

**To:** David Pederson, P.E., Structures Project Manager

**From:** <sup>ASA</sup> August Arles, Geotechnical Engineer via <sup>CEE</sup> Callie Ewald, P.E., Geotechnical Engineering Manager

**Date:** June 9<sup>th</sup>, 2025

**Subject:** Mount Holly ER P23-1(334) – Geotechnical Recommendations

## 1.0 INTRODUCTION

As requested, we have completed our geotechnical assessment of the proposed foundations for the new bridge construction as part of the Mount Holly ER P23-1(334) project. This project consists of the construction of a new Bridge #11 founded on pile supported integral abutments carrying VT Route 155 over Meadow Brook in the town of Mount Holly, VT. The new bridge is located approximately 2.7 miles south of the intersection of VT Route 140 and VT Route 155. Contained herein are the results of our geotechnical analysis and design parameter recommendations as determined using the 2024 AASHTO LRFD Bridge Design Specifications (BDS).

## 2.0 FIELD INVESTIGATION

The field investigation was conducted by VTrans' drillers between October 29<sup>th</sup>, 2024, and November 18<sup>th</sup>, 2024. Four standard penetration borings were advanced to evaluate the subsurface profile for design and construction of the replacement structure. Preliminary boring locations were provided by David Pederson in a Geotechnical Request Form dated July 1<sup>st</sup>, 2024. The borings were located in the field by personnel from the Geotechnical Section using the Geotechnical Section's handheld Trimble TDC600 and Trimble DA2 GNSS GPS receiver with submeter accuracy. A summary of the final location of each boring and corresponding ground surface elevation can be found in Table 2.1 and the attached boring location plan. The values for the Northings and Easting are based on the Vermont State Plan Grid Coordinate System NAD 83. Elevations, based on the North American Vertical Datum, NAVD 88, were estimated using the design file, x23b756sv.dgn, dated May, 2024. The locations and elevations for the borings should be considered accurate only to the degree implied by the method used to determine them.

**Table 2.1** Boring Locations and Elevations

| Boring No. | Northing (ft) | Easting (ft) | Station | Offset (ft) | Approximate Ground Surface Elevation (ft) | Approximate Bedrock Elevation (ft) |
|------------|---------------|--------------|---------|-------------|-------------------------------------------|------------------------------------|
| B-101      | 333998.0      | 1547218.7    | 263+67  | 9.1 LT      | 1476.8                                    | 1412.8                             |
| B-102      | 334043.0      | 1547202.9    | 264+12  | 7.5 RT      | 1476.3                                    | -                                  |
| B-102a     | 334047.0      | 1547199.9    | 264+17  | 7.7 RT      | 1476.3                                    | -                                  |
| B-102b     | 334051.0      | 1547196.9    | 264+22  | 7.9 RT      | 1476.3                                    | 1405.3                             |

The borings were performed in general accordance with AASHTO T206, *Standard Method of Test for Penetration Test and Split-Barrel Sampling of Soils*. During boring operations for B-101, split spoon samples and standard penetration tests (SPT) were taken continuously to 20 feet (ft) below ground surface (bgs), then samples at 5 ft intervals until bedrock was encountered at a depth of 64 ft bgs. For boring B-102, samples were taken continuously to a depth of 6.9 ft where an obstruction was encountered and the hole was abandoned, a new hole, B-102a, was moved 5 ft northbound. For B-102a, samples were taken continuously from a depth of 8 ft to 20 ft bgs, then at 5 ft intervals to a depth of 52 ft where the hole was abandoned due to the inability to advance the casing. A new hole, B-102b was moved 5 ft northbound. For B-102b, the boring was advanced to bedrock with no soil samples until refusal was encountered at a depth of 71 ft bgs. When bedrock was encountered in B-101, two 5 ft runs of NX core, totaling 10 ft were advanced to confirm the presence of bedrock. When refusal was encountered in B-102b, one 5 ft NX run was advanced to confirm bedrock based on the drilling conditions and similar depth at which rock was encountered previously.

Soil samples were visually identified in the field and SPT blow counts were recorded on the boring logs when applicable. Soil samples were preserved and returned to the VTrans Construction and Materials Bureau Central Laboratory for testing and further evaluation. Upon completion of the laboratory testing, the boring logs were revised to reflect the results of the laboratory classification analysis. The attached boring logs in Appendix A detail the soil strata encountered and include the laboratory test data, SPT data, and any pertinent observations made by the Drilling Unit.

Details of the bedrock coring were recorded on the boring logs when applicable. Cores were then placed in core boxes and returned to the VTrans Construction and Materials Bureau Laboratory for further evaluation and testing, where applicable. The boring logs were revised to reflect the classification and description of the bedrock.

### **3.0 FIELD AND LABORATORY TESTINGS**

The standard penetration resistance of the in-situ soil is determined by the number of blows required to drive a 2-inch outside diameter (OD) split-barrel sampler into the soil with a 140-pound hammer dropped from a height of 30 inches, in accordance with procedures specified in AASHTO T206. The number of blows required to drive the sampler each 6-inch increment is recorded, and the Standard Penetration Resistance (N-Value) is calculated as the sum of the blows over the second and third 6-inch intervals. The SPT N-value is commonly used with established correlations to estimate several soil parameters, particularly the shear strength and density of cohesionless soils. The N-values provided on the boring logs are raw values and have not been corrected for energy, borehole diameter, rod length, or overburden pressure.

The VT Agency of Transportation has determined a hammer correction value,  $C_E$ , to account for the efficiency of the SPT hammers on its drill rigs. An Acker Renegade was used for the drilling for this project, because this is a new drill rig, a hammer energy correction factor has yet to be determined. As a result, a conservative  $C_E$  value of 1.3, based on a standard value for an automatic hammer, should be used in all soil parameter calculations.

Geotechnical laboratory tests were performed on samples to assist with soil classification and evaluate engineering properties of the soil. Grain size analyses were performed on select soil samples in accordance with AASHTO T 88, *Standard Method of Test for Particle Size Analysis of Soils*. Results from this testing can be found on the attached boring logs.

A detailed description of the rock cores is presented on the boring logs including run length, drill times, recovery, and Rock Quality Designation (RQD). Recovery is defined as the length of core obtained expressed as a percentage of the total length cored. In accordance with ASTM D6032, *Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core*, RQD is the total length of core pieces, 4 inches or greater in length, expressed as a percentage of the total length cored. RQD provides an indication of the integrity of the rock mass and relative extent of seams, jointing and bending planes. The Rock Mass Rating (RMR) is also included on the logs. RMR is AASHTO's (LRFD Bridge Design Specification) recommended method of classifying rock and is based on five different parameters that all have relative ratings which combine to form the RMR. These parameters include rock strength, RQD, joint spacing, joint condition, and groundwater (AASHTO Section 10.4.6.4).

#### **4.0 SOIL PROFILE**

The following soil strata have been identified based on our review of the boring logs and laboratory testing. It should be noted that groundwater elevations are subject to change given the fact that boreholes were generally left open for a short period of time. Because groundwater elevations can fluctuate seasonally and are affected by temperature and precipitation, groundwater may be encountered during construction when not previously noted on the boring logs.

##### **4.1 Abutment 1 (B-101)**

The ground surface elevation at B-101 was approximately 1476.8 ft, while the bottom of pile cap elevation for Abutment 1 is 1463.8 ft. Bedrock was encountered at a depth of 64 ft bgs, corresponding to an elevation of 1412.8 ft. Groundwater was not measured during drilling operations. The soil parameters used in the analysis for Abutment 1 are displayed below in Table 4.1.

