GEOTECHNICAL RECOMMENDATIONS REPORT
FIFTEEN PERCENT DESIGN
NFTA LIGHT RAIL RAPID TRANSIT EXTENSION

ERIE COUNTY, NEW YORK

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1.0 INTRODUCTION

The Buffalo Light Rail Rapid Transit (LRRT) is operated by the Niagara Frontier Transportation Authority (NFTA) and was completed in 1986. The LRRT currently extends from the Special Events Station near the KeyBank Center, along Main Street to University Station at the University at Buffalo (UB) South Campus in Buffalo, NY. The NFTA plans to extend the LRRT from the South Campus to beyond the North Campus of UB, to where the I-990 crosses the John James Audubon Parkway in Amherst NY. Figure 1 shows the planned route.

The NFTA has engaged WSP USA (WSP) to develop a preliminary design for the extension. WSP requested that McMahon & Mann Consulting Engineering and Geology, P.C. (McMahon & Mann) explore the subsurface conditions and provide geotechnical recommendations for preliminary design. McMahon & Mann completed subsurface explorations along the proposed extension corridor, including 75 borings and 33 monitoring wells. The data collected from these explorations is included in the Geotechnical Data Report[1] (the Data Report).

As a follow up to the data report, we have developed geotechnical recommendations for the project relative to the subsurface conditions. The recommendations pertain to the tunnel portion connecting the University Station to the portal at Niagara Falls Boulevard, as well as the elements of the rail extension that will require geotechnical design considerations. These elements include:

- Center and Side Platform Stations
- Power Traction Substations
- Cut and Cover – Segment 1
- Cut and Cover – Segment 4
- Bizer Creek Bridge/Culvert
- Lee Road Retaining Wall
- Train Storage Shed – Segment 8

Conceptual recommendations are provided in the following sections for each of these elements as well as track subgrade recommendations. As described in the Data Report, the ground conditions vary along the planned corridor and the variable conditions are addressed below.

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[1] Geotechnical Data Report, NFTA Light Rail Rapid Transit Extension, prepared for WSP USA, Inc., prepared by McMahon & Mann Consulting Engineering and Geology, P.C., dated March 2025.

2.0 LIGHT RAIL RAPID TRANSIT EXTENSION

The proposed LRRT extension corridor (the corridor) is shown on Figure 1. The corridor will extend both above and below grade through approximately 7.2 miles of commercial and residential districts. Supporting infrastructure along the route includes passenger stations, power substations, bridges and retaining walls, as described in the following sections.

2.1 UB SOUTH, KENMORE AVENUE AND NIAGARA FALLS BOULEVARD TUNNEL

The corridor begins at the UB South Campus where the current LRRT terminates in a tunnel north of University Station, approximately 60 feet below the ground surface. The proposed tunnel section will continue northeast beneath the UB South Campus parking lots before making an approximate 140 degree turn to continue beneath Kenmore Avenue. The tunnel continues to the intersection of Kenmore Avenue and Niagara Falls Boulevard before turning north and extending to a portal beneath Niagara Falls Boulevard near Princeton Avenue.

A traction power substation is proposed at the corner of Kenmore Avenue and Niagara Falls Boulevard.

2.2 NIAGARA FALLS BOULEVARD, MAPLE ROAD, AND SWEET HOME ROAD

The corridor will portal near Princeton Avenue on Niagara Falls Boulevard, transitioning to an at grade alignment that will extend to the Boulevard Mall before turning east along Maple Road. The corridor will continue at grade on Maple Road until Sweet Home Middle School, where it transitions to a cut and cover tunnel section, extending below grade as the corridor turns north onto Sweet Home Road. The corridor will portal on Sweet Home Road, transitioning back to an at grade corridor before extending under the I-290 overpass and continuing nearly to Rensch Road before turning east to cross Bizer Creek.

Four passenger stations are proposed along this section, two on Niagara Falls Boulevard, one on Maple Road, and one on Sweet Home Road. Four traction power substations are also proposed along this section, including two along Niagara Falls Boulevard, one at the Boulevard Mall and one on the corner of Maple Road and Sweet Home Road.

2.3 UB NORTH, AUDUBON PARKWAY, AND MUIR WOODS

The corridor will extend east through the UB North Campus, turning north just past Lockwood Library to extend down Lee Road before turning northeast onto the John James Audubon Parkway. The corridor will stay at grade generally north along the John James Audubon Parkway, extending under the I-990 overpass, and terminate in the Muir Woods Development.

A new bridge will be required to cross Bizer Creek and existing bridges will need to be repurposed or replaced to cross Ellicott Creek as well as a waterway connecting Lake

LaSalle to the north and south sides of the John James Audubon Parkway. A retaining wall will also be required along Lee Road on the UB North Campus.

Five passenger stations are proposed along this section, two on the UB North Campus, two along Audubon Parkway and one in the Muir Woods Development. Four traction power substations are proposed along this section, including one on the UB North Campus, two along Audubon Parkway and one at the end of the line in the Muir Woods Development. A storage facility will also be constructed at the end of the line in Muir Woods.

3.0 GEOTECHNICAL RECOMMENDATIONS

Subsurface profiles in the Data Report illustrate the subsurface conditions in each segment of the corridor. Refer to the Data Report figures (specifically Figures 5 through 20) for descriptions of the soil and rock type, SPT N-values, RQD, rock core recovery, groundwater elevations and the results of laboratory and field testing. Recommendations pertaining to the components of the corridor are provided and discussed below.

3.1 UB SOUTH CAMPUS TO PRINCETON AVENUE (TUNNEL EXTENSION)

The tunnel section will continue with twin 16-foot finished inside diameter tunnels proposed to extend northeast beneath UB South Campus before making an approximately 140 degree turn to continue beneath Kenmore Avenue. Current plans have the tunnel transitioning to a cut and cover section beneath Kenmore Avenue before turning north as a cut and cover section to extend below Niagara Falls Boulevard where it will transition to an at-grade corridor near Princeton Avenue on Niagara Falls Boulevard.

3.1.1 Geotechnical Issues

- *Very Intensely Fractured Camillus Shale* - Along the current corridor, the tunnel will traverse up from the Bertie formation as it remains within the limits of the UB campus. Near the beginning of where the tunnel is beneath Kenmore Avenue, the track crosses into the Camillus shale formation which contains zones that are very intensely fractured.

  These very intensely fractured zones and pockets are severely weathered and solutioned rock within the Camillus formation, which can yield large quantities of water. When sampled with a split-spoon and cored, the very intensely fractured and weathered rock resembles soil-infilled gravel over tens of feet. The intensely fractured Camillus Formation is much more pervious than the Bertie Formation and the groundwater within the Camillus commonly contains dissolved hydrogen sulfide.

  This formation was also encountered during the subsurface explorations for the existing LRRT in a 36-inch diameter exploratory shaft that was drilled at the Amherst Station. A diver descended into the shaft and described the formation as follows:

1. Down to a depth of 40 feet the shaft walls were regular and smooth,
2. From 40 to 62 feet deep (fractured zone), the shaft walls were very jagged and oversized,
3. Pieces of rock could be pulled from the walls in the fractured zone,
4. Voids around the walls in the fractured zone were large enough for the diver to insert his arm.

We recommend avoiding the Very Intensely Fractured Camillus shale with the track alignment, as possible. It is worth noting that the existing LRRT avoided the Very Intensely Fractured Camillus and was mostly constructed in the Bertie Formation, likely a result of these findings.

- *Tunnel Lining* – As described in the Data Report, after the LRRT Tunnel was completed and lined and the pumps were turned off, leaks occurred at many locations through the unreinforced concrete lining. This led to numerous claims, delays and eventually a grouting program to reduce the water inflow.

  The design of the tunnel should consider the need for a lining that will reduce groundwater inflow and a groundwater collection system to collect groundwater that seeps through the liner. In addition, the design should consider the need for measures to mitigate the effects of rock creep on the tunnel liner.
- *Settlement from dewatering* – Settlement of the overburden soil and possibly the intensely fractured Camillus Formation due to construction dewatering should be considered when selecting the track alignment. In addition to cost and schedule increases, dewatering efforts may lead to settlement issues.

3.1.2 Cut and Cover Section – Segment 1

The cut and cover section will begin between the UB south campus and extend to the Niagara Falls Boulevard intersection with Princeton Avenue. Excavation for the tracks could extend up to over 40 feet below the ground surface. Based on the subsurface information for this section the excavation will be through the overburden soils and into the underlying Bertie and Camillus rock formations. Groundwater data indicate that groundwater infiltration will be present within excavation within the Bertie and even more prevalent within excavations into the Camillus.

3.1.2.1 Excavation Support

We recommend using soldier piles and lagging to support excavations above the groundwater and concrete secant piles to support the excavation that extends below the groundwater. The secant piles will serve to control groundwater seepage and could be incorporated into the final tunnel design. The soldier piles and lagging will be a more economical option where groundwater is not expected. The excavation should be braced as needed to reduce the length and depth of the piles. Our preliminary estimates show that two rows of bracing may be required for the deeper excavation. The following table summarizes our recommended shoring design parameters.

Table 1
Recommended Shoring Design Parameters for Segment 1 Tunnel

Soil Zone	Design Parameter	Value
Fill Soils and Glacial Till (Ground Surface to El. 572)(1)	Total Unit Weight, pcf(2)	120
	Angle of Internal Friction, degrees	30
	Active Earth Pressure Coefficient(3)	0.33
	Passive Earth Pressure Coefficient(3)(4)	2.40

Notes: 1.) The soldier pile should not extend deeper than El. 572 to avoid artesian groundwater conditions.
2.) pcf – pounds per cubic foot
3.) Considers level backfill and level dredge line. Coefficients should be adjusted if conditions are sloped. Coefficients do not consider wall friction.
4.) Considers a factor of safety of 1.25 for temporary retaining walls.

