long term.

Hart Crowser can design this monitoring program and work with Parks teams on installation and data acquisition. Alternatively, Hart Crowser can conduct the full monitoring program. If plans and specifications are needed for any of the planned remedial actions we can work with MKA or your team on preparation.

Closing

We trust that this letter report meets your needs. Please contact us if you have any questions.

Sincerely,

HART CROWSER, INC.

CARLOS VALDEZ, EIT
Senior Staff Geotechnical Engineer

BRICE J. EXLEY, PE
Project Engineer

DAVID WINTER, PE, LEED AP
Senior Principal

Attachments:
Figure 1 - Vicinity Map
Figure 2 - Site Map and Historical Explorations
Figure 3 – Current Settlement Estimate
Figure 4 – Future Settlement Estimate – Year 75
Figure 5 – Calculated Settlement along the Bulkhead Wall – Settle3D Results
Figure 6 – Calculated Current Settlement Due to Hog Fuel Replacement – Fill Type A
Figure 7 - Calculated Current Settlement Due to Hog Fuel Replacement – Fill Type B
Figure 8 – Time Rate of Settlement behind Bulkhead due to Hog Fuel Replacement

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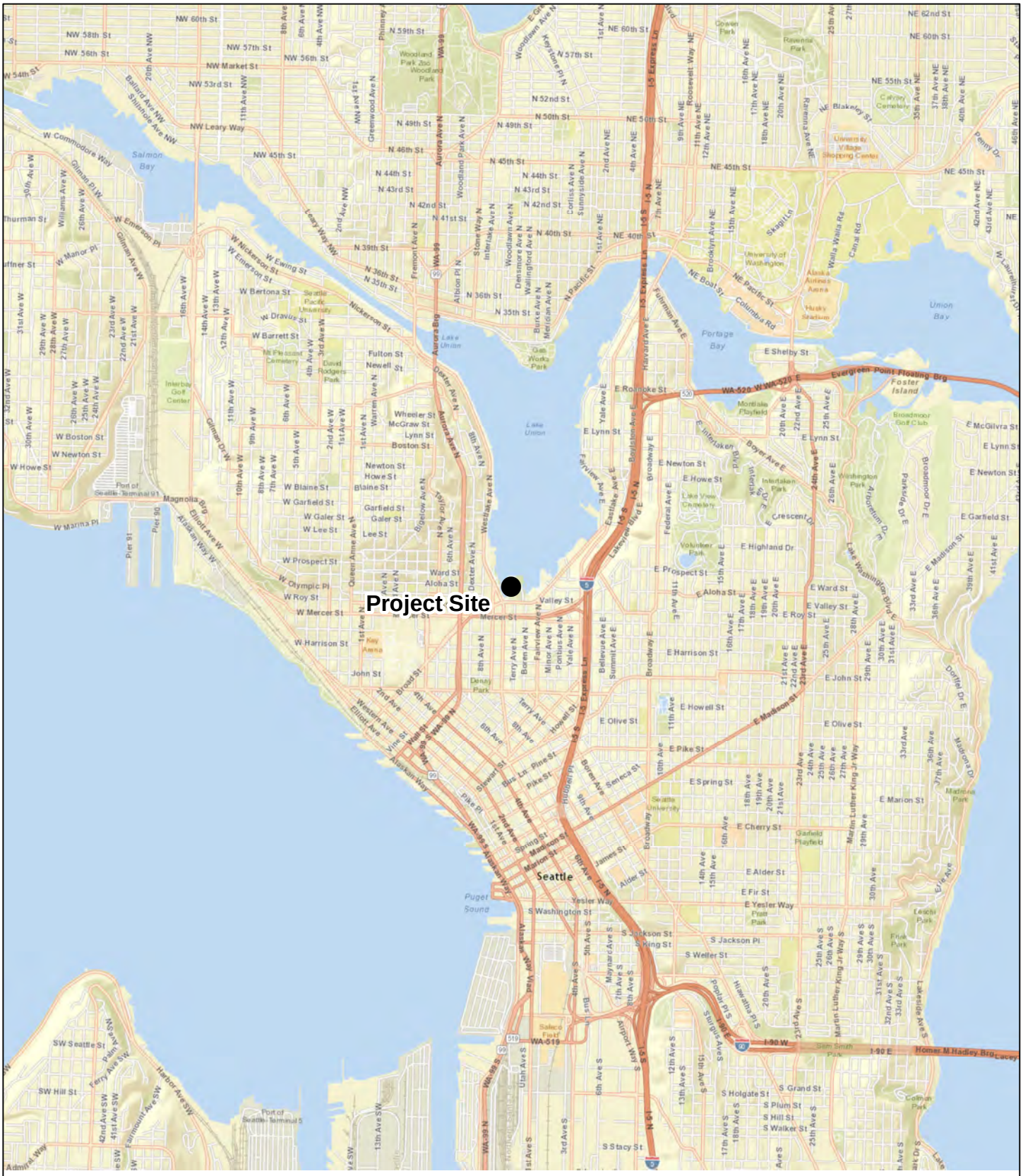

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4,000 2,000 0 4,000

Scale in Feet

N

South Lake Union Park
Seattle, Washington

Vicinity Map

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Figure
1

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Historical Explorations

B4 ● Boring

CPT2 ◆ Cone penetrometer test

TP3 ▪ Test pit

0 50 100

Scale in Feet

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Source: Aerail photograph from ArcGIS Online, 2014.