**Table 4.1** FB-MultiPier Analysis Soil Parameters – Abutment 1 (B-101, B-102)

| Elevation (ft) | Description                             | Friction Angle (deg.) | Unit Weight (pcf) | Subgrade Modulus (pci) | Shear Modulus (ksi) | Nominal Skin Friction (psf) | Poisson's Ratio |
|----------------|-----------------------------------------|-----------------------|-------------------|------------------------|---------------------|-----------------------------|-----------------|
| 1463.8-1461    | Dense GRAVEL, some Sand                 | 38                    | 130               | 225                    | 3.48                | 1093.8                      | 0.40            |
| 1461-1442      | Loose SILT, some Sand                   | 29                    | 95                | 20                     | 0.11                | 749.9                       | 0.25            |
| 1442-1428      | Medium Dense SAND, some Silt            | 31                    | 110               | 60                     | 0.47                | 1152.7                      | 0.25            |
| 1428-1412      | Very Dense SILT, some Sand, little Silt | 38                    | 125               | 125                    | 1.45                | 3003.6                      | 0.35            |
| <1412          | Bedrock (GNEISS)                        | -                     | 160               | -                      | 1.45                | 3003.6                      | 0.22            |

**4.2 Abutment 2 (B-102a/B102b):**

The ground surface elevation at B-102b was approximately 1476.3 ft, while the bottom of pile cap elevation for Abutment 2 is 1463.8 ft. Bedrock was encountered at a depth of 71 ft, corresponding to an elevation of 1405.3 ft. The soil parameters used in the analysis for Abutment 2 are displayed below in Table 4.2.

**Table 4.2** FB-MultiPier Analysis Soil Parameters – Abutment 2 (B-103, B-104)

| Elevation (ft) | Description                                 | Friction Angle (deg.) | Unit Weight (pcf) | Subgrade Modulus (pci) | Shear Modulus (ksi) | Ultimate Skin Friction (psf) | Poisson's Ratio |
|----------------|---------------------------------------------|-----------------------|-------------------|------------------------|---------------------|------------------------------|-----------------|
| 1463.8-1448    | Loose SILT, some Sand                       | 30                    | 95                | 20                     | 0.11                | 764.9                        | 0.25            |
| 1448-1405      | Medium Dense SAND, some Gravel, little Silt | 29                    | 110               | 125                    | 1.39                | 1777.0                       | 0.30            |
| <1405          | Bedrock (GNEISS)                            | -                     | 160               | -                      | 1.39                | 1777.0                       | 0.22            |

**4.3 Rock Parameters**

A summary of the rock core findings can be found in Appendix 3 as well as available in the attached boring logs. Information from the cores indicated very hard GNEISS and hard AMPHIBOLITE to be present at the boring locations. The

cores were recovered and brought back to the VTrans Construction and Materials Bureau Laboratory for further evaluation and the results of this evaluation can be found in Section 4.4. The bedrock had an average rock mass rating (RMR) of 70, indicating good rock. Rock parameters used for both abutments are summarized in Table 4.3.1 and were correlated from the 2024 AASHTO LRFD BDS.

**Table 4.3.1** FB-MultiPier Analysis Rock Parameters

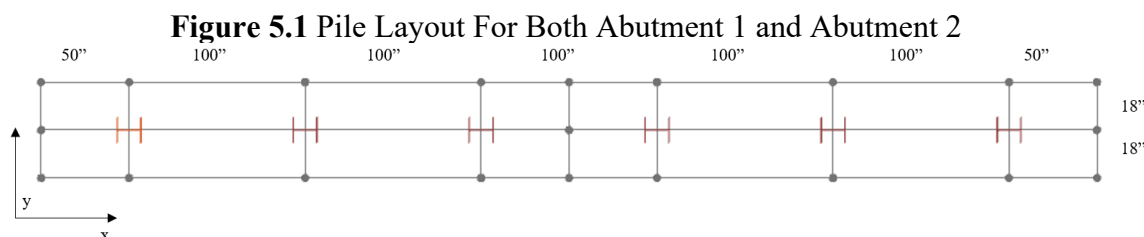
| Parameter                             | Value |
|---------------------------------------|-------|
| Unconfined Compressive Strength (ksf) | 1600  |
| Poisson's Ratio                       | 0.22  |
| Shear Modulus (ksi)                   | 3.6   |

## 5.0 ANALYSIS

Developed by the Florida Bridge Software Institute, FB-MultiPier, version 6.0.0, is a multi-aspect software that allows the user to analyze a bridge pier system in three dimensions. Its analysis factors in the subsurface strata, pile group including cap, and the structural capabilities of the pier system. For this pinned integral abutment analysis, only the piles and cap were modeled in FB-MultiPier.

### 5.1 Geometry

Final geometry for the foundations was taken from the Final Plans, dated April 22<sup>nd</sup>, 2025. Both abutments will consist of a pile cap that is 50.0 ft long, 3.0 ft wide, and a maximum of 9.0 ft tall. The bottom of the pile cap for abutment 1 and abutment 2 will be set at an elevation of 1463.81 and 1463.80 ft, respectively, and will be supported by six HP 14x117 steel piles spaced 8 ft 4 inches (in) center to center. Figure 5.1 below details the pile layout at both Abutment 1 and Abutment 2.



### 5.2 Loads

Final unfactored loads were provided by David Peterson, via an email dated January 28<sup>th</sup>, 2025. Per AASHTO Section 3.4.1, the unfactored loads were assessed at all Strength, Service, and Extreme Event limit states with the appropriate load factors as specified in AASHTO LRFD BDS Table 3.4.1-1.

### 5.3 Modeling

The models were analyzed for all Strength, Service, and Extreme Event load combinations as described in Section 5.2. A detailed layout of each pile cap and pile group geometry can be found attached to this report in Appendix 4.4. The unfactored input loads provided by David Peterson can be found in Table 5.3.1 and Table 5.3.2, as well as in Appendix 4.1 attached to this report. It should be noted that scour

conditions govern for both Strength Limit and the Service Limit. Extreme Limit State was evaluated for scour condition only, and did not govern the design.

All piles were assumed to be driven plumb and oriented for weak axis bending in a single row for each abutment. The piles were modeled as 51 ft and 58.5 ft long driven piles for both abutment 1 and abutment 2, respectively.

**Table 5.3.1** Unfactored Input Loads at Abutment 1

| Load Type                  | Load | Value          | Elevation (ft) | Direction    |
|----------------------------|------|----------------|----------------|--------------|
| Superstructure Dead        | DC   | 642.1 kips     | 1463.8         | Vertical     |
| Dead Load Wearing Surfaces | DW   | 57.6 kips      | 1463.8         | Vertical     |
| Vehicular Live             | LL   | 142.06 kips    | 1463.8         | Vertical     |
| Braking Force              | BR   | +/- 18 kips    | 1476.85        | Longitudinal |
| Wind Load                  | WL   | +/- 0.887 kips | 1476.85        | Longitudinal |
|                            |      | +/- 2.127 kips |                | Transverse   |
| Thermal Deformation        | TU   | 5/64"          | 1463.8         | Expansion    |
|                            |      | 3/16"          |                | Contraction  |

**Table 5.3.2** Unfactored Input Loads at Abutment 2

| Load Type                  | Load | Value          | Elevation (ft) | Direction    |
|----------------------------|------|----------------|----------------|--------------|
| Superstructure Dead        | DC   | 583.7 kips     | 1463.81        | Vertical     |
| Dead Load Wearing Surfaces | DW   | 56.7 kips      | 1463.81        | Vertical     |
| Vehicular Live             | LL   | 177.2 kips     | 1463.81        | Vertical     |
| Braking Force              | BR   | +/- 18 kips    | 1476.76        | Longitudinal |
| Wind Load                  | WL   | +/- 0.887 kips | 1476.76        | Longitudinal |
|                            |      | +/- 2.127 kips |                | Transverse   |
| Thermal Deformation        | TU   | 5/64"          | 1463.8         | Expansion    |
|                            |      | 3/16"          |                | Contraction  |

#### 5.4 Scour Analysis

Scour elevations at the bridge location were provided by Dave Peterson in an email dated March 30<sup>th</sup>, 2025. Design Scour and Check Scour elevations were determined to be 1462.8 ft.