The earth pressure acting on the shoring system should include traffic surcharge and loadings from adjacent existing structures.

The excavation will widen as the track turns onto Niagara Falls Boulevard to accommodate underground traction power substation 1. Tie-backs or rakers may need to be considered in the shoring design.

3.1.3 Control of Water

Groundwater may enter the excavation from the tunneling section of the corridor. We recommend collecting the water via gravity methods and pumping the water out of the excavation. The dewatering methods for the tunneling section should remain in place until the cut and cover section has progressed outside the zone of influence.

3.1.4 Tail Track Observations

The existing LRRT terminates in a tunnel at University Station, approximately 60 feet below the ground surface. McMahon & Mann representative met with two representatives from the NFTA to observe the University Station adit tunnels on January 24, 2024. We first observed Tunnel No. 2 (outbound side) crossed over through the vent shaft at the end of the line and then observed Tunnel No. 1 (inbound side). The following items were noted during our approximately one hour-long visit and should be considered during design development:

- Shrinkage cracks were present at many of the construction joints and were frequent and continuous. Seepage was observed from the cracks in the tunnel lining, mostly below the springline.

- Water flow was observed coming through the north end of Tunnel No. 2, near the tunnel crown in the upper left-hand corner. The flow rate was approximately one gallon per minute.
- The water did not appear to accumulate at the bottom of the tunnel, but seemed to drain beneath the rails as the tunnel was pitched away from the end wall. This slope in the tunnel supposedly continues all the way to the pump station near intersection of Main Street and Hertel Avenue.
- Horizontal (longitudinal) cracks were not observed along the springline or the crown in either tunnel.
- Cracks were not observed in the walls of the vent shaft.
- Overall, it seemed there were fewer cracks and less seepage in Tunnel #1.
- Much of the metal of the conduits, rails, and utility lines are corroded.

3.2 CENTER AND SIDE PLATFORMS

The locations of the center and side platforms along the corridor are shown on Figure 2. Based on discussions with WSP, the platforms will be supported by spread footings. (At this time, design drawings for the platform foundations are not available.) We assumed that the spread footings will be 4 feet by 4 feet in plan and bear at least 4 feet below the ground surface for frost protection. We recommend constructing the spread footings on native soils or up to 2 feet of structural fill, as described in the following sections.

3.2.1 Excavation Considerations

All excavations should be made in accordance with standards set by the Occupational Safety and Health Administration (OSHA). Excavations for the platforms will be in fill soils, lake sediments, outwash sediments, and glacial till. The contractor should consider the soils as Soil Type C for planning its excavations.

The excavations for the platform footings will be 4 feet to 6 feet deep. We recommend sloping or benching the sides of these excavations. We do not expect to encounter groundwater in shallow excavations. However, surface water may enter the excavations. Water that enters the excavations should be removed by conventional sump and pump methods.

3.2.2 Subgrade Preparation

Subsurface sections for each station are provided in Figure 3 through Figure 12. The subgrade below most of the platforms will be native soils, such as lake sediment and glacial till. These soils are fine-grained and degrade under repeated foot and equipment traffic and changes in moisture. Therefore, the subgrade should not be exposed for long periods of time.

The subgrade should be proofrolled if there is enough room for operating the equipment. The subgrade should be observed and any loose and/or soft areas should be removed and replaced with structural fill.

3.2.3 Suitable Subgrade and Allowable Bearing Pressures

The subsurface data for the platforms show that the topsoil/fill soils range from 1 foot thick to 32 feet thick. Our footing recommendations for varying fill thicknesses are as follows:

- For platforms where the fill soils are less than 4 feet thick, we recommend excavating to 4 feet and constructing the footings on the native soils.
- For platforms where the fill soils are between 4 feet and 6 feet thick, we recommend excavating the fill, backfilling with structural fill to the bearing grade, and constructing the footings on the structural fill. Alternatively, the stems of the footings can be extended and the footings can be constructed on the native soils.
- For platforms where the fill soils are over 6 feet thick, we recommend overexcavating the bearing grade by 2 feet, backfilling with structural fill, and constructing the footings on the structural fill.

The above recommendations are based on a minimum bearing grade of 4 feet below the ground surface and should be adjusted as necessary.

Table 2
Summary of Suitable Subgrades and Bearing Pressures for Platforms

Segment	Platform	Associated Borings	Ground Surface Elevation[1]	Depth to Suitable Subgrade (El.)[2]	Subgrade Soil	Allowable Bearing Pressure, psf[3]
2	Decatur (Figure 3)	BH-15, BH-16	603.6	4 feet (599.6)	Glacial Till	5,000
	Eggert (Figure 4)	BH-20, BH-21	595.9	6 feet (589.9)	Fill[4]	5,000
3	Boulevard (Figure 5)	BH-24, BH-25	590.3	6 feet (584.3)[5]	Lake Sediment	5,000
	Maple (Figure 6)	BH-29, BH-30	594.5	4 feet (590.5)	Lake Sediment	5,000
5	Sweethome (Figure 7)	BH-40, BH-41	601.2	6 feet (595.2)	Fill[4]	5,000
6	Flint (Figure 8)	BH-48, BH-49	597.0	6 feet (591.0)[5]	Fill[4] and Lake Sediment	3,000
	Lee (Figure 9)	BH-53, BH-54	583.2	5 feet (578.2)	Lake Sediment	5,000
7	Ellicott Complex (Figure 10)	BH-55, BH-56	590.3	6 feet (584.3)	Fill[4]	2,500
8	Audubon (Figure 11)	BH-62, BH-63	578.8	4 feet (574.8)	Outwash Sediment	2,500
	I-990 (Figure 12)	BH-68, BH-69	574.9	4 feet (570.9)	Outwash/Lake Sediment	2,500

Notes: 1.) Approximate ground surface elevation; average from both borings.
2.) Approximate depth below the ground surface to the suitable bearing grade.
3.) psf – pounds per square foot.
4) Structural fill pads are required when fill soils remain below the footings.
5.) The fill soils vary in thickness; however, the thickest fill depth is shown.

3.2.4 Backfill and Final Grading

Structural fill should be used to backfill excavations below planned structures. In areas not below planned structures, suitable fill can be used. Hand compaction equipment should be used to compact the material within 5 feet of concrete structures to limit the potential for damage to the structures. If there is not enough room to properly compact structural fill, drainage stone can be used as backfill.

The ground surface adjacent to any structure should be sloped to direct surface water away from it.

3.3 POWER TRACTION SUBSTATIONS

According to WSP, power traction substation equipment will be installed on structural concrete pads, constructed at grade. At this time, design drawings for the substations are not available. The concrete pads should be designed and constructed in accordance with American Concrete Institute (ACI) 360R-10, “Guide to Design of Slabs-on-Ground.” The concrete pads should also conform to the construction standards set in ACI 302.1R and ACI 318. The following sections describe our recommendations for slabs on grade.

3.3.1 Site Preparation

All pavement, concrete, vegetation, topsoil, and other organic matter should be removed from the ground surface within the construction limits.

3.3.2 Subgrade Preparation

The subgrade soils below the concrete pads vary along the corridor. Generally, the materials are topsoil/fill soils, lake sediment, or glacial till. These materials are fine-grained and degrade under repeated foot and equipment traffic and changes in moisture. Therefore, the subgrade should not be exposed for long periods of time.

The subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. Because the subgrade is fine-grained, we recommend placing a separation geotextile on the prepared subgrade, prior to placing subbase material.

We recommend placing a 12-inch (minimum) layer of structural fill subbase over the separation geotextile and below the base layer.

3.3.3 Concrete Pad Considerations

The concrete pads should be designed considering a modulus of subgrade reaction of 100 pounds per cubic inch (pci). This value can be adjusted for the subbase thickness, per ACI 360R-10. For example, a 12-inch thick subbase layer increases the modulus of subgrade reaction to about 190 pci.

If the concrete pads will be designed as mat foundations, these design recommendations should be revisited and updated.

3.3.4 Backfill and Final Grading

Backfill around the perimeter of the concrete pads can be suitable fill. The ground surface adjacent to the concrete pads should be sloped to direct surface water away from the pad. Care should be taken to avoid the collection of water in the subbase and base materials, below the concrete pads.

3.4 CUT AND COVER SECTION – SEGMENT 4

The cut and cover section will begin along Maple Road near Hillcrest Drive and extend down Sweet Home Road near the Interstate-290 overpass. WSP has indicated that the excavation will be up to 20 feet deep. The excavation will be through fill soils and lake sediment and into glacial till. We do not anticipate the excavation extending into the underlying rock with enough glacial till left in place to limit groundwater seepage during excavation. However, the tips of the soldier piles will likely extend below the groundwater level.

3.4.1 Dewatering

The bottom of the excavation will likely be near the groundwater level and water may seep into the excavation. Additionally, the bottom of the excavation will be fine-grained soils that may degrade under repeated foot and equipment traffic and changes in moisture. Therefore, we recommend placing a layer of structural fill along the bottom to maintain a stable working platform. Furthermore, the structural fill can be integrated into a gravity dewatering system, such as sumps and pumps.

3.4.2 Excavation Support

We recommend providing temporary shoring for the excavation with soldier piles and lagging. Our preliminary estimate considers a 20-foot cut with one row of bracing and shows an embedment of about 15 feet for a total pile length of 35 feet. The following table summarizes our recommended shoring design parameters.