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Seattle, Washington

Site Map and Historical Explorations

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Figure

2

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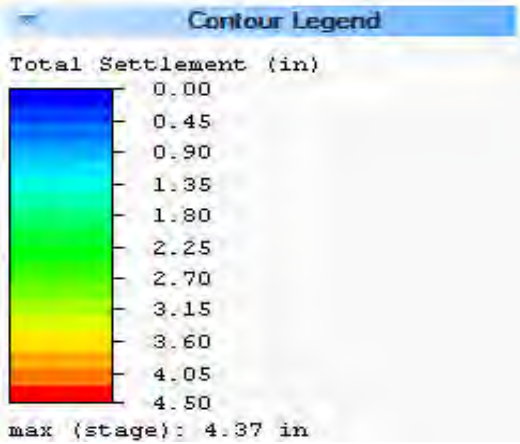

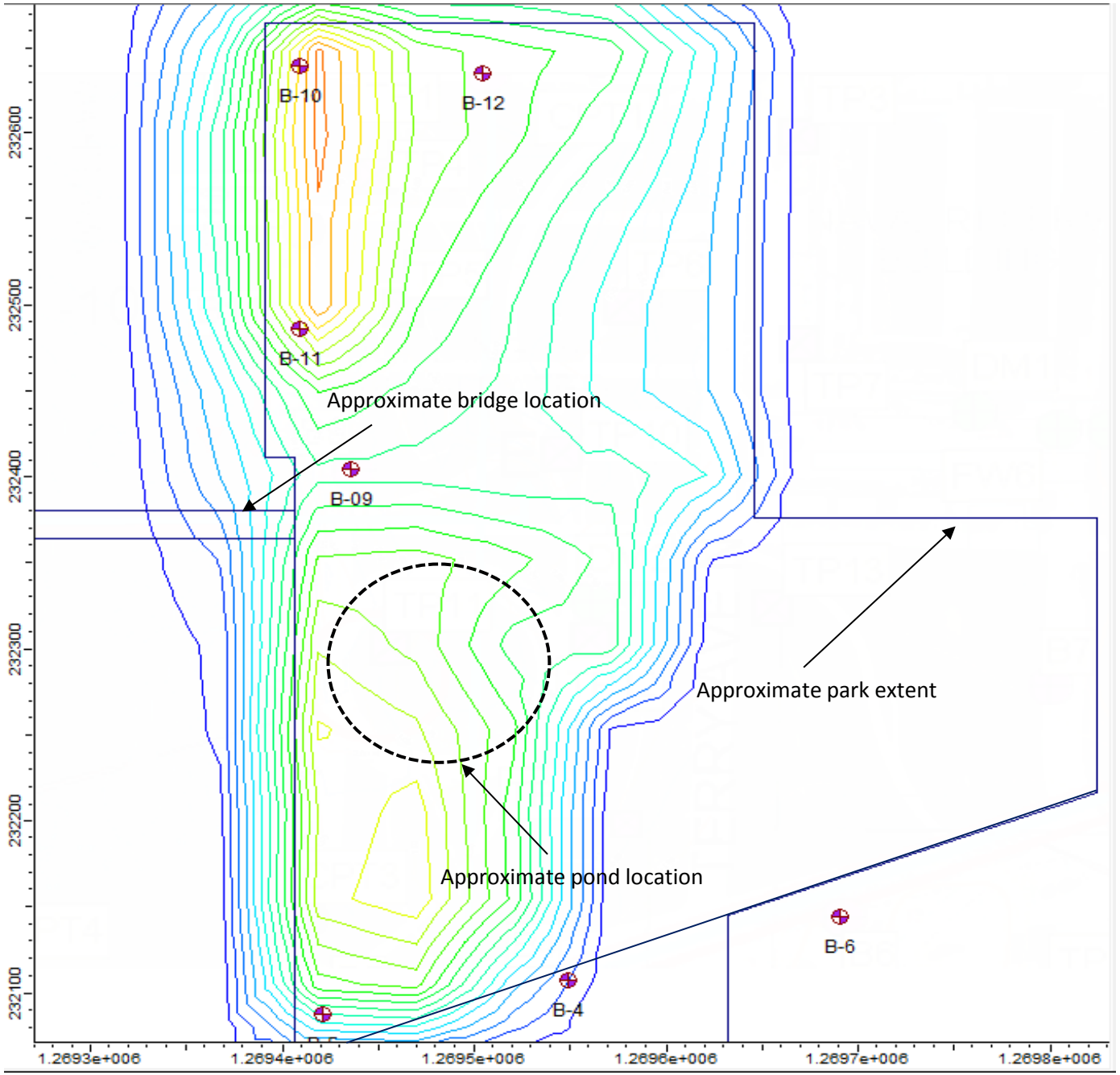

South Lake Union Park
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Current Settlement Estimate