## 6.0 RESULTS

### 6.1 Pile Stresses

Six HP14x117 steel piles were found to satisfy design requirements at each abutment for the Strength Limit State and to limit deflection to less than 1.0 inch in the Service Limit State. FB-MultiPier analyses were performed by applying each loading

combination, which consisted of longitudinal, transverse, and vertical loads along with their respective moments, at the top of each pile. For both abutments, Strength I was determined to be the governing cases for maximum loads and moments in Strength Limit State when evaluating for structural capacity of the piles for non-scour and scour conditions. Additionally, Service II was determined to be the governing case resulting in maximum deflections under scour conditions for both abutments, respectively. The piles were designed for 1.0 foot of freestanding length in the design scour and check scour conditions for both abutments.

The piles were checked for combined axial compression and flexure under the non-scour and scour conditions using the requirements of AASHTO LRFD 6.9.2.2, 6.9.4.1, and 6.10.8.2, as well as the moment that would cause a plastic hinge in the pile, in accordance with the VTrans 2008 Integral Abutment Bridge Design Guidelines. Maximum resultant forces from the FB MultiPier analyses and calculated values can be found below in Table 6.1.1. Resultant forces and deflection for each load combination can be found attached to the end of this report in Appendix 4.7.

**Table 6.1.1** Resultant Forces at both Abutments

| Abutment | Load Combination       | Max Applied Moment (kip-ft) | Factored Lateral Load (kips) | Max. Axial Compression (kips) |
|----------|------------------------|-----------------------------|------------------------------|-------------------------------|
| 1        | Strength I (Non-Scour) | 85.3                        | 11.5                         | 184.6                         |
|          | Strength I (Scour)     | 100.0                       | 12.0                         | 189.6                         |
| 2        | Strength I (Non-Scour) | 95.3                        | 11.7                         | 186.8                         |
|          | Strength I (Scour)     | 106.1                       | 12.8                         | 187.5                         |

## 6.2 Driving Resistances

Soil conditions were evaluated in all of the borings to determine the drivability of H-piles through the materials to reach minimum tip elevation. Past experience and information collected suggest that the HP 14x117 piles can be driven through the soils encountered at both abutments by pile-driving equipment commonly used by contractors in the region.

Section 10.7.8 of the AASHTO LRFD Bridge Design Specifications stipulates that the maximum tension and compression stresses allowed in the piles shall not exceed  $\sigma = 0.9 \cdot \phi_{da} \cdot f_y$ .  $\phi_{da}$  as defined in AASHTO LRFD 6.5.4.2 as 1.0, resulting in a maximum induced stress in the pile of  $0.9 \cdot f_y$  or 45 ksi for grade 50 (50 ksi) piles.

## 6.3 Nominal Axial Pile Resistance

Due to the depth of bedrock encountered in the boring, the piles are assumed to be seated on bedrock or in the cobbly layer just above bedrock and are assumed to reach nominal axial resistance through end bearing on rock. The nominal bearing resistance,

$R_N$ , shall be factored using the resistance factors,  $\phi_{dyn}$ , in Table 10.5.5.2.3-1 of the AASHTO LRFD Bridge Design Specifications. The factored resistance,  $R_R$ , may be taken as  $R_R = \phi_{dyn} * R_n$ . The resistance factor,  $\phi_{dyn}$ , which should be applied to those piles bearing in either soil or on rock to attain the factored resistance, is 0.65. The use of 0.65 requires a minimum of 2 dynamic tests performed during installation, with a minimum of one per abutment, in accordance with Table 10.5.5.2.3-1 of the AASHTO LRFD Bridge Design Specification. The remaining piles should be calibrated by wave equation analysis. Given the loads provided in Tables 5.3.1 and Table 5.3.2, the nominal axial pile resistance, or resistance the piles should be driven to, is 292 kips at both abutments.

Although pile lengths of 51 ft and 58.5 ft should be anticipated for estimating purposes, if the required resistance is obtained while driving before this length is achieved the minimum embedment required to meet the design requirements is 31 ft, measured from the bottom of the pile cap.

#### 6.4 Downdrag Analysis

Negative skin friction, or downdrag, is considered when the relative settlement between the pile and soil equals or exceeds 0.4 inches according to AASHTO 3.11.8. The proposed roadway does not vary significantly in grade with the existing roadway and as a result will not require large amounts of fill. Therefore, neither settlement nor downdrag due to an additional roadway surcharge is expected.

#### 6.5 Settlement Analysis

Settlement of the abutment is anticipated to be negligible due to the piles being driven to bedrock. Any settlement that does occur should be caused by the elasticity in the piles, which should occur as the piles are loaded.

### 7.0 RECOMMENDATIONS

7.1 The following table provides a summary of the requirements for the piles at Abutment 1 and 2

**Table 7.1** Summary of requirements of H-piles at each abutment

| Requirements                  | Information     |
|-------------------------------|-----------------|
| Pile Size                     | HP 14x117       |
| Number of Piles per Abutment  | 6               |
| Pile Spacing                  | 8 ft 4 in       |
| Pile Orientation              | Weak Axis       |
| Minimum Pile Embedment*       | 31 ft           |
| Estimated Pile Length         | 51 ft, Abut 1   |
| Estimated Pile Length         | 58.5 ft, Abut 2 |
| Method of Installation        | Driven pile     |
| Nominal Axial Pile Resistance | 292 kips        |

\*Length of pile below bottom of pile cap.

## 7.2 Construction Considerations:

**7.2.1 Cofferdams/Temporary Earthwork Support:** Cofferdams or temporary shoring may be necessary during construction of the abutments. If required, the Contractor should be reminded that Section 208.06 of VTrans' *2024 Standard Specifications for Construction* indicates that "The Contractor shall prepare detailed plans and a schedule of operations for each cofferdam specified in the Contract. Construction drawings shall be submitted in accordance with Subsection 105.06."

**7.2.2 Construction Dewatering:** Temporary construction dewatering may be required to construct the foundations. Temporary dewatering can likely be accomplished by open pumping from shallow sumps, temporary ditches, and trenches within and around the excavation limits. Sumps should be provided with filters suitable to prevent pumping of fine-grained soil particles. The water trapped by the temporary dewatering controls should be discharged to settling basins or an approved filter "sock" so that the fine particles suspended in the discharge have adequate time to "settle out" prior to discharge. All effluent water, or discharge, should comply with all applicable permits and regulations.

**7.2.3 Placement and Compaction of Soils:** Fills should be placed systematically in horizontal layers not more than 12 inches in thickness, prior to compaction. Cobbles larger than 8 inches should be removed from the fill prior to placement. Compaction equipment should preferably consist of large, self-propelled vibratory rollers. Where hand-guided equipment is used, such as a small vibratory plate compactor, the loose lift thickness shall not exceed 6 inches. Cobbles larger than 4 inches should be removed from the fill prior to placement.

Embankment fills should be compacted to a dry density of no less than 95% of the maximum dry density determined in accordance with AASHTO T-99, Method C. Granular Backfill for Structures, or other select materials placed within the roadway base section, shall be compacted to a dry density of 95% of the maximum dry density determined in accordance with AASHTO T-99.

## 7.3 Design Parameters

Engineering properties of common construction materials are shown in Table 7.3.1. These values should be used when designing the substructure units. It is recommended that values of  $K_0$  be used for calculating earth pressures where the structure is not allowed to deflect longitudinally, away from or into the retained soil mass. Values for  $K_a$  should be utilized for an active earth pressure condition where the structure is moving away from the soil mass and  $K_p$  where the structure is moving toward the soil mass. The design earth pressure coefficients are based on horizontal surfaces (non-sloping backfill) and a vertical wall face.