Table 3
Recommended Shoring Design Parameters for Segment 4

Soil Zone	Design Parameter	Value
Overburden Soils(1) (Ground Surface to Top of Rock, El. 560)(2)	Total Unit Weight, pcf(3)	120
	Angle of Internal Friction, degrees	30
	Active Earth Pressure Coefficient(4)	0.33
	Passive Earth Pressure Coefficient(4)(5)	2.40

Notes: 1.) Overburden soils include fill soils, lake sediment, and glacial till.
2.) The top of rock elevation changes along the track alignment. Refer to boring logs for details.
3.) pcf – pounds per cubic foot
4.) Considers level backfill and level dredge line. Coefficients should be adjusted if conditions are sloped. Coefficients do not consider wall friction.
5.) Considers a factor of safety of 1.25 for temporary retaining walls.

The earth pressure acting on the shoring system should include traffic surcharge and loadings from adjacent existing structures.

3.5 BIZER CREEK BRIDGE – SEGMENT 6

The corridor will be carried by a new bridge over Bizer Creek. We understand that the new bridge will be a three-sided, precast concrete culvert structure. We recommend supporting the culvert on strip footings bearing at approximately El. 567 on competent shale bedrock. The bottoms of the footings may bear deeper; however, the tops of the footings should be no higher than the creek bed at El. 570.

3.5.1 Excavation Considerations

All excavations should be made in accordance with standards set by the Occupational Safety and Health Administration (OSHA). Excavations for the new culvert will be in fill soils, lake sediments, glacial till, and the upper few feet of rock. The contractor should consider the soils as Soil Type C for planning its excavations.

Based on the RQD and the rock hardness classification of the shale rock core samples retrieved from the borings, it is our opinion that the rock can be excavated with an excavator bucket. However, if the rock becomes too difficult to excavate, we recommend using a mechanical hammer attachment (hoe ram) to break it apart before excavating.

Borings at this location indicate the presence of gypsum seams within the rock. If the final bearing grade is within a foot of the gypsum seams, the gypsum should be over-excavated and removed and replaced with compacted structural fill.

3.5.2 Excavation Dewatering and Control of Water

To limit sediments from entering the creek during construction and to dewater the excavations, we recommend constructing a temporary cofferdam system upstream and downstream of the planned culvert. A pipe, sized for the expected flow conditions, should be used to convey the flow of the creek around the construction for the duration of the project.

The excavations for the footings will be below the creek and the contractor should expect water to enter the excavation even after the cofferdam is in place. The contractor will likely be able to remove the water by directing it to sumps in the excavation and pumping from them.

3.5.3 Suitable Bearing Grade and Bearing Resistance

We recommend supporting the culvert on strip footings bearing on competent shale rock. Based on our observations, we estimate that the suitable bearing grade will be El. 567. Additionally, we recommend that the top of the footings be no higher than the bottom of the creek bed at El. 570.

We recommend that the footings bearing at the suitable bearing grade be designed for a factored nominal bearing resistance of 9,000 psf. Strip footings should have a minimum width of 2 feet. Additional bearing resistance parameters are summarized below.

Table 4
Summary of Bearing Resistance Parameters for Bizer Creek

Parameter	Value
Nominal Bearing Resistance (q_n)	20,000 psf
Resistance Factor (φ_b)	0.45
Factored Nominal Bearing Resistance (q_R)	9,000 psf

We estimate that the settlement of the footings loaded to this pressure will be less than 1 inch.

3.5.4 Backfill and Drainage

We recommend backfilling the culvert with a 3-foot (minimum) wide zone of drainage stone. A perforated drainage pipe should be placed within the drainage stone to direct water away from the backside of the culvert. Structural fill should be used to backfill the remainder of the excavation behind the culvert.

The culvert should be designed to resist the lateral earth pressure from the structural fill placed behind the culvert walls. The lateral load from the structural fill should be estimated using a total unit weight of 125 pcf.

3.5.5 Scour Protection

The banks upstream and downstream from the culvert should have scour protection. Most of the banks appear to be shale rock and do not require additional protection. However, stone fill should be placed in areas where fill has been placed along the banks and in areas below the design flood elevation.

The subgrade for the stone fill should be stable and sloped no steeper than 2.5H:1V. It should be cleared and grubbed before placing the stone fill.

3.6 PERMANENT RETAINING WALL – SEGMENT 6

The corridor will follow Lee Road between UB’s Lockwood Memorial Library and Clemens Hall. Lee Road slopes down towards the north with the existing grade being too steep for the rail system. However, there appears to be room to flatten the slope for the rail. In flattening the slope, the existing site features will need to be supported by permanent retaining walls.

The retaining walls could start near the south intersection of Lee Road and Mary Talbert Way and extend to the north intersection of Lee Road and Mary Talbert Way. The change in elevation over this distance would flatten the slope to about 2 percent. The retaining walls supporting the existing site features could be as high as 10 feet.

If space permits, we recommend constructing a gravity-type retaining wall, such as a reinforced concrete cantilever wall. This type of wall will require room to slope a temporary excavation to construct the wall. The wall would then be backfilled with structural fill to the original grade. We do not expect to encounter groundwater during construction of this option.

Alternatively, if gravity walls are not feasible, we recommend soldier pile and lagging walls. The soldier piles can be drilled or driven to depth, based on the sensitivity of the existing infrastructure. A permanent and decorative concrete facing can be installed over the lagging. The soldier piles, however, may penetrate into the underlying outwash sediment and groundwater may enter the excavation. Groundwater management should be further explored for this option.

The retaining walls should be designed to resist lateral earth pressures. The following table summarizes our recommended design parameters.

Table 5
Recommended Retaining Wall Design Parameters for Segment 6

Material	Design Parameter	Value
Existing Fill and Native Soils	Total Unit Weight, pcf[1]	120
	Angle of Internal Friction, degrees	30
	Active Lateral Earth Pressure Coefficient[2]	0.33
	Passive Lateral Earth Pressure Coefficient[2][3]	2.0
Structural Fill	Total Unit Weight, pcf[1]	125
	Angle of Internal Friction, degrees	34
	Active Lateral Earth Pressure Coefficient[2]	0.28

Notes: 1.) pcf – pounds per cubic foot
2.) Considers level backfill. Coefficients should be adjusted for sloping backfill.
3.) Considers a factor of safety of 1.5 for permanent retaining walls.

The pressures acting on the backside of the retaining walls should include the traffic surcharge and other loads from adjacent existing infrastructure, if applicable.

Once a retaining wall type has been selected, we can provide additional design and construction recommendations.

3.7 TRAIN STORAGE SHED – SEGMENT 8

A train storage shed will be located at Muir Woods. (Design plans for the shed were not available at the time of this report.) We assume the shed will be single level and supported on spread footings. The footings should bear a minimum of 4 feet below the ground surface (for frost protection) on native soil. The depth of the footings should also consider uplift resistance.

3.7.1 Excavation Considerations

All excavations should be made in accordance with standards set by the Occupational Safety and Health Administration (OSHA). Excavations for the storage shed will be through fill soils, outwash sediment, and lake sediment. The contractor should consider the soils as Soil Type C for planning its excavations.

3.7.2 Subgrade Preparation

The subgrade is fine-grained and may degrade under repeated foot and equipment traffic and changes in moisture. Therefore, the subgrade should not be exposed for long periods of time.

The subgrade should be proofrolled if there is enough room for the equipment. The subgrade should be observed and any loose and/or soft areas should be removed and replaced with structural fill.

3.7.3 Suitable Bearing Grade and Allowable Bearing Pressure

At 4 feet deep, the footings will bear on the lake sediment or outwash sediment and should be designed considering an allowable bearing pressure of 2,500 psf. We estimate that footings loaded to this pressure will settle less than 1 inch. Spread footings should have a minimum width of 4 feet.

3.7.4 Floor Slab Considerations

The floor slab should be designed considering a modulus of subgrade reaction of 150 pci and in accordance with ACI 360R-10. The floor slab should also conform to the construction standards set in ACI 302.1R and ACI 318.

3.8 TRACK SLAB RECOMMENDATIONS

The track system will likely be a combination of direct fixation tracks (ballast-less open tracks), embedded tracks, and ballasted tracks. Each track types include the installation and construction of supporting concrete slabs. The tracks and concrete slabs should be designed in accordance with American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering*, in addition to other applicable standards set by local agencies. The following sections describe our recommendations for the track slabs.

3.8.1 Direct Fixation Tracks – Segment 1

Direct fixation tracks will likely be implemented in the tunnel section of Segment 1. From University Station to the cut and cover transition, the subgrade for the track system will be rock. We recommend clearing the subgrade of loose material and constructing the supporting concrete slab on the rock.

From the cut and cover transition to where the tunnel daylights along Niagara Falls Boulevard (near Princeton Avenue), the subgrade for the track system will be native glacial till. The subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. We recommend placing a separation geotextile on the prepared subgrade, followed by 12 inches of structural fill subbase on the geotextile. The concrete slab and any additional sublayers should be constructed on the subbase. A drainage system should be implemented to keep water from collecting below the concrete slabs.

3.8.2 Embedded Tracks – Segments 2 and 3

The tracks will be embedded in a concrete slab along Segments 2 and 3, where the tracks will be at-grade along Niagara Falls Boulevard and Maple Road. The corridor will be along existing roadways and paved parking areas. The existing pavement within the construction limits should be removed.

The subgrade will likely be a mix of fill soils from the exiting roadways and native glacial till and slackwater sediment. The subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. We recommend placing a separation geotextile on the prepared subgrade, followed by 12 inches of structural fill subbase on the geotextile. The concrete slab and any additional sublayers should be constructed on the subbase.