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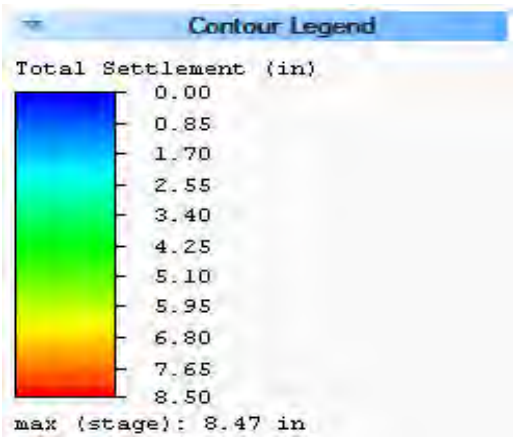
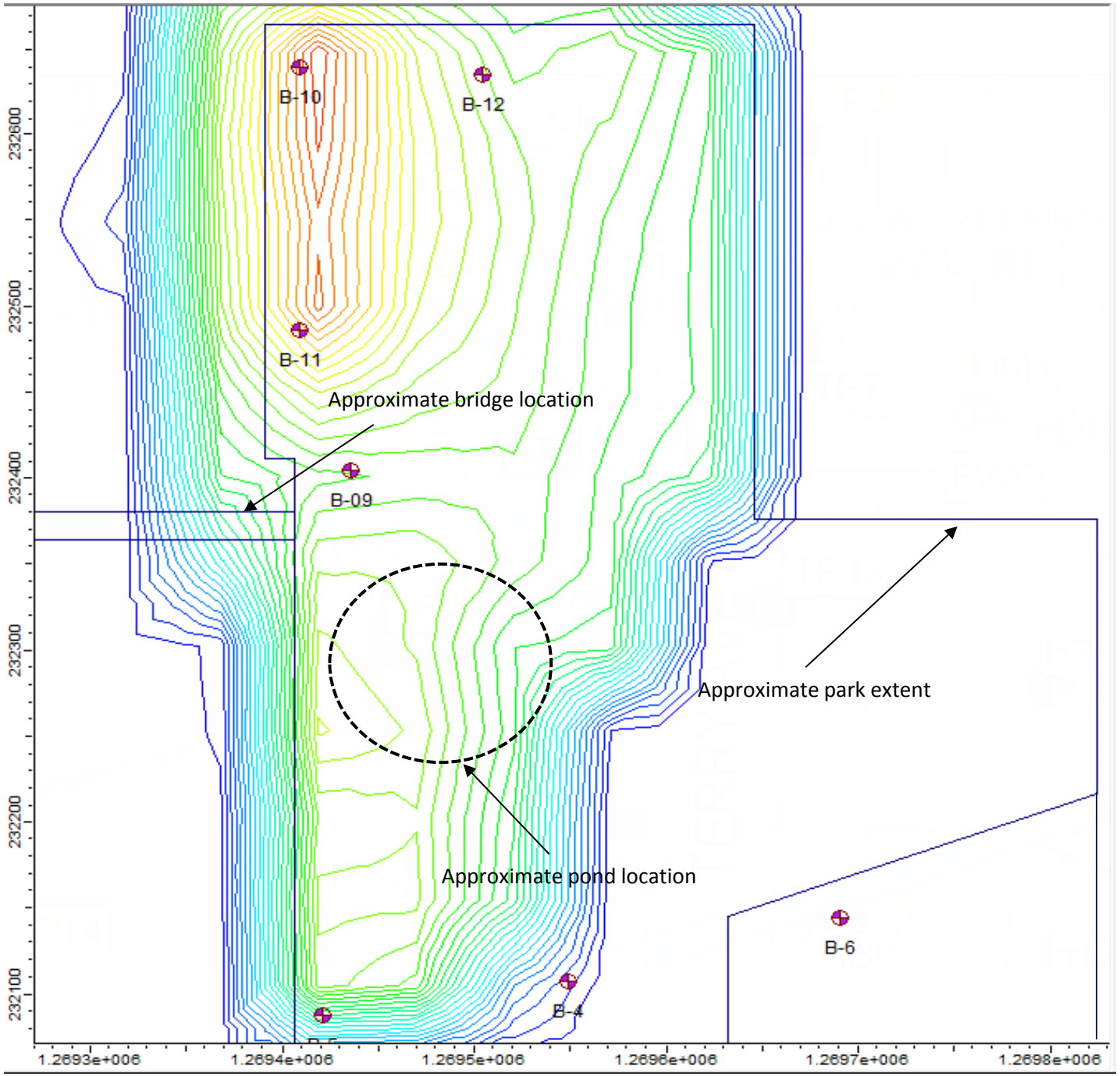
Figure