**Table 7.3.1:** Engineering Properties of Construction Materials

|                                               | <b>703.04 – Granular Borrow</b> | <b>704.08 – Granular Backfill for Structures</b> |
|-----------------------------------------------|---------------------------------|--------------------------------------------------|
| Unit Weight, $\gamma$ (lbs/ft <sup>3</sup> ): | 130                             | 140                                              |
| Internal Friction Angle, $\phi$ (degrees):    | 32                              | 34                                               |
|                                               |                                 |                                                  |
| Coefficient of Friction, $f$                  |                                 |                                                  |
| - mass concrete cast against soil:            | 0.45                            | 0.55                                             |
| - soil against precast/formed concrete:       | 0.40                            | 0.48                                             |
|                                               |                                 |                                                  |
| Active Earth Pressure Coef., $K_a$ :          | 0.31                            | 0.28                                             |
| Passive Earth Pressure Coef., $K_p$ :         | 3.26                            | 3.54                                             |
| At-Rest Earth Pressure Coefficient, $K_o$ :   | 0.47                            | 0.44                                             |

## 8.0 CONCLUSION

If any further analysis is needed or if you would like to discuss this report, please reach out to our section via email. Final FB-MultiPier input files used in the analyses are located in the folder on the M/drive.

Reviewed by: Eric Denardo, P.E., Geotechnical Engineer

END

cc: Electronic Read File/MG  
Project File/CEE  
AJA

Enclosures: Appendix 1 – Boring Layout Plan (1 Page)  
Appendix 2 – Boring Logs (2 Pages)  
Appendix 3 – Rock Core Tables  
Appendix 4 – FB MultiPier Analysis (56 Pages)  
    4.1 – Supplied Load Tables  
    4.2 – Calculated Load Tables  
    4.3 – FB MultiPier Soil and Rock Parameters  
    4.4 – FB MultiPier Pile and Cap Geometry  
    4.5 – FB MultiPier Nodal Loading Schematic  
    4.6 – FB MultiPier Output Graphs  
    4.7 – Maximum Forces and Displacement Tables  
    4.8 – Structural Resistance Calculations

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# **Appendix 1**

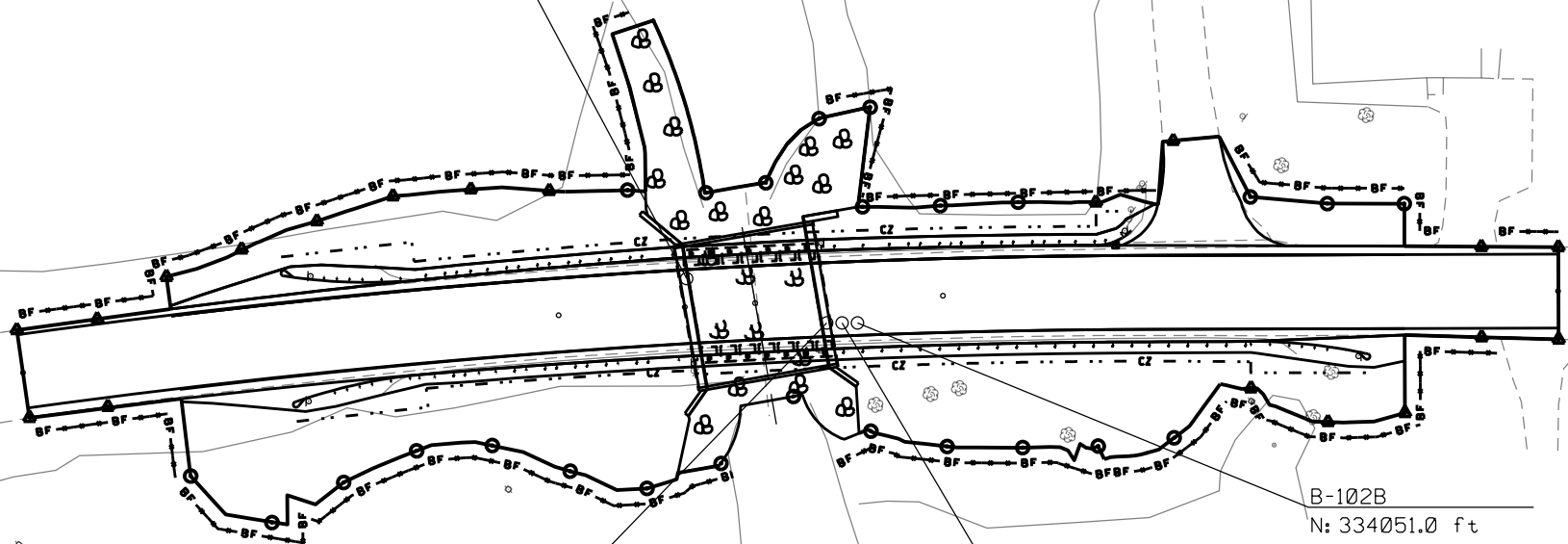
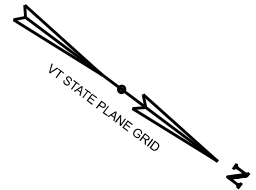
## **Boring Layout Plan**

B-101

N: 333998.0 ft

E: 1547218.7 ft

Approx Ground Elev.: 1476.8 ft



B-102

N: 334043.0 ft

E: 1547202.9 ft

Approx Ground Elev.: 1476.3 ft

B-102A

N: 334047.0 ft

E: 1547199.9 ft

Approx Ground Elev.: 1476.3 ft

B-102B

N: 334051.0 ft

E: 1547196.9 ft

Approx Ground Elev.: 1476.3 ft

SCALE 1" = 20'-0"

EXISTING BRIDGE INFORMATION  
CGMPPA, 15'-10" SPAN  
BUILT 1919  
197 SO FT WATERWAY OPENING

PROJECT NAME: MT. HOLLY  
PROJECT NUMBER: ER P23-1(334)

FILE NAME: s23b756bdr.dgn  
PROJECT LEADER: D. PETERSON  
DESIGNED BY: Z. BULLOCK  
PROPOSED LAYOUT  
PLOT DATE: \$\$\$DATE\$\$\$  
DRAWN BY: J. PAQUETTE  
CHECKED BY: D. PETERSON  
SHEET \$\$\$ OF \$\$\$

# **Appendix 2**

## **Boring Logs**



STATE OF VERMONT  
AGENCY OF TRANSPORTATION  
CONSTRUCTION AND  
MATERIALS BUREAU  
CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-101**  
Page No.: 1 of 2  
Pin No.: 23b756  
Checked By: AJA

Boring Crew: Thurston, Lubas, Arles  
Date Started: 10/29/24 Date Finished: 11/06/24  
VTSPG NAD83: N 333998.00 ft E 1547218.70 ft  
Station: 263+67.00 Offset: 9.13 LT  
Ground Elevation: 1476.8 ft

Casing: WB Sampler: SS  
Type: WB I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade  $C_E = 1.3$

Groundwater Observations

| Date | Depth (ft) | Notes |
|------|------------|-------|
|      |            |       |
|      |            |       |
|      |            |       |