A drainage system should be implemented to allow the subbase to drain. Additionally, surface water should be directed away from the tracks and roadways.

3.8.3 Direct Fixation Tracks – Segment 4 Tunnel

The corridor enters a tunnel along Maple Road near Hillcrest Drive and exits just south of I-290 along Sweet Home Road. The subgrade for the track system will be native glacial till and slackwater sediment. The subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. We recommend placing a separation geotextile on the prepared subgrade, followed by 12 inches of structural fill subbase on the geotextile. The concrete slab and any additional sublayers should be constructed on the subbase.

The groundwater level will be near the bottom of the track system at the deepest section of the tunnel. We recommend implementing a drainage system to keep water from collecting below the concrete slabs.

3.8.4 Embedded/Direct Fixation Tracks – Segments 4 At-Grade, 5, 6, and 7

The track system will likely be a combination of embedded and direct fixation tracks. The subgrade soils will be fill and lake sediments. The subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. We recommend placing a separation geotextile on the prepared subgrade, followed by 12 inches of structural fill subbase on the geotextile. The concrete slab and any additional sublayers should be constructed on the subbase.

A drainage system should be implemented to allow the subbase to drain. Additionally, surface water should be directed away from the tracks and roadways.

3.8.5 Embedded/Direct Fixation Tracks – Segment 8

The track corridor is underlain by fill and soft slackwater sediments. We recommend revisiting this segment for potential settlement issues once the design has progressed.

If settlement is not an issue, the subgrade should be proofrolled and observed. Any loose and/or soft areas in the subgrade should be removed and replaced with structural fill. We recommend placing a separation geotextile on the prepared subgrade, followed by 12 inches of structural fill subbase on the geotextile. The concrete slab and any additional sublayers should be constructed on the subbase.

3.9 SLOPE STABILITY RECOMMENDATIONS

We anticipate certain areas of the corridor will require grading of the ground surface to match the surrounding conditions and grades. These areas will likely include the portals from both tunnels, the passage beneath I-290, at each of the bridge approaches, and along Mary Talbert Way and Lee Road on the UB north campus.

For preliminary design, we recommend these slopes be no greater than 3 horizontal to 1 vertical. As the design progresses and track elevations and alignments are refined, these slope inclinations can be re-evaluated relative to the existing soil and rock conditions. In areas where slopes are not practical, grade breaks and structural retaining walls can be incorporated.

4.0 LIMITATIONS

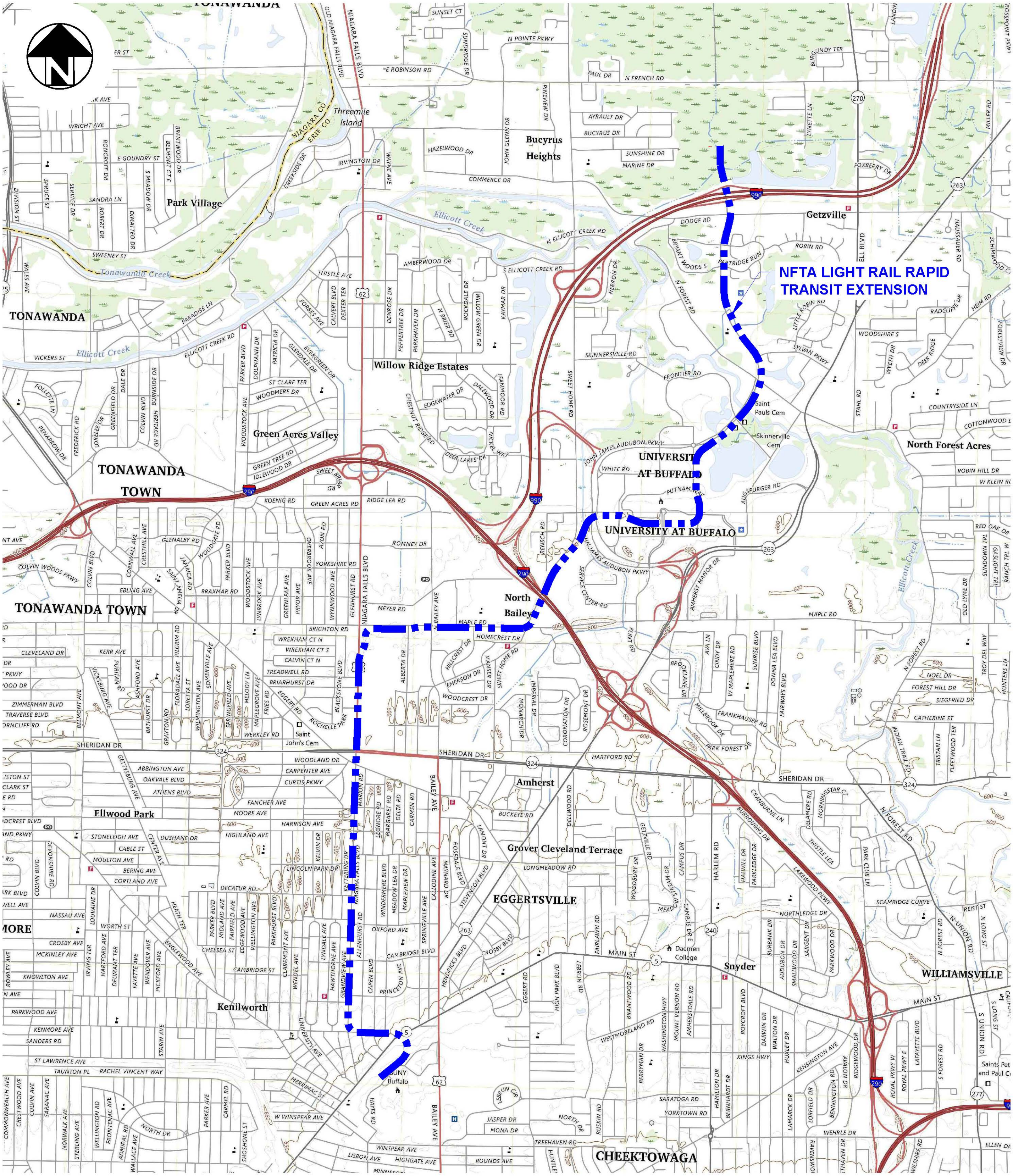
The scope of McMahon & Mann Consulting Engineering and Geology, P.C.'s services are limited to the geotechnical engineering considerations identified in our agreement, and further described below:

- The scope of work for this project does not include an evaluation of the presence of hazardous substances. WSP USA Inc. should contact McMahon & Mann Consulting Engineering and Geology, P.C. in the event that hazardous substances are encountered to evaluate the impact on the geotechnical recommendations.
- The analyses and recommendations submitted in this report are based in part upon the data obtained from the subsurface explorations. The nature and extent of variations between these explorations may not become evident until construction. If

variations then appear, it will be necessary to re-evaluate the recommendations in this report.

- The generalized soil and rock profiles described in the text are intended to convey trends in subsurface conditions. The boundaries between strata are approximate and idealized. They have been developed by interpretations of widely-spaced explorations and samples. Actual soil and rock transitions can vary.
- Water levels were observed at the times and under the conditions stated. Fluctuations in the groundwater levels occur from rainfall, seasonal runoff and other factors differing from the time that the measurements were made.
- In the event that any changes in the nature or design of the project are planned, the conclusions and recommendations contained in this report will not be considered valid unless the changes are reviewed and conclusions of this report are modified or verified in writing by McMahon & Mann Consulting Engineering and Geology, P.C. It is recommended that McMahon & Mann Consulting Engineering and Geology, P.C. be given the opportunity to review the final design and specifications to verify that our recommendations are properly interpreted.
- It is recommended that McMahon & Mann Consulting Engineering and Geology, P.C. be retained to monitor geotechnical aspects of the project construction.
- This report has been prepared for the exclusive use of WSP USA Inc. for the specific application to the design of the proposed NFTA Light Rail Rapid Transit Extension in Erie County, New York in accordance with generally accepted soil and foundation engineering practice. No other warranty, expressed or implied, is made.