3





South Lake Union Park
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Future Settlement Estimate - Year 75

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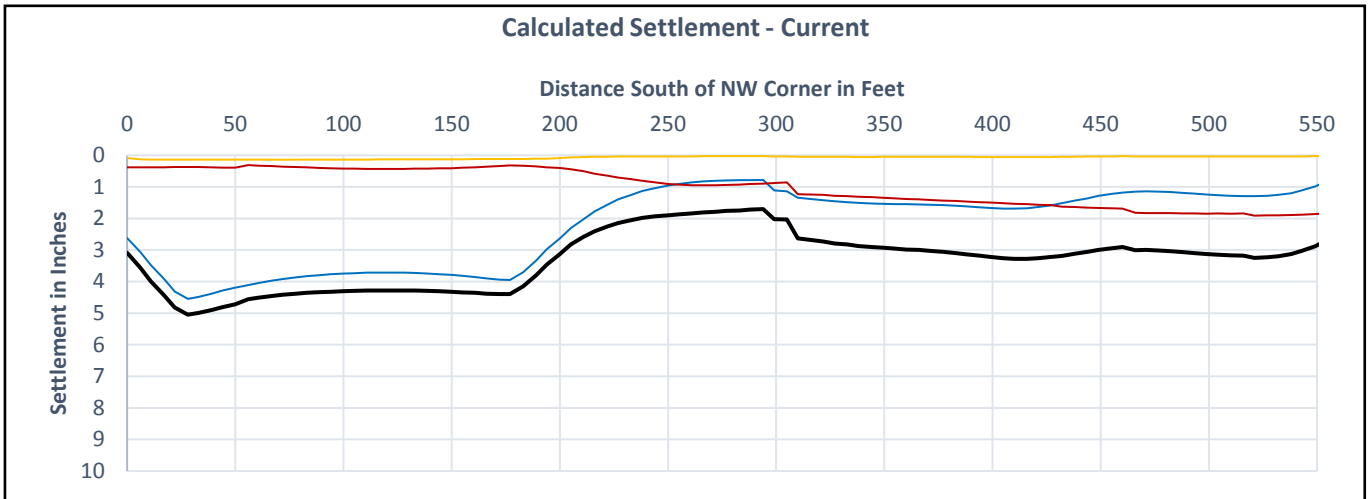
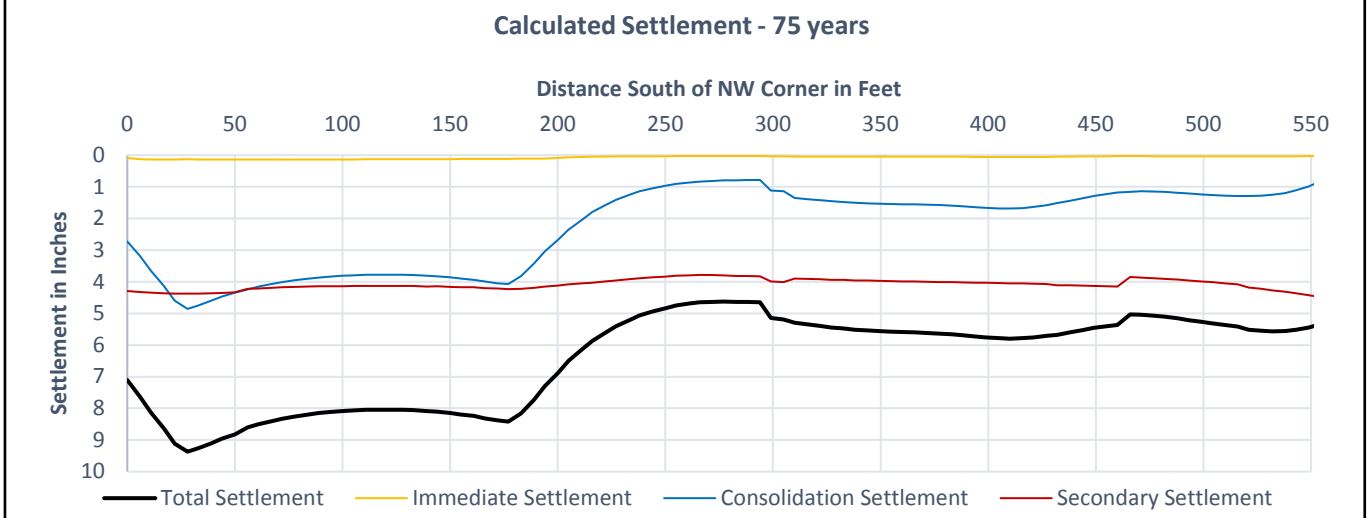
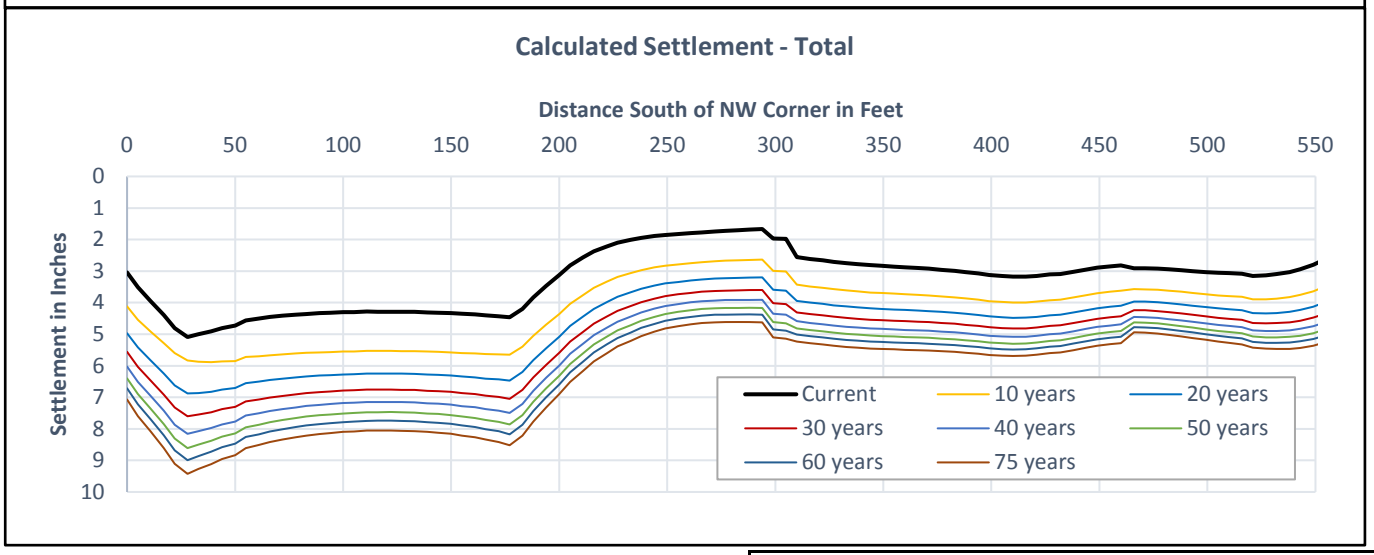
Figure 4