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)                                                                 | Run (Dip deg.) | Core Rec. % (RQD %) | Drill Rate minutes/ft | Blows/6" (N Value) | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|-----------------------------------------------------------------------------------------------------------|----------------|---------------------|-----------------------|--------------------|--------------------|----------|--------|---------|
|            |            | Field Note, ASPHALT 0'-0.8'                                                                               |                |                     |                       |                    |                    |          |        |         |
| 5          |            | Field Description, Very Dense, Gap Graded, SAND, some Gravel, brn/gry, Dry, Rec. = 0.9 ft                 |                |                     |                       | 10-24-020-17 (44)  |                    |          |        |         |
|            |            | Field Description, Dense, Gap Graded, SAND and GRAVEL, brn/gry, MTD, Rec. = 1.7 ft                        |                |                     |                       | 19-18-23-21 (41)   |                    |          |        |         |
|            |            | Field Description, Dense, Gap Graded, GRAVEL, little Sand, gry, Wet, Rec. = 0.5 ft                        |                |                     |                       | 15-25-15-15 (40)   |                    |          |        |         |
| 10         |            | Field Note, NO RECOVERY. Gravel in end of sampler. Lost water return at 8', Rollercone Cleanout 8.2'-9.0' |                |                     |                       | 2-5-13-26 (18)     |                    |          |        |         |
|            |            | Field Note, NO RECOVERY. Gravel in end of sampler                                                         |                |                     |                       | 10-13-16-8 (29)    |                    |          |        |         |
|            |            | Field Note, Refusal @ 11.0', 10 blows no movement                                                         |                |                     |                       | R@0" (R)           |                    |          |        |         |
| 15         |            | Field Description, Sample transitioned from BROKEN ROCK to SAND, some Silt, gry, Wet, Rec. = 0.5 ft       |                |                     |                       | 31-34-27-19 (61)   |                    |          |        |         |
|            |            | Field Description, SILT, some Gravel. Sample transitioned into SILT, some Sand, green, Wet, Rec. = 2.0 ft |                |                     |                       | WOH-2-2-3 (4)      | 32.8               |          |        |         |
|            |            | Field Description, SILT, some Gravel. Sample transitioned into SILT, some Sand, green, Wet, Rec. = 2.0 ft |                |                     |                       | 2-3-3-3 (6)        |                    |          |        |         |
| 20         |            | A-4, Lab Classification: Very Loose, Poorly Graded, SILT, trace Sand, green, Wet, Rec. = 0.8 ft           |                |                     |                       | 2-2-3-2 (5)        | 31.4               |          | 2.0    | 98.0    |
| 25         |            | Field Description, Very Loose, Poorly Graded, SILT, some Fine Sand, green, Wet, Rec. = 1.5 ft             |                |                     |                       | 2-3-3-4 (6)        | 33.6               |          |        |         |
| 30         |            | Field Description, Very Loose, Poorly Graded, SILT, some Fine Sand, green, Wet, Rec. = 0.85 ft            |                |                     |                       | 1-2-2-2 (4)        | 34.3               |          |        |         |
| 35         |            | Field Description, Fine to Coarse SAND and SILT, trace Clay, green, Wet, Rec. = 1.25 ft                   |                |                     |                       | 4-7-7-8 (14)       | 19.6               |          |        |         |
| 40         |            | Field Description, Medium to Coarse SAND, gry, Wet, Rec. = 1.4 ft                                         |                |                     |                       | 4-4-5-6 (9)        | 16.6               |          |        |         |

Notes: 1. Stratification lines represent approximate boundary between material types. Transition may be gradual.  
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STATE OF VERMONT  
AGENCY OF TRANSPORTATION  
CONSTRUCTION AND  
MATERIALS BUREAU  
CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-101**

Page No.: 2 of 2

Pin No.: 23b756

Checked By: AJA

Boring Crew: Thurston, Lubas, Arles  
Date Started: 10/29/24 Date Finished: 11/06/24  
VTSPG NAD83: N 333998.00 ft E 1547218.70 ft  
Station: 263+67.00 Offset: 9.13 LT  
Ground Elevation: 1476.8 ft

Casing Type: WB Sampler: SS  
I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade C<sub>E</sub> = 1.3

Groundwater Observations

Date Depth (ft) Notes

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)                                                                                                                                                     | Run (Dip deg.) | Core Rec. % (RQD %) | Drill Rate minutes/ft | Blows/6" (N Value)       | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------|-----------------------|--------------------------|--------------------|----------|--------|---------|
| 45         |            | Field Note, Mechanical issue with casing advancer, changed methods and advanced to 48.5' due to disturbed ground                                                                              |                |                     |                       |                          |                    |          |        |         |
| 50         |            | Field Description, SILT, some Sand, trace Gravel, gry, Wet, Rec. = 1.5 ft                                                                                                                     |                |                     |                       | 19-43-31-17 (74)         |                    |          |        |         |
| 55         |            | Field Note, NO RECOVERY. Gravel in end of sampler                                                                                                                                             |                |                     |                       | 28-30-26-11 (56)         |                    |          |        |         |
| 60         |            | Field Description, SILT, some Sand, trace Gravel. Fractured ROCK within sample, gry, Wet, Rec. = 1.1 ft                                                                                       |                |                     |                       | 57-37-37-45 (74)         | 5.8                | 65.5     | 21.8   | 12.7    |
|            |            | Field Note, Casing could not advance past 60 ft. Rollercone advanced to refusal @ 62.3'                                                                                                       |                |                     |                       |                          |                    |          |        |         |
| 65         |            | 64.0 ft - 69.0 ft, Gray Biotite-Muscovite-Quartz-Plagioclase-GNEISS with Garnet. Gneissic layering / foliation, joint surfaces rough. Very hard, Slightly weathered, Good rock, NQ2, RMR = 68 | R-1 (50-70)    | 50 (35)             | 1<br>0<br>1<br>2<br>3 | Top of Bedrock @ 64.0 ft |                    |          |        |         |
| 70         |            | 69.0 ft - 73.5 ft, Gray Biotite-Muscovite-Quartz-Plagioclase-GNEISS with Garnet. Gneissic layering / foliation, joint surfaces rough. Very hard, Slightly weathered, Good rock, NQ2, RMR = 74 | R-2 (50)       | 103 (103)           | 3<br>4<br>5<br>7      |                          |                    |          |        |         |
| 75         |            | Hole stopped @ 73.5 ft                                                                                                                                                                        |                |                     |                       |                          |                    |          |        |         |
| 80         |            | Remarks:<br>WT was not measured during drilling.                                                                                                                                              |                |                     |                       |                          |                    |          |        |         |

Notes:

1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
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CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-102**  
Page No.: 1 of 1  
Pin No.: 23b756  
Checked By: AJA

Boring Crew: Thurston, Lubas, Arles  
Date Started: 11/07/24 Date Finished: 11/07/24  
VTSPG NAD83: N 334043.00 ft E 1547202.90 ft  
Station: 264+12.00 Offset: 7.53 RT  
Ground Elevation: 1476.3 ft

Casing WB Sampler SS  
Type: WB SS  
I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade C<sub>E</sub> = 1.3

Groundwater Observations

| Date | Depth (ft) | Notes |
|------|------------|-------|
|      |            |       |
|      |            |       |
|      |            |       |

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)                                                                                         | Blows/6" (N Value) | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|----------|--------|---------|
|            |            | Field Note, ASPHALT 0.0'-0.5'                                                                                                     |                    |                    |          |        |         |
|            |            | Field Description, CRUSHED STONE, gry, Dry, Rec. = 1.0 ft                                                                         | 10-9-7-8 (16)      |                    |          |        |         |
| 2.5        |            | Field Description, CRUSHED STONE, gry, Dry, Rec. = 0.8 ft                                                                         | 10-9-7-6 (16)      |                    |          |        |         |
| 5.0        |            | Field Description, CRUSHED STONE, gry, Dry, Rec. = 1.0 ft                                                                         | 8-10-2-26          |                    |          |        |         |
|            |            | Field Note, NO RECOVERY. CRUSHED STONE in end of Sampler, Refusal @ 6.9', 10 blows no movement.                                   |                    |                    |          |        |         |
| 7.5        |            | Hole stopped @ 6.9 ft                                                                                                             |                    |                    |          |        |         |
|            |            | Remarks:<br>Casing would not advance past 6.9 ft. Hole was abandoned and moved west 5 ft.<br>WT was not measured during drilling. |                    |                    |          |        |         |
| 10.0       |            |                                                                                                                                   |                    |                    |          |        |         |
| 12.5       |            |                                                                                                                                   |                    |                    |          |        |         |

Notes: 1. Stratification lines represent approximate boundary between material types. Transition may be gradual.  
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CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-102a**

Page No.: 1 of 2

Pin No.: 23b756

Checked By: AJA

Boring Crew: Thurston, Lubas, Arles  
Date Started: 11/08/24 Date Finished: 11/18/24  
VTSPG NAD83: N 334047.00 ft E 1547199.90 ft  
Station: 264+17.00 Offset: 7.7 RT  
Ground Elevation: 1476.3 ft

Casing: WB Sampler: SS  
Type: WB I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade C<sub>E</sub> = 1.3

Groundwater Observations

| Date | Depth (ft) | Notes |
|------|------------|-------|
|      |            |       |
|      |            |       |
|      |            |       |