FIGURES



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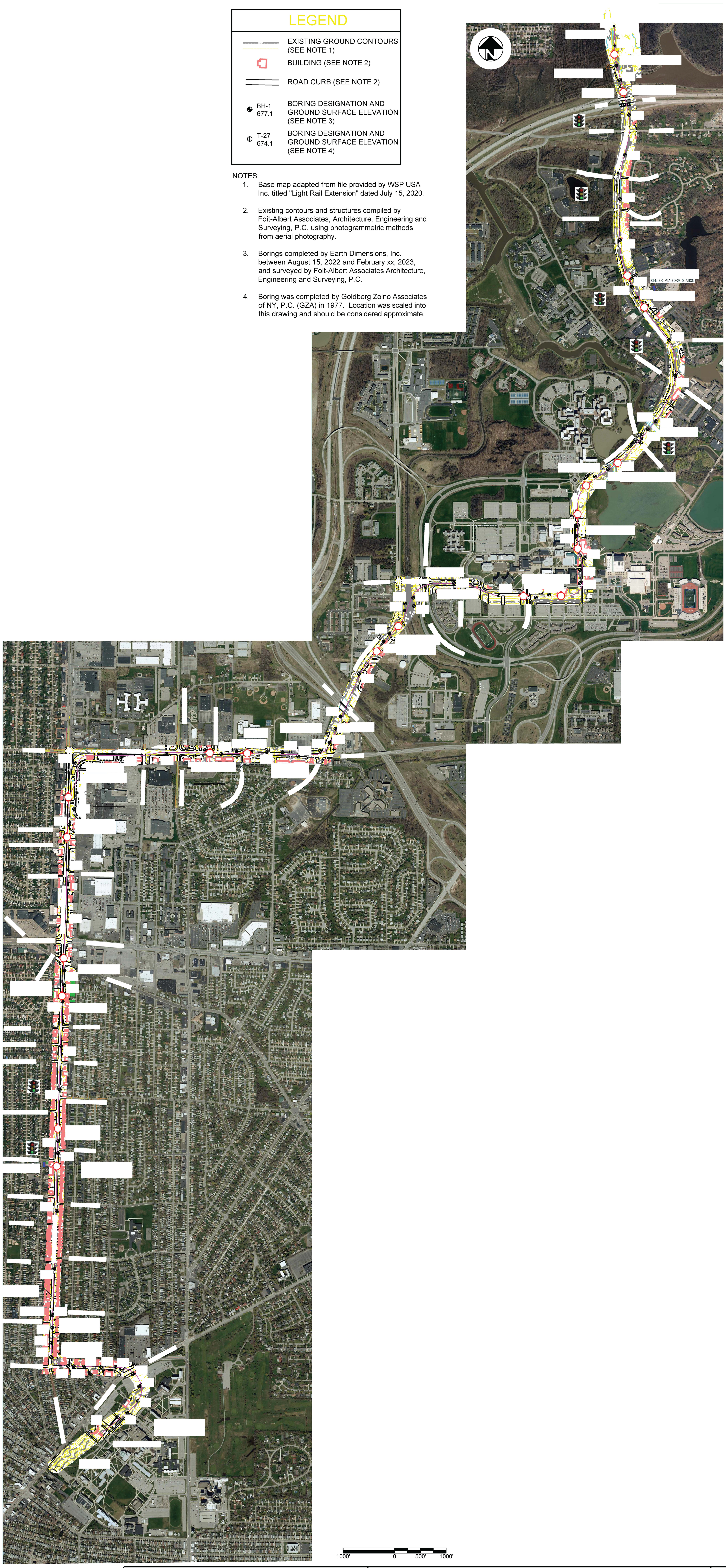
NOTE:

1. Base map image adapted from 7.5 Minute Series USGS maps Buffalo NE and Tonawanda E, NY, dated 2023.

4000' 0 2000' 4000'

APPROXIMATE SCALE: 1" = 4000'

McMahon & Mann Consulting Engineering and Geology, P.C. 2495 Main Street, Suite 432 Buffalo, NY 14214 (716) 834-8932 www.mmce.net	NFTA LIGHT RAIL RAPID TRANSIT EXTENSION ERIE COUNTY NEW YORK	PROJECT LOCATION MAP DWG. NO. 18020-010a FIGURE 1



LEGEND

- EXISTING GROUND CONTOURS (SEE NOTE 1)
- BUILDING (SEE NOTE 2)
- ROAD CURB (SEE NOTE 2)
- BH-1 677.1 — BORING DESIGNATION AND GROUND SURFACE ELEVATION (SEE NOTE 3)
- T-27 674.1 — BORING DESIGNATION AND GROUND SURFACE ELEVATION (SEE NOTE 4)

NOTES:

1. Base map adapted from file provided by WSP USA Inc. titled "Light Rail Extension" dated July 15, 2020.
2. Existing contours and structures compiled by Foit-Albert Associates, Architecture, Engineering and Surveying, P.C. using photogrammetric methods from aerial photography.
3. Borings completed by Earth Dimensions, Inc. between August 15, 2022 and February xx, 2023, and surveyed by Foit-Albert Associates Architecture, Engineering and Surveying, P.C.
4. Boring was completed by Goldberg Zoino Associates of NY, P.C. (GZA) in 1977. Location was scaled into this drawing and should be considered approximate.

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NFTA LIGHT RAIL RAPID TRANSIT EXTENSION

ERIE COUNTY NEW YORK

SUBSURFACE SECTION LOCATION PLAN

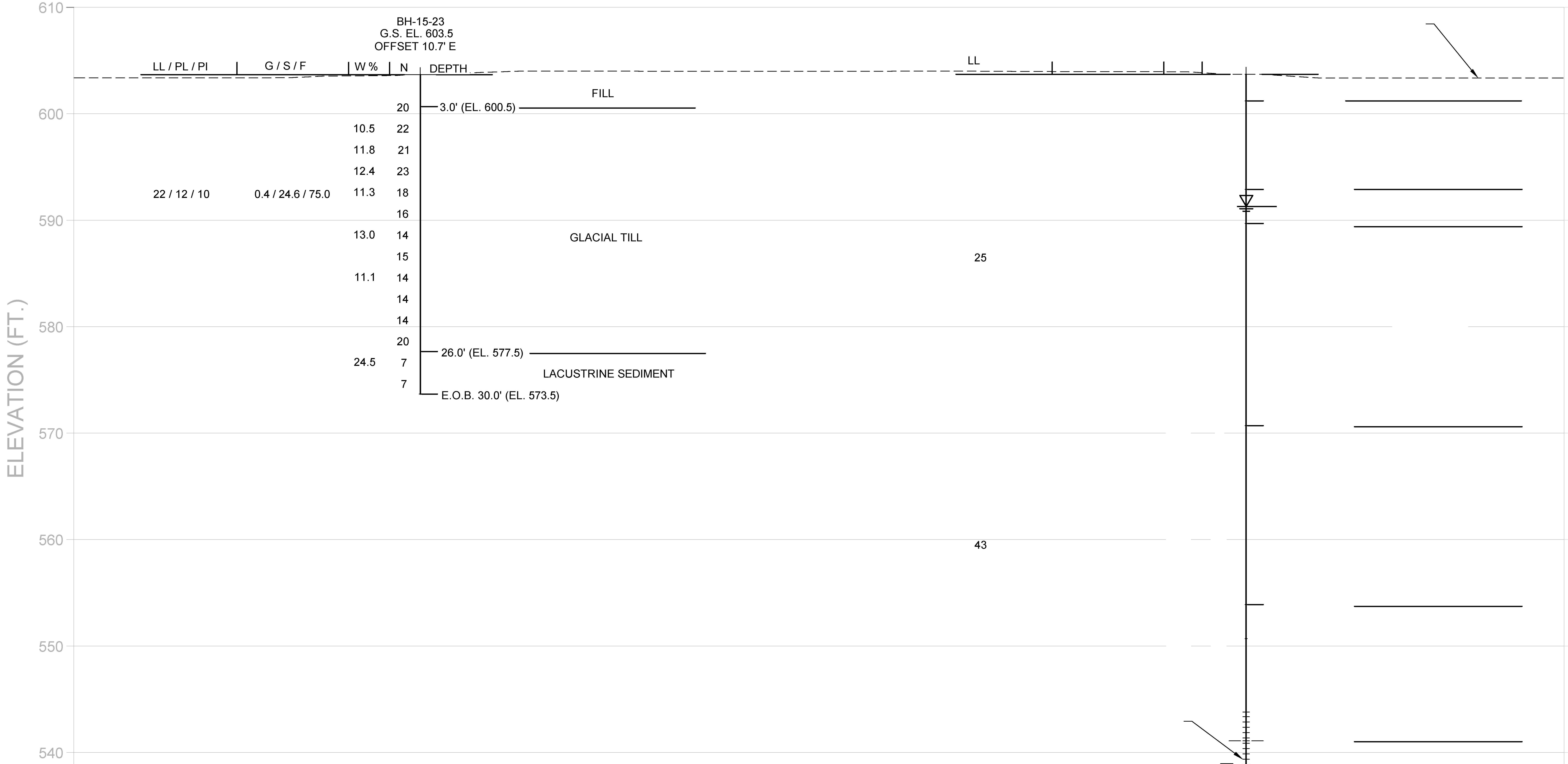
DWG. NO. 18020-013a

FIGURE 2

S:\CAD\DRAWING\PROJECT\WSP\Amherst St. Light Rail Extension\18020-013.dwg

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	LL	LIQUID LIMIT	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION	R1: 62.6 - 67.1	RUN NUMBER: RUN DEPTH
GW EL. 591.4	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	PL	PLASTIC LIMIT	S	PERCENT SAND CONTENT	W%	MOISTURE CONTENT	89 / 44	RECOVERY / RQD
		PI	PLASTICITY INDEX	F	PERCENT FINES CONTENT	BH-15-23	BORE HOLE DESIGNATION	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED



NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

1 DECATUR SIDE PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

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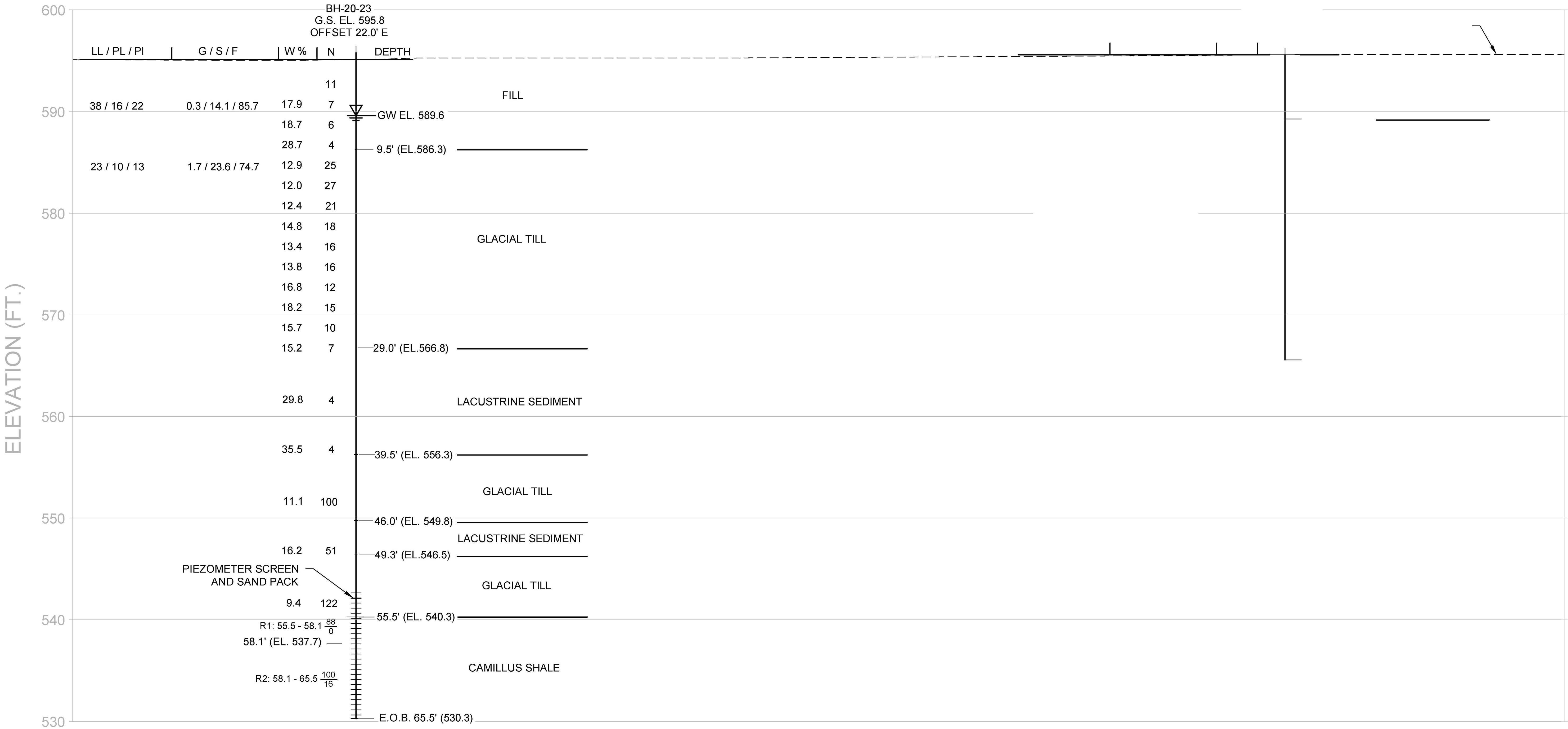
DECATUR SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013b

FIGURE 3



W %	N
	11
17.9	7
18.7	6
28.7	4
12.9	25
12.0	27
12.4	21
14.8	18
13.4	16
13.8	16
16.8	12
18.2	15
15.7	10
15.2	7
29.8	4
35.5	4
11.1	100
16.2	51
9.4	122

NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

2 EGGERT SIDE PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
GW EL. 589.6	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 55.5 - 58.1	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	88/0	RECOVERY/RQD
PI	PLASTICITY INDEX	BH-20-23	BORE HOLE DESIGNATION		

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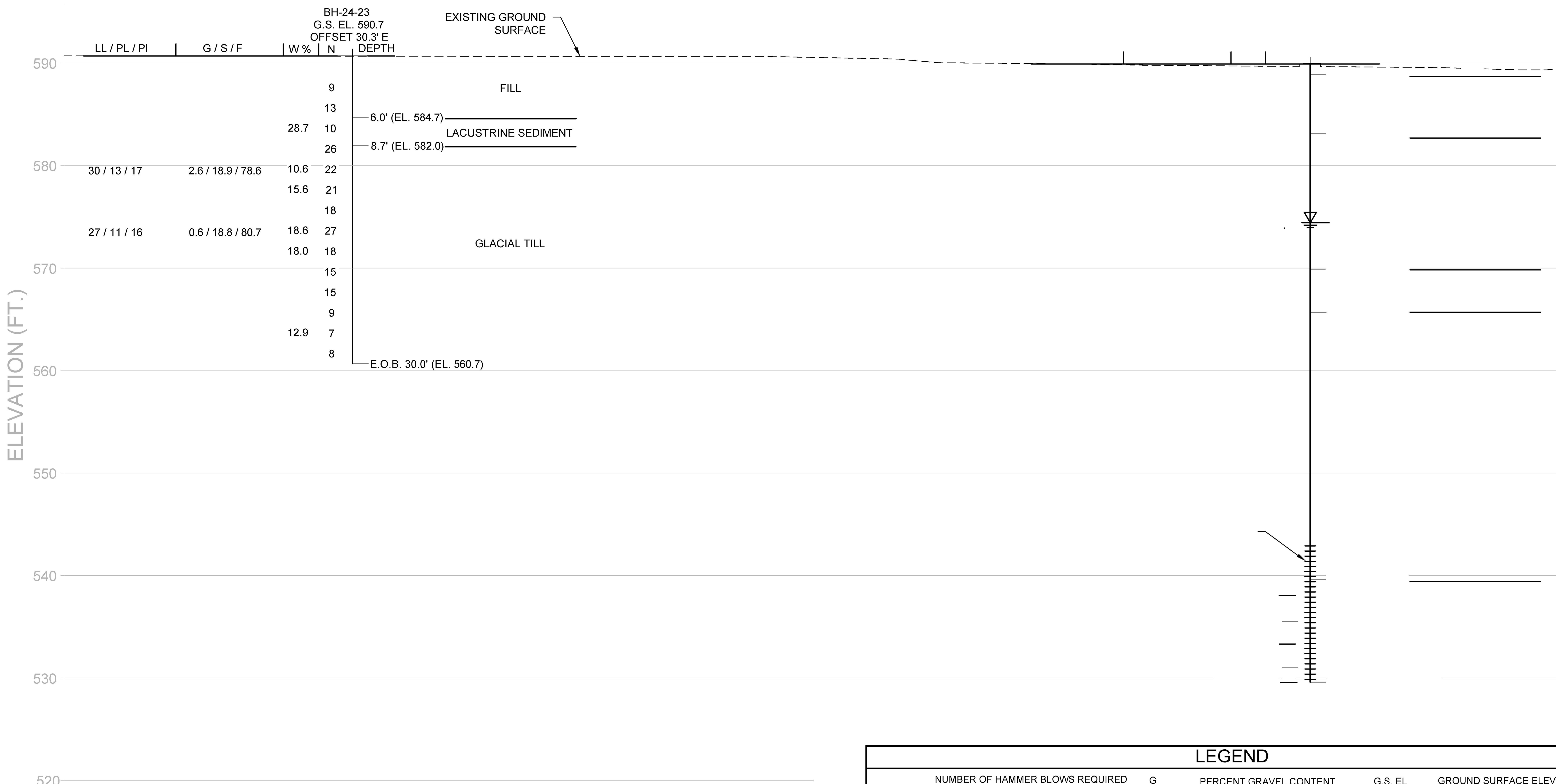
EGGERT SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013c

FIGURE 4



NOTES:
1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
GW EL. 574.5	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 50.3 - 54.4	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	93 / 83	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-24-23	BORE HOLE DESIGNATION		

3 BOULEVARD SIDE PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

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BOULEVARD SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013d

FIGURE 5

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
∇ GW EL. 574.0	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 28.9 - 32.6	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	95 / 30	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-29-22	BORE HOLE DESIGNATION		

NOTES:
1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

4 MAPLE SIDE PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

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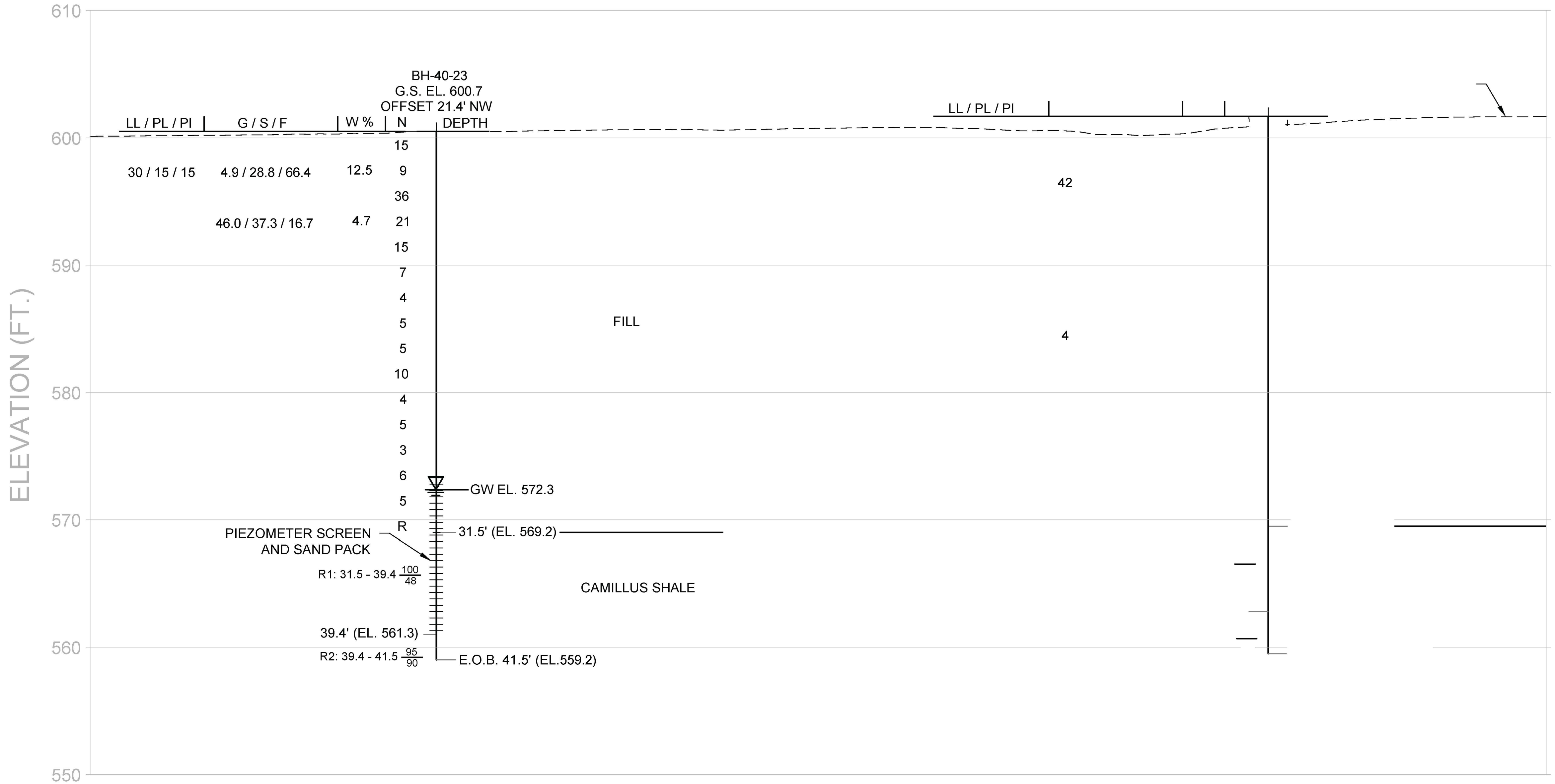
MAPLE SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013e