South Lake Union Park
Seattle, WA

Calculated Settlement along the Bulkhead Wall - Settle3D Results

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Figure

5

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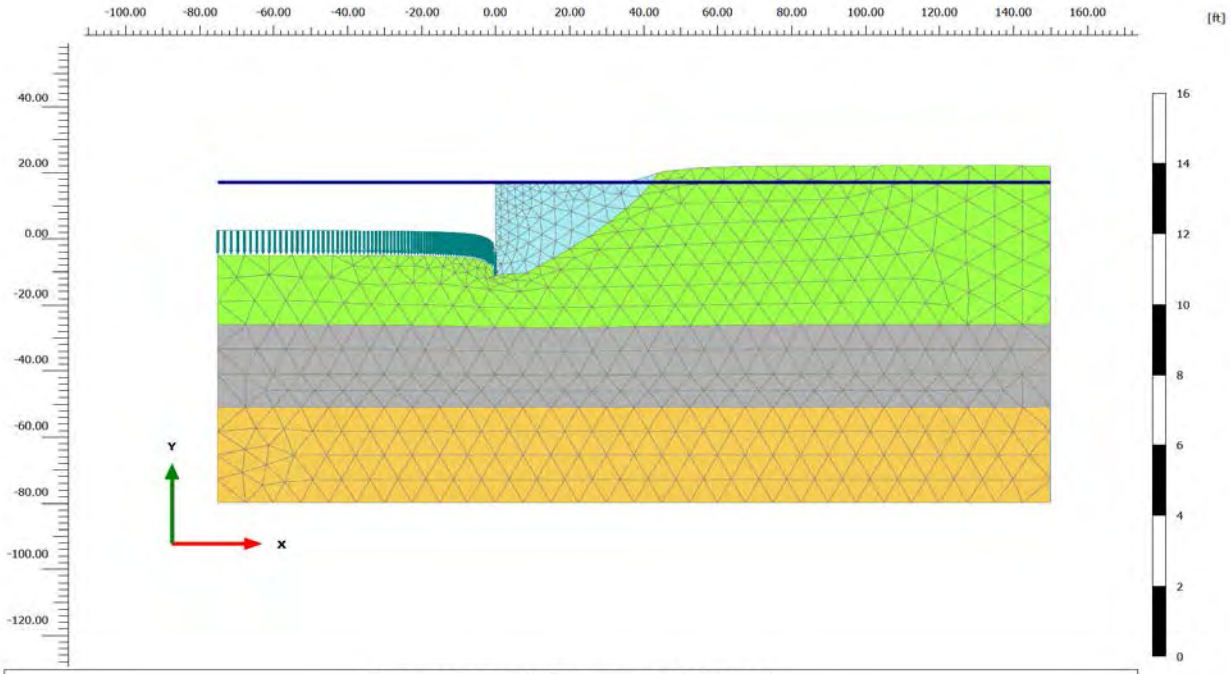
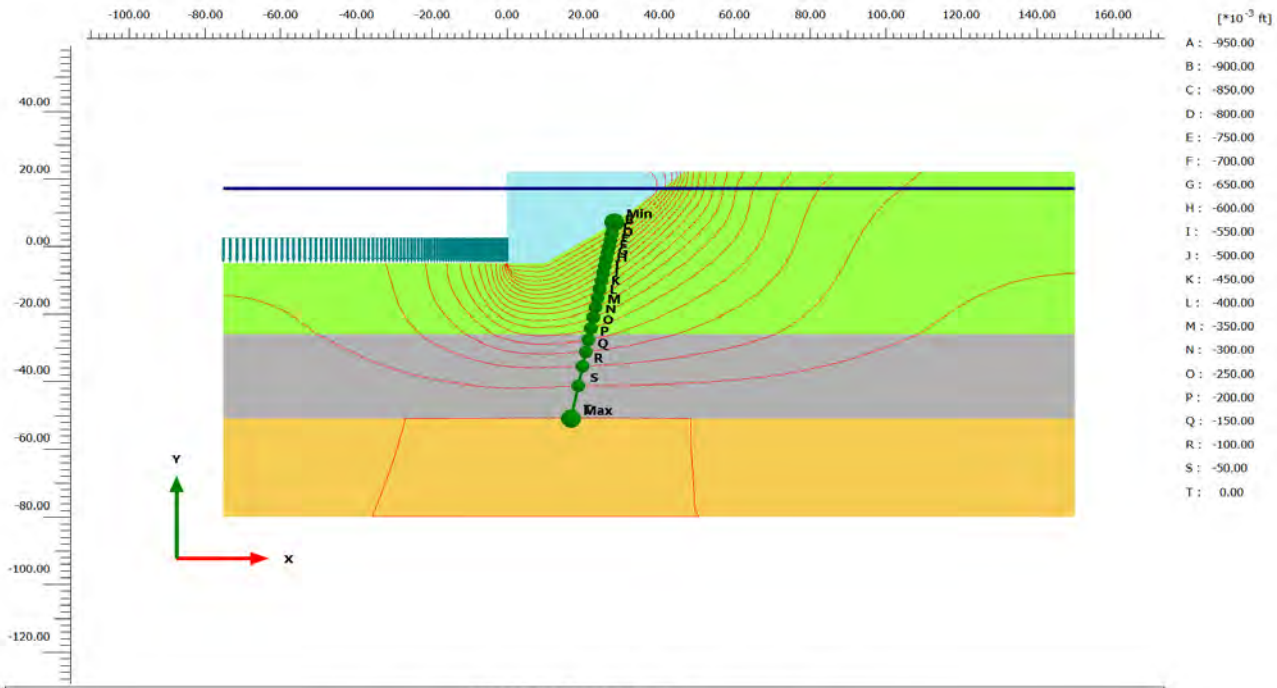


Deformed mesh |u| (scaled up 10.0 times)

Maximum value = 0.6677 ft (Element 149 at Node 1532)



Total displacements u_y

Maximum value = $0.9445*10^{-3}$ ft (Element 674 at Node 4371)

Minimum value = -0.9427 ft (Element 1 at Node 3615)

Note: Fill Type A includes potential for long-term settlement within the fill. Type B assumes the fill behaves as a granular soil without long-term deformation behavior.