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)                                                                                  | Blows/6" (N Value) | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|----------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|----------|--------|---------|
| 5          |            | Field Note, ASPHALT 0.0'-0.4'                                                                                              |                    |                    |          |        |         |
|            |            | Field Note, Spun Casing to 8.0' without sampling                                                                           |                    |                    |          |        |         |
| 10         |            | Field Description, Very Loose GRAVEL, some Sand, Gravel in end of sampler, brn, Wet, Rec. = 0.4 ft                         | 5-2-3-4 (5)        |                    |          |        |         |
|            |            | Field Description, Dense GRAVEL, some Sand. Rollercone cleanout 11.0'-12.0', brn, MTW, Rec. = 0.2 ft                       | 6-10-27-52 (37)    |                    |          |        |         |
| 15         |            | Field Description, Loose SAND and SILT, Lt brn, Wet, Rec. = 0.7 ft                                                         | 15-6-1-1 (7)       | 27.7               |          |        |         |
|            |            | Field Description, Very Loose, Fine SAND and SILT, Lt brn, Wet, Rec. = 0.8 ft                                              | 1-1-1-1 (2)        | 27.1               |          |        |         |
|            |            | Field Description, Very Loose, Poorly Graded, SILT, some Fine Sand, Lt brn, Wet, Rec. = 2.0 ft                             | 2-2-2-2 (4)        |                    |          |        |         |
| 20         |            | Field Description, NO RECOVERY                                                                                             | 2-2-3-4 (5)        |                    |          |        |         |
| 25         |            | Field Description, Very Loose, Poorly Graded, SILT, some Fine Sand, Lt/brn-gry, Wet, Rec. = 1.5 ft                         | 2-3-2-3 (5)        | 28.9               |          |        |         |
|            |            | Field Description, Very Loose, Poorly Graded, SILT and FINE SAND, gry, Wet, Rec. = 1.6 ft, Rollercone Cleanout 32.0'-33.0' | 2-1-2-3 (3)        | 29.4               |          |        |         |

Notes: 1. Stratification lines represent approximate boundary between material types. Transition may be gradual.  
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STATE OF VERMONT  
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CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-102a**

Page No.: 2 of 2

Pin No.: 23b756

Checked By: AJA

Boring Crew: Thurston, Lubas, Arles  
Date Started: 11/08/24 Date Finished: 11/18/24  
VTSPG NAD83: N 334047.00 ft E 1547199.90 ft  
Station: 264+17.00 Offset: 7.7 RT  
Ground Elevation: 1476.3 ft

Casing      Sampler  
Type: WB      SS  
I.D.: 4 in      1.5 in  
Hammer Wt: N.A.      140 lb.  
Hammer Fall: N.A.      30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade      C<sub>E</sub> = 1.3

Groundwater Observations

| Date | Depth (ft) | Notes |
|------|------------|-------|
|      |            |       |
|      |            |       |
|      |            |       |

| Depth (ft) | Strata (1)                                                                          | CLASSIFICATION OF MATERIALS (Description)                                                                                                                               | Blows/6" (N Value) | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|----------|--------|---------|
| 35         |    | Field Note, NO RECOVERY                                                                                                                                                 | 12-6-5-3 (11)      | 13.2               |          |        |         |
| 40         |   | A-2-4, Lab Classification: SAND, little Gravel, trace Silt, gray, Wet, Rec. = 0.6 ft, Casing refusal @ 40.2', Cored through apparent boulder                            | 11-13-15-11 (28)   |                    |          |        |         |
| 50         |  | Field Description, SILT, some Sand, trace Gravel, gry, Wet, Rec. = 0.65 ft                                                                                              | 2-2-18-18 (20)     |                    |          |        |         |
| 55         |                                                                                     | Hole stopped @ 52.0 ft<br><br>Remarks:<br>Casing would not advance past 50 ft. Casing was pulled, and hole was moved 4 ft west.<br>WT was not measured during drilling. |                    |                    |          |        |         |

Notes:

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STATE OF VERMONT  
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CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-102b**  
Page No.: 1 of 2  
Pin No.: 23b756  
Checked By: AJA

Boring Crew: Thurston, Lubas, Denardo  
Date Started: 11/18/24 Date Finished: 11/18/24  
VTSPG NAD83: N 334051.00 ft E 1547196.90 ft  
Station: 264+22.00 Offset: 7.9 RT  
Ground Elevation: 1476.3 ft

Casing WB Sampler SS  
Type: WB SS  
I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade C<sub>E</sub> = 1.3

Groundwater Observations

| Date | Depth (ft) | Notes |
|------|------------|-------|
|      |            |       |
|      |            |       |
|      |            |       |

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)               | Run (Dip deg.) | Core Rec. % (RQD %) | Drill Rate minutes/ft | Blows/6" (N Value) | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|---------------------------------------------------------|----------------|---------------------|-----------------------|--------------------|--------------------|----------|--------|---------|
| 5          |            | Field Note, ASPHALT 0.0'-0.5'                           |                |                     |                       |                    |                    |          |        |         |
| 10         |            | Field Note, Advanced casing to bedrock without sampling |                |                     |                       |                    |                    |          |        |         |
| 15         |            |                                                         |                |                     |                       |                    |                    |          |        |         |
| 20         |            |                                                         |                |                     |                       |                    |                    |          |        |         |
| 25         |            |                                                         |                |                     |                       |                    |                    |          |        |         |
| 30         |            |                                                         |                |                     |                       |                    |                    |          |        |         |
| 35         |            |                                                         |                |                     |                       |                    |                    |          |        |         |

Notes:

1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
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CENTRAL LABORATORY

BORING LOG

Mount Holly  
ER P23-1(334)  
VT Route 155

Boring No.: **B-102b**

Page No.: 2 of 2

Pin No.: 23b756

Checked By: AJA

Boring Crew: Thurston, Lubas, Denardo  
Date Started: 11/18/24 Date Finished: 11/18/24  
VTSPG NAD83: N 334051.00 ft E 1547196.90 ft  
Station: 264+22.00 Offset: 7.9 RT  
Ground Elevation: 1476.3 ft

Casing WB Sampler SS  
Type: WB I.D.: 4 in 1.5 in  
Hammer Wt: N.A. 140 lb.  
Hammer Fall: N.A. 30 in.  
Hammer/Rod Type: Auto/AWJ  
Rig: Acker Renegade C<sub>E</sub> = 1.3

Groundwater Observations

Date Depth (ft) Notes

| Depth (ft) | Strata (1) | CLASSIFICATION OF MATERIALS (Description)                                                                                                                                                                                                                 | Run (Dip deg.) | Core Rec. % (RQD %) | Drill Rate minutes/ft | Blows/6" (N Value)       | Moisture Content % | Gravel % | Sand % | Fines % |
|------------|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------|-----------------------|--------------------------|--------------------|----------|--------|---------|
| 45         |            |                                                                                                                                                                                                                                                           |                |                     |                       |                          |                    |          |        |         |
| 50         |            |                                                                                                                                                                                                                                                           |                |                     |                       |                          |                    |          |        |         |
| 55         |            |                                                                                                                                                                                                                                                           |                |                     |                       |                          |                    |          |        |         |
| 60         |            |                                                                                                                                                                                                                                                           |                |                     |                       |                          |                    |          |        |         |
| 65         |            | Field Note, Cored through nested cobbles and boulders to 71 ft                                                                                                                                                                                            |                |                     |                       |                          |                    |          |        |         |
| 70         |            |                                                                                                                                                                                                                                                           |                |                     |                       |                          |                    |          |        |         |
| 75         |            | 71.0 ft - 76.0 ft, Dark-grayish-green, Quartz-Chlorite-Plagioclase-Hornblende--AMPHIBOLITE. Foliated, joint surfaces rough. Stains / alteration from 71 ft to 72 ft and again from 75 ft to 75.9 ft.. Hard, Slightly weathered, Good rock, BVDC, RMR = 69 | R-1 (50-70)    | 98 (81)             | 4<br>4<br>4<br>3<br>3 | Top of Bedrock @ 71.0 ft |                    |          |        |         |
|            |            | Hole stopped @ 76.0 ft                                                                                                                                                                                                                                    |                |                     |                       |                          |                    |          |        |         |
|            |            | Remarks:<br>WT was not measured during drilling.                                                                                                                                                                                                          |                |                     |                       |                          |                    |          |        |         |

Notes:

1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
2. N Values have not been corrected for hammer energy. C<sub>E</sub> is the hammer energy correction factor.
3. Water level readings have been made at times and under conditions stated. Fluctuations may occur due to other factors than those present at the time measurements were made.