FIGURE 6

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
GW EL. 572.3	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 31.5 - 39.4	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	100 / 48	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-40-23	BORE HOLE DESIGNATION		



NOTES:
1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

5 SWEET HOME CENTER PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

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SWEET HOME CENTER PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013f

FIGURE 7

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT
GW EL. 568.8	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT
W%	MOISTURE CONTENT	F	PERCENT FINES CONTENT
LL	LIQUID LIMIT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
PL	PLASTIC LIMIT	BH-48-22	BORE HOLE DESIGNATION
PI	PLASTICITY INDEX	G.S. EL	GROUND SURFACE ELEVATION
		R1: 37.8 - 42.8	RUN NUMBER: RUN DEPTH
		94 / 34	RECOVERY / RQD

NOTES:
1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

6 FLINT SIDE STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'
10' 0 5' 10'
30' 0 15' 30'
HORIZONTAL SCALE: 1" = 30'

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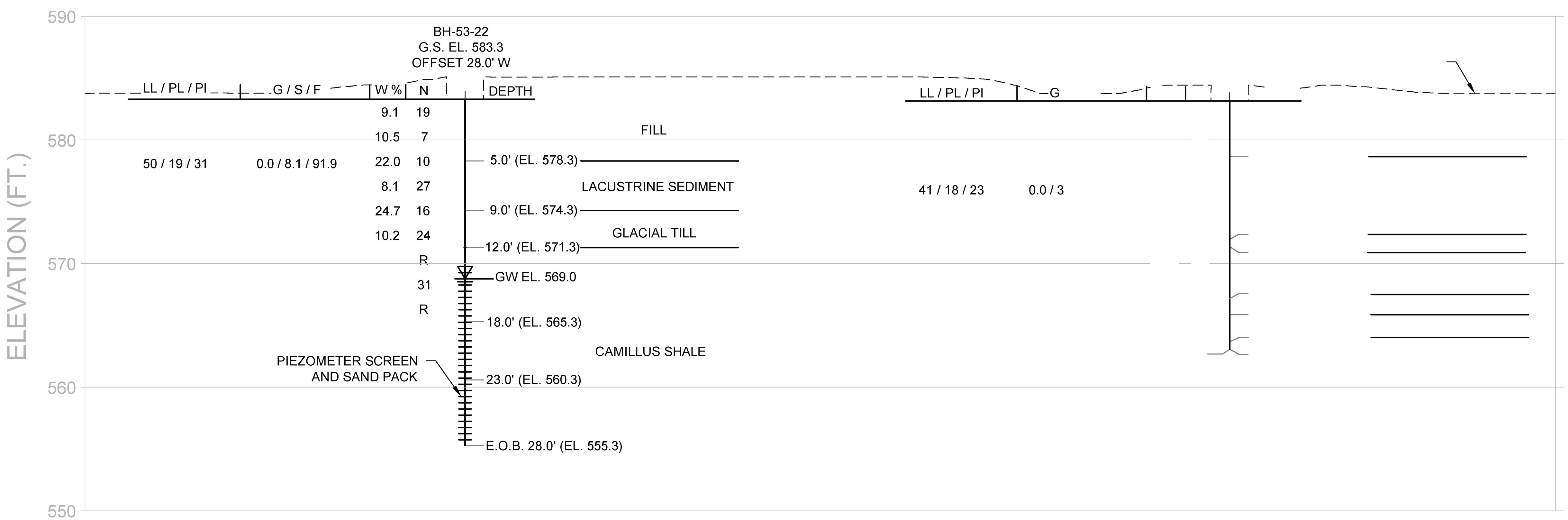
FLINT SIDE
PLATFORM STATION
SUBSURFACE SECTION

DWG. NO. 18020-013g

FIGURE 8

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT
▽ GW EL. 569.0	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT
		F	PERCENT FINES CONTENT
W%	MOISTURE CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	BH-53-22	BORE HOLE DESIGNATION
PL	PLASTIC LIMIT	G.S. EL	GROUND SURFACE ELEVATION
PI	PLASTICITY INDEX		



NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

7 LEE SIDE STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

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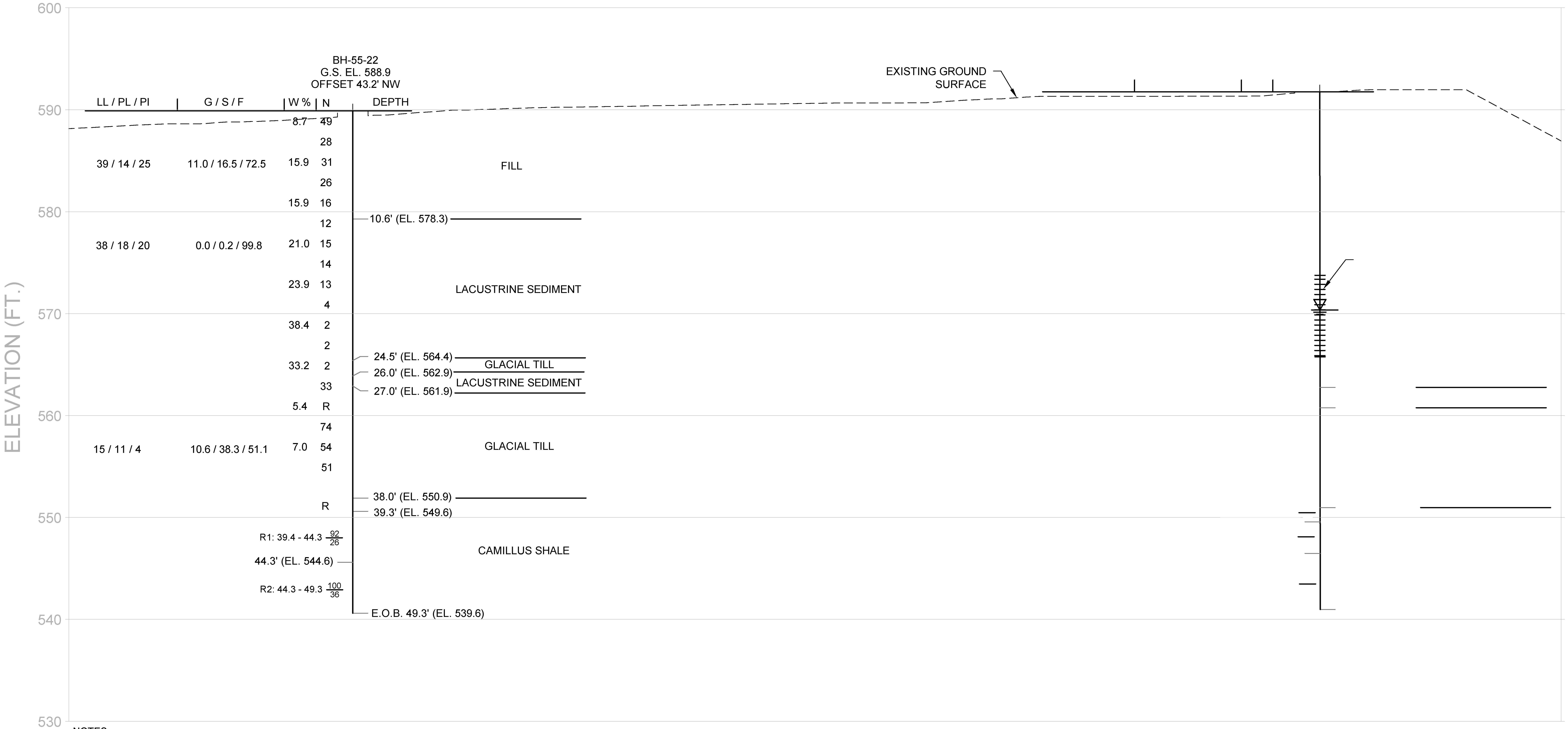
LEE SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013h