South Lake Union Park
Seattle, WA

Calculated Current Settlement Due to Hog Fuel Replacement - Fill Type A

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Figure
6

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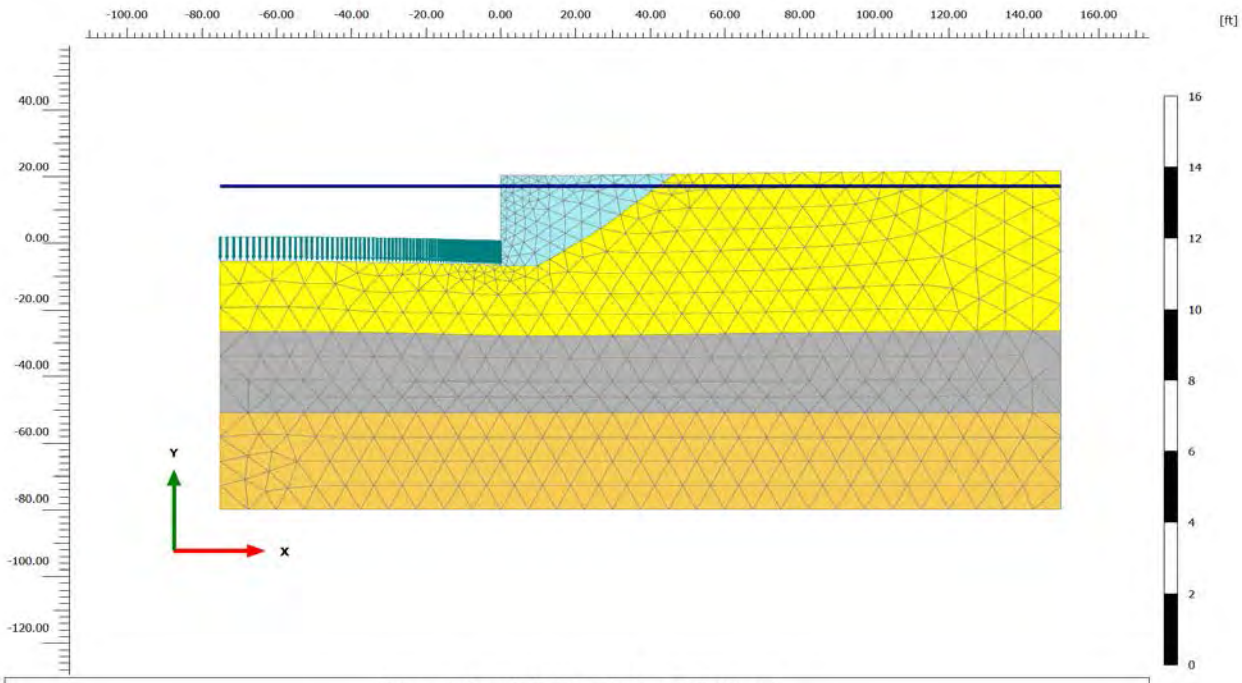
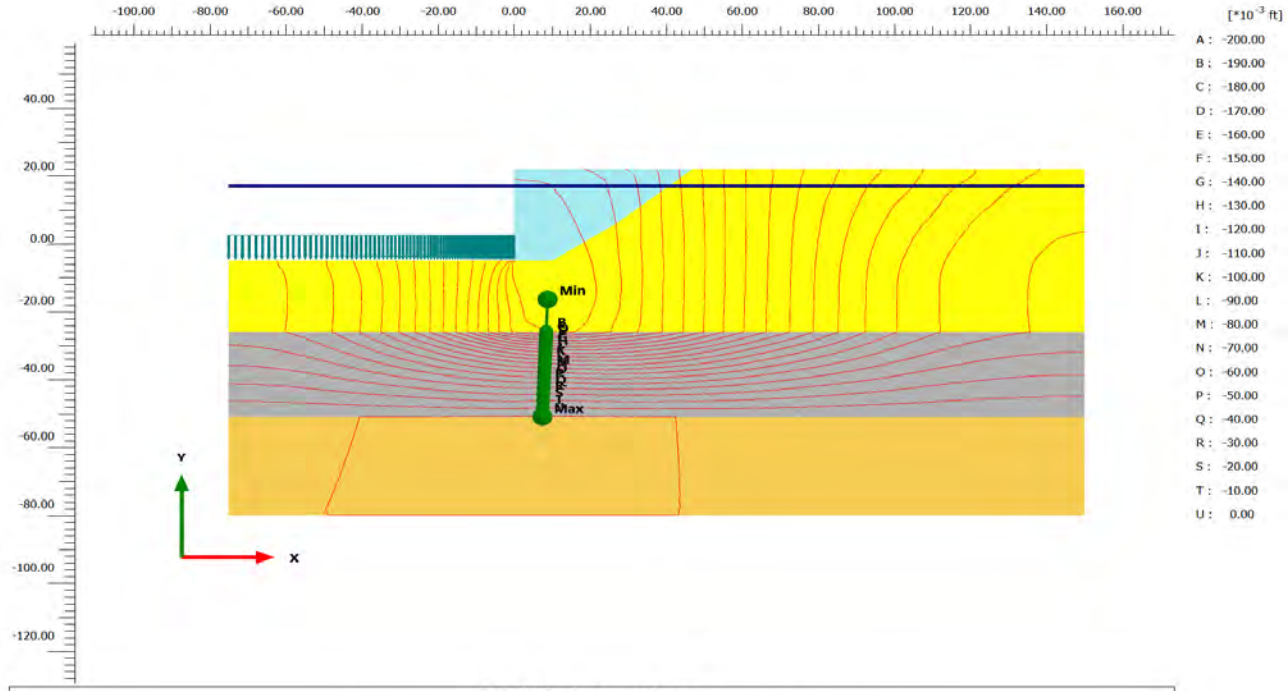


Deformed mesh |u| (scaled up 10.0 times)

Maximum value = 0.1977 ft (Element 333 at Node 3243)



Total displacements u_y

Maximum value = $0.9554*10^{-3}$ ft (Element 675 at Node 4067)

Minimum value = -0.1976 ft (Element 333 at Node 3243)

Note: Fill Type A includes potential for long-term settlement within the fill. Type B assumes the fill behaves as a granular soil without long-term deformation behavior.

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Seattle, WA

Calculated Current Settlement Due to Hog Fuel Replacement - Fill Type B

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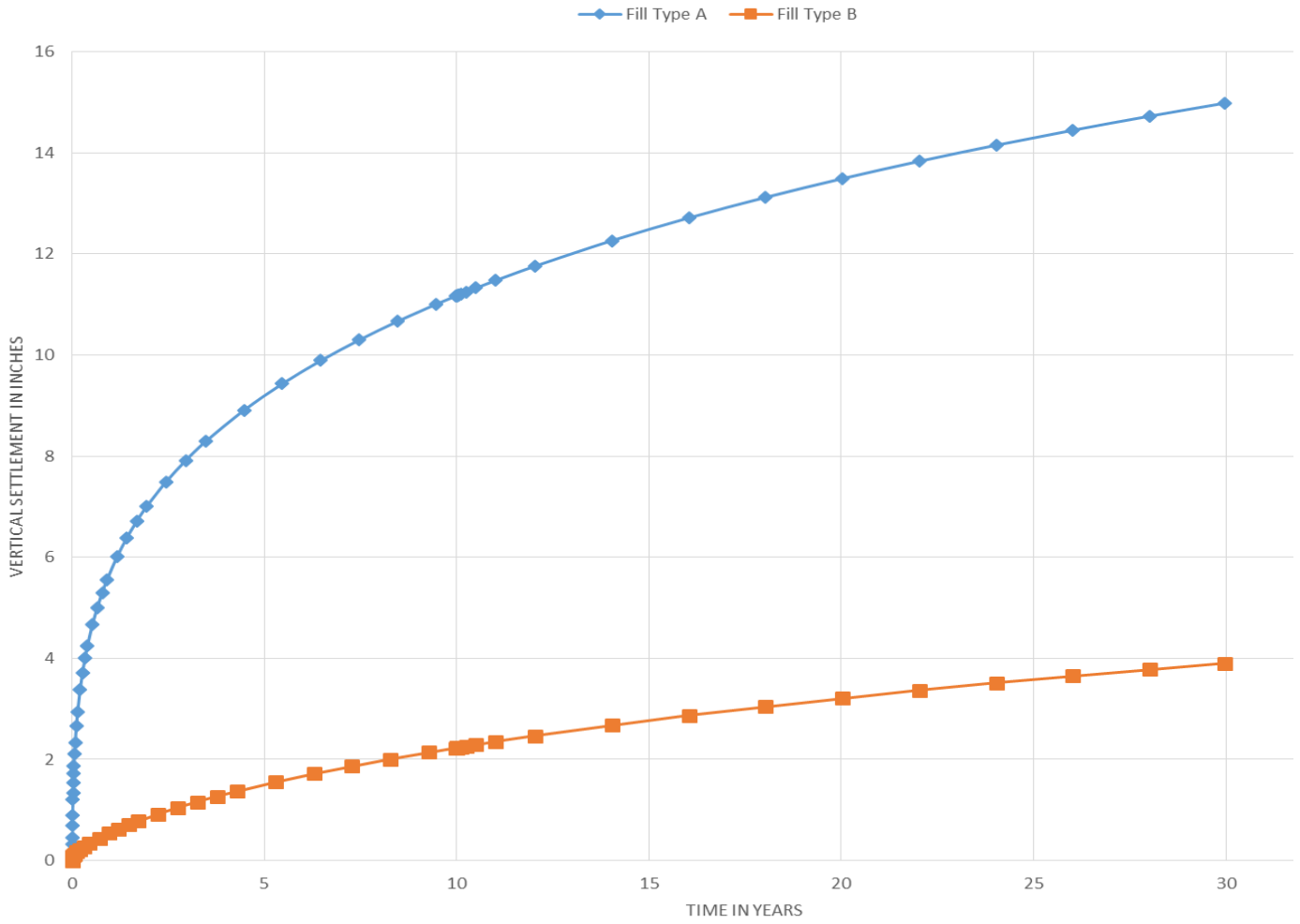
Figure

7

JCV 03/26/15 L:\Notebooks\1911800_Lake Union Park Geotech Assessment\Analysis and Calcs\Settlement\Settlement Results.xlsx



Note: Fill Type A includes potential for long-term settlement within the fill. Type B assumes the fill behaves as a granular soil without long-term deformation behavior.

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Time Rate of Settlement Behind Bulkhead Due to Hog Fuel Replacement

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Figure
8

JCV 03/26/15 L:\Notebooks\1911800_Lake Union Park Geotech Assessment\Analysis and Calcs\Settlement\Settlement Results.xlsx