# **Appendix 3**

## **Rock Core Tables**

**Table A3.1:** Rock Core Sample Results

| Run Number | Core Size | Depth (ft) | Recovery (%) | RQD (%) | Dip (deg) | Lithologic Description                                                                                                                                                                                         | RMR |
|------------|-----------|------------|--------------|---------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| B-101      | NQ2       | 64 – 69    | 50           | 35      | 50 – 70   | Gray Biotite-Muscovite-Quartz-Plagioclase-GNEISS with Garnet. Gneissic layering / foliation, joint surfaces rough. Very hard and slightly weathered. Good Rock                                                 | 68  |
| B-101      | NQ2       | 69 – 73.5  | 103          | 103     | 50        | Gray Biotite-Muscovite-Quartz-Plagioclase-GNEISS with Garnet. Gneissic layering / foliation, joint surfaces rough. Very hard and slightly weathered. Good Rock                                                 | 74  |
| B-102b     | BV        | 71 – 76    | 98           | 81      | 50 – 70   | Dark-grayish-green, Quartz-Chlorite-Plagioclase-Hornblende--AMPHIBOLITE. Foliated, joint surfaces rough. Hard and slightly weathered, stains / alteration from 71 ft to 72 ft and again from 75 ft to 75.9 ft. | 69  |

# **Appendix 4**

## **FB MultiPier Analysis**

| Abutment 1 Loads, in Kips |              |           |            |           |           |
|---------------------------|--------------|-----------|------------|-----------|-----------|
| Load Type                 | Longitudinal |           | Transverse |           | Vertical  |
|                           | Magnitude    | Elevation | Magnitude  | Elevation | Magnitude |
| DC                        | ---          | ---       | ---        | ---       | 642.1     |
| DW                        | ---          | ---       | ---        | ---       | 57.6      |
| LL                        | ---          | ---       | ---        | ---       | 142.06    |
| CE                        | ---          | ---       | ---        | ---       | ---       |
| BR                        | +/-36        | 1476.85   | ---        | ---       | ---       |
| WS                        | ---          | ---       | ---        | ---       | ---       |
| WL                        | +/-0.887     | 1476.85   | +/-2.127   | ---       | ---       |

| Abutment 2 Loads, in Kips |              |           |            |           |           |
|---------------------------|--------------|-----------|------------|-----------|-----------|
| Load Type                 | Longitudinal |           | Transverse |           | Vertical  |
|                           | Magnitude    | Elevation | Magnitude  | Elevation | Magnitude |
| DC                        | ---          | ---       | ---        | ---       | 583.7     |
| DW                        | ---          | ---       | ---        | ---       | 56.7      |
| LL                        | ---          | ---       | ---        | ---       | +177.2    |
| CE                        | ---          | ---       | ---        | ---       | ---       |
| BR                        | +/-36        | 1476.76   | ---        | ---       | ---       |
| WS                        | ---          | ---       | ---        | ---       | ---       |
| WL                        | +/-0.887     | 1476.76   | +/-2.217   | ---       | ---       |

| Sign Convention for Loads |                                          |
|---------------------------|------------------------------------------|
| Longitudinal              | Positive is upstation                    |
| Transverse                | Positive is right when looking upstation |
| Vertical                  | Positive is downward                     |

| Thermal Deformations at Each Abutment |       |
|---------------------------------------|-------|
| Expansion                             | 5/64" |
| Contraction                           | 3/16" |

\*Reported temperature deformations are maximums that could occur in each direction, but do not occur under the same case. The maximum expansion would occur if the abutment closure pours occur at 32°F. The maximum contraction would occur if the abutment closure pour occurred at 90°F.

| Freestanding Heights in Scour Condition |                    |                          |                          |
|-----------------------------------------|--------------------|--------------------------|--------------------------|
| Abutment #                              | Bottom of Abutment | Scour Elevation          | Freestanding Height (ft) |
| 1                                       | 1463.81            | pending final hydraulics | #VALUE!                  |
| 2                                       | 1463.80            | pending final hydraulics | #VALUE!                  |

**Table A4.2.1** Abutment 1 Input Loads

| Abut No. 1 | Fy(kip) | Fx (kip) | Fz (kip) | Mx(k-ft) | My(k-ft) | Per Pile   | Fx (kip) | Fy(kip) | Fz (kip) | Mx(k-ft) | My(k-ft) |
|------------|---------|----------|----------|----------|----------|------------|----------|---------|----------|----------|----------|
| Load Combo |         |          |          |          |          | Load Combo |          |         |          |          |          |
| STR I      | 0.0     | 31.7     | 1137.6   | 410.8    | 0.0      | STR I      | 0.0      | 5.3     | 189.6    | 68.5     | 0.0      |
| STR II     | 0.0     | 24.5     | 1080.8   | 410.8    | 0.0      | STR II     | 0.0      | 4.1     | 180.1    | 68.5     | 0.0      |
| STR III    | 0.0     | 0.2      | 889.0    | 0.0      | 0.0      | STR III    | 0.0      | 0.0     | 148.2    | 0.0      | 0.0      |
| STR IV     | 0.0     | 0.2      | 1049.6   | 0.0      | 0.0      | STR IV     | 0.0      | 0.0     | 174.9    | 0.0      | 0.0      |
| STR V      | 2.2     | 25.4     | 1080.8   | 328.4    | 28.9     | STR V      | 0.4      | 4.2     | 180.1    | 54.7     | 4.8      |
| SER I      | 2.2     | 19.1     | 841.8    | 246.3    | 28.9     | SER I      | 0.4      | 3.2     | 140.3    | 41.0     | 4.8      |
| SER II     | 0.0     | 23.6     | 884.4    | 305.1    | 0.0      | SER II     | 0.0      | 3.9     | 147.4    | 50.9     | 0.0      |
| SER III    | 0.0     | 18.2     | 841.8    | 234.7    | 0.0      | SER III    | 0.0      | 3.0     | 140.3    | 39.1     | 0.0      |
| SER IV     | 0.0     | 0.2      | 841.8    | 0.0      | 0.0      | SER IV     | 0.0      | 0.0     | 140.3    | 0.0      | 0.0      |

**Table A4.2.2** Abutment 2 Input Loads

| Abut No. 2 | Fy(kip) | Fx (kip) | Fz (kip) | Mx(k-ft) | My(k-ft) | Per Pile   | Fx (kip) | Fy(kip) | Fz (kip) | Mx(k-ft) | My(k-ft) |
|------------|---------|----------|----------|----------|----------|------------|----------|---------|----------|----------|----------|
| Load Combo |         |          |          |          |          | Load Combo |          |         |          |          |          |
| STR I      | 0.0     | 31.5     | 1124.8   | 408.2    | 0.0      | STR I      | 0.0      | 5.3     | 187.5    | 68.0     | 0.0      |
| STR II     | 0.0     | 24.3     | 1053.9   | 408.2    | 0.0      | STR II     | 0.0      | 4.1     | 175.6    | 68.0     | 0.0      |
| STR III    | 0.0     | 0.0      | 814.7    | 0.0      | 0.0      | STR III    | 0.0      | 0.0     | 135.8    | 0.0      | 0.0      |
| STR IV     | 0.0     | 0.0      | 960.6    | 0.0      | 0.0      | STR IV     | 0.0      | 0.0     | 160.1    | 0.0      | 0.0      |
| STR V      | 2.2     | 25.2     | 1053.9   | 326.4    | 28.7     | STR V      | 0.4      | 4.2     | 175.6    | 54.4     | 4.8      |
| SER I      | 2.2     | 18.9     | 817.6    | 244.8    | 28.7     | SER I      | 0.4      | 3.1     | 136.3    | 40.8     | 4.8      |
| SER II     | 0.0     | 23.4     | 870.8    | 303.3    | 0.0      | SER II     | 0.0      | 3.9     | 145.1    | 50.5     | 0.0      |
| SER III    | 0.0     | 18.0     | 817.6    | 233.3    | 0.0      | SER III    | 0.0      | 3.0     | 136.3    | 38.9     | 0.0      |
| SER IV     | 0.0     | 0.0      | 817.6    | 0.0      | 0.0      | SER IV     | 0.0      | 0.0     | 136.3    | 0.0      | 0.0      |

**Table A4.3.1** Abutment 1 General Soil Data

| Soil Set | Soil Layer | Soil Type    | Top Layer Elevation (ft) | Bottom Layer Elevation (ft) | Lateral Model     | Axial Model         | Torsional Model | Tip Model           | Unit Weight (pcf) |
|----------|------------|--------------|--------------------------|-----------------------------|-------------------|---------------------|-----------------|---------------------|-------------------|
| 1        | 1          | Cohesionless | 1463.8                   | 1461.8                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 130.0             |
| 1        | 2          | Cohesionless | 1461.8                   | 1442.8                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 95.0              |
| 1        | 3          | Cohesionless | 1442.8                   | 1428.3                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 110.0             |
| 1        | 4          | Cohesionless | 1428.3                   | 1412.8                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 125.0             |
| 1        | 5          | Rock         | 1412.8                   | 1390.0                      | Limestone (McVay) | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 160.0             |

**Table A4.3.2** Abutment 1 Lateral Soil Data

| Soil Set | Soil Layer | Lateral Model     | Internal Friction Angle (deg) | Subgrade Modulus (lb/in <sup>3</sup> ) | Unconfined Compressive Strength (ksf) |
|----------|------------|-------------------|-------------------------------|----------------------------------------|---------------------------------------|
| 1        | 1          | Sand (Reese)      | 38                            | 225                                    |                                       |
| 1        | 2          | Sand (Reese)      | 29                            | 20                                     |                                       |
| 1        | 3          | Sand (Reese)      | 31                            | 60                                     |                                       |
| 1        | 4          | Sand (Reese)      | 38                            | 125                                    |                                       |
| 1        | 5          | Limestone (McVay) |                               |                                        | 1600.0                                |

**Table A4.3.3** Abutment 1 Axial Soil Data

| Soil Set | Layer | Axial Model         | Shear Modulus (ksi) | Poisson's Ratio | Nominal Unit Skin Friction (psf) |
|----------|-------|---------------------|---------------------|-----------------|----------------------------------|
| 1        | 1     | Driven Pile (McVay) | 3.48                | 0.40            | 1093.75                          |
| 1        | 2     | Driven Pile (McVay) | 0.11                | 0.25            | 749.90                           |
| 1        | 3     | Driven Pile (McVay) | 0.47                | 0.25            | 1152.72                          |
| 1        | 4     | Driven Pile (McVay) | 1.45                | 0.35            | 3003.59                          |
| 1        | 5     | Driven Pile (McVay) | 1.45                | 0.22            | 3003.59                          |

**Table A4.3.4** Abutment 1 Torsional Soil Data

| Soil Set | Soil Layer | Torsional Model | Shear Modulus (ksi) | Torsional Shear Stress (psf) |
|----------|------------|-----------------|---------------------|------------------------------|
| 1        | 1          | Hyperbolic      | 3.48                | 1093.75                      |
| 1        | 2          | Hyperbolic      | 0.11                | 749.90                       |
| 1        | 3          | Hyperbolic      | 0.47                | 1152.72                      |
| 1        | 4          | Hyperbolic      | 1.45                | 3003.59                      |
| 1        | 5          | Hyperbolic      | 1.45                | 3003.59                      |

**Table A4.3.5** Abutment 1 Tip Rock Data

| Soil Set | Tip Model           | Shear Modulus (ksi) | Poisson's Ratio | Nominal Tip Resistance (ksf) |
|----------|---------------------|---------------------|-----------------|------------------------------|
| 1        | Driven Pile (McVay) | 3.92                | 0.22            | 1600.00                      |

**Table A4.3.6** Abutment 2 General Soil Data

| Soil Set | Soil Layer | Soil Type    | Top Layer Elevation (ft) | Bottom Layer Elevation (ft) | Lateral Model     | Axial Model         | Torsional Model | Tip Model           | Unit Weight (pcf) |
|----------|------------|--------------|--------------------------|-----------------------------|-------------------|---------------------|-----------------|---------------------|-------------------|
| 1        | 1          | Cohesionless | 1463.8                   | 1448.3                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 95                |
| 1        | 2          | Cohesionless | 1448.3                   | 1405.3                      | Sand (Reese)      | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 110               |
| 1        | 3          | Rock         | 1405.3                   | 1390.0                      | Limestone (McVay) | Driven Pile (McVay) | Hyperbolic      | Driven Pile (McVay) | 160               |

**Table A4.3.7** Abutment 2 Lateral Soil Data

| Soil Set | Soil Layer | Lateral Model     | Internal Friction Angle (deg) | Subgrade Modulus (lb/in^3) | Unconfined Compressive Strength (ksf) |
|----------|------------|-------------------|-------------------------------|----------------------------|---------------------------------------|
| 1        | 1          | Sand (Reese)      | 30                            | 20                         |                                       |
| 1        | 2          | Sand (Reese)      | 29                            | 125                        |                                       |
| 1        | 3          | Limestone (McVay) |                               |                            | 1600.00                               |

**Table A4.3.8** Abutment 2 Axial Soil Data

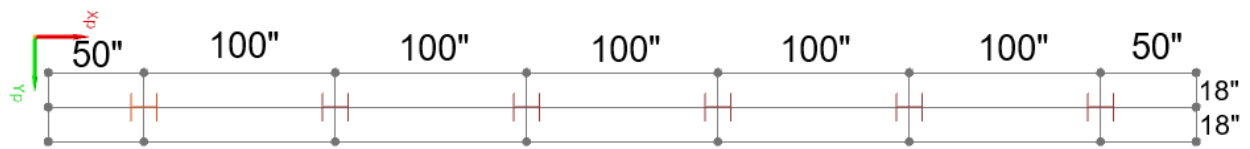
| Soil Set | Soil Layer | Axial Model         | Shear Modulus (ksi) | Poisson's Ratio | Nominal Unit Skin Friction (psf) |
|----------|------------|---------------------|---------------------|-----------------|----------------------------------|
| 1        | 1          | Driven Pile (McVay) | 0.11                | 0.25            | 764.89                           |
| 1        | 2          | Driven Pile (McVay) | 1.39                | 0.30            | 1777.00                          |
| 1        | 3          | Driven Pile (McVay) | 1.39                | 0.22            | 1777.00                          |

**Table A4.3.9** Abutment 2 Torsional Soil Data

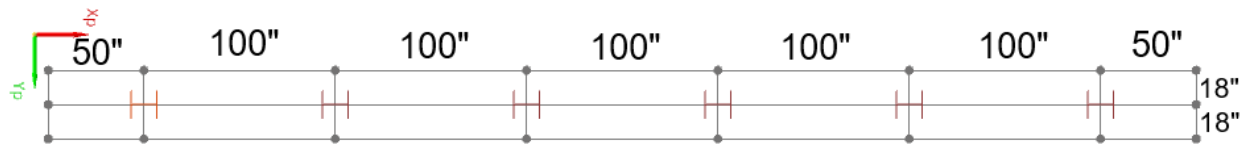
| Soil Set | Soil Layer | Torsional Model | Shear Modulus (ksi) | Torsional Shear Stress (psf) |
|----------|------------|-----------------|---------------------|------------------------------|
| 1        | 1          | Hyperbolic      | 0.11                | 764.89                       |
| 1        | 2          | Hyperbolic      | 1.39                | 1777.00                      |
| 1        | 3          | Hyperbolic      | 1.39                | 1777.00                      |

**Table A4.3.10** Abutment 2 Tip Rock Data