FIGURE 9



NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

8 ELLICOTT SIDE STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
GW EL. 570.3	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 39.4 - 44.3	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	92/26	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-55-22	BORE HOLE DESIGNATION		

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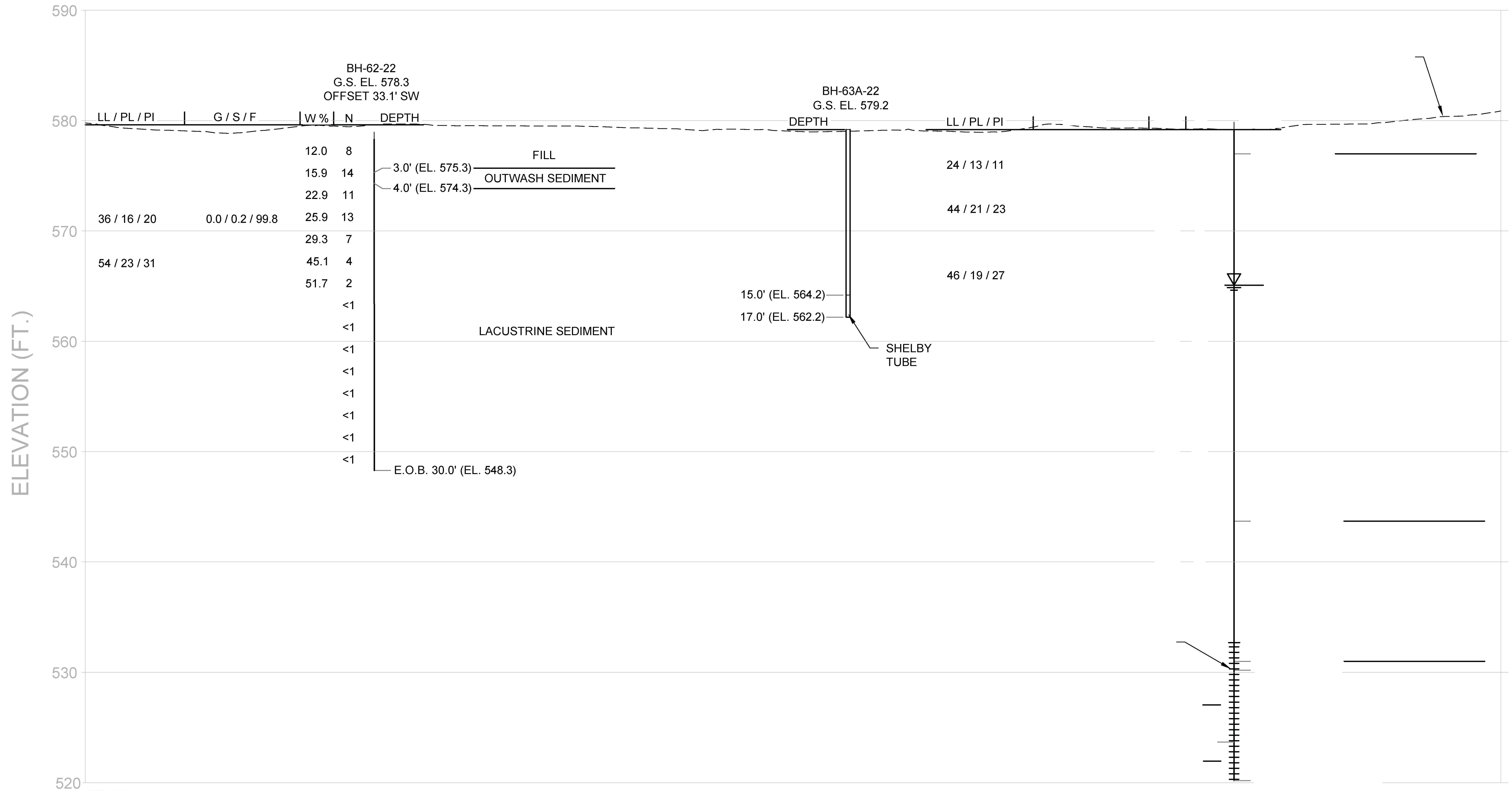
ELLICOTT SIDE PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013i

FIGURE 10



NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

9 JJ AUDUBON CENTER PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
GW EL. 565.1	WATER / GROUNDWATER ELEVATION (MEASURED IN AUGUST 2023)	S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
LL	LIQUID LIMIT	F	PERCENT FINES CONTENT	R1: 49.0 - 55.5	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT	W%	MOISTURE CONTENT	98 / 58	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-62-22	BORE HOLE DESIGNATION		

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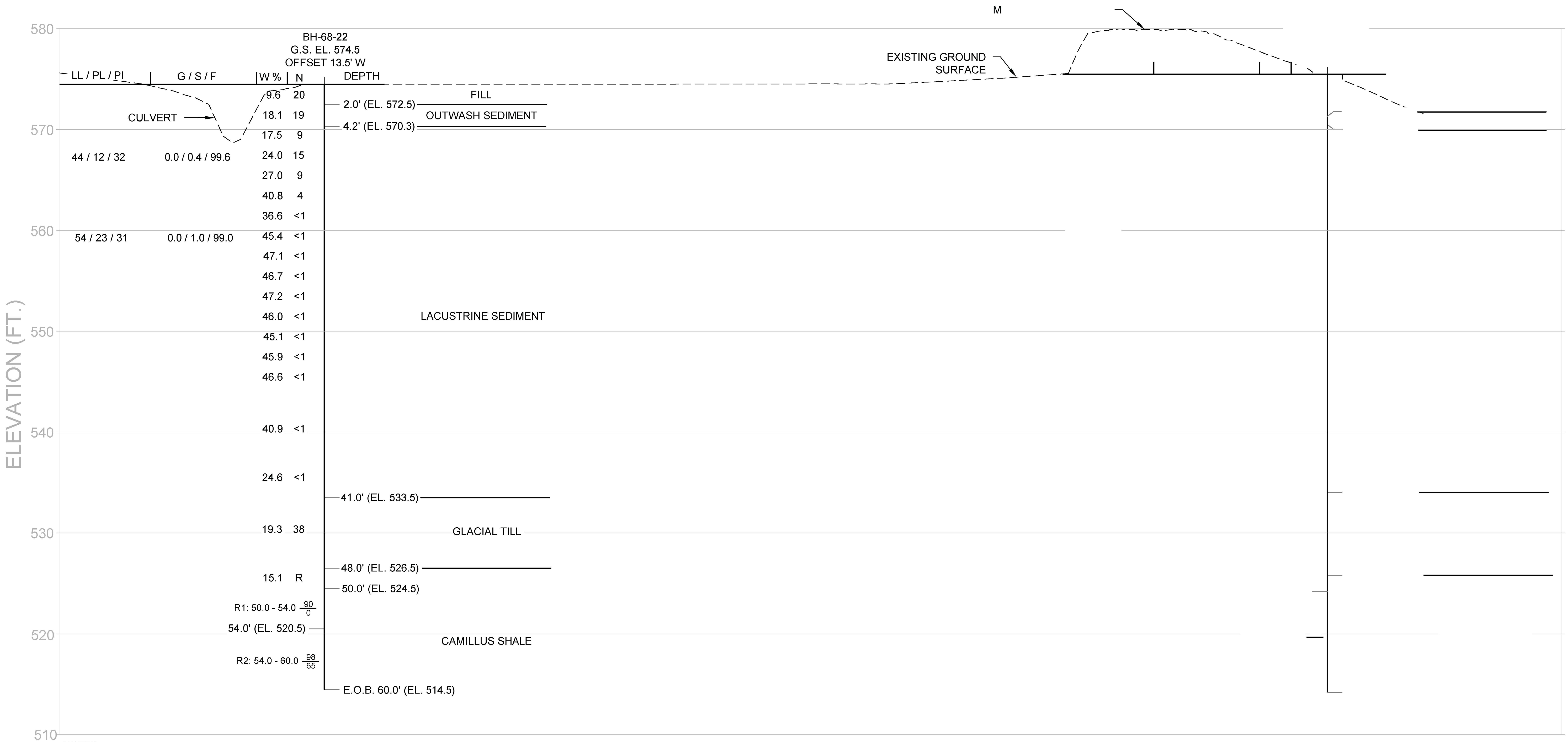
JJ AUDUBON CENTER PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013j

FIGURE 11



NOTES:

1. Platform station foundation limits will generally be located between the boring locations as estimated from base mapping provided by WSP USA, Inc.

10 I-990 PLATFORM STATION SUBSURFACE SECTION

VERTICAL SCALE: 1" = 10'

10' 0 5' 10'

30' 0 15' 30'

HORIZONTAL SCALE: 1" = 30'

LEGEND

N	NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLITSPOON SAMPLER 12 INCHES AS PER ASTM D1586.	G	PERCENT GRAVEL CONTENT	G.S. EL	GROUND SURFACE ELEVATION
		S	PERCENT SAND CONTENT	R	INDICATES SPLIT-SPOON "REFUSAL" WAS ENCOUNTERED
		F	PERCENT FINES CONTENT		
LL	LIQUID LIMIT	W%	MOISTURE CONTENT	R1: 51.3 - 61.3	RUN NUMBER: RUN DEPTH
PL	PLASTIC LIMIT			86/38	RECOVERY / RQD
PI	PLASTICITY INDEX	BH-68-22	BORE HOLE DESIGNATION		

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I-990 PLATFORM STATION SUBSURFACE SECTION

DWG. NO. 18020-013k

FIGURE 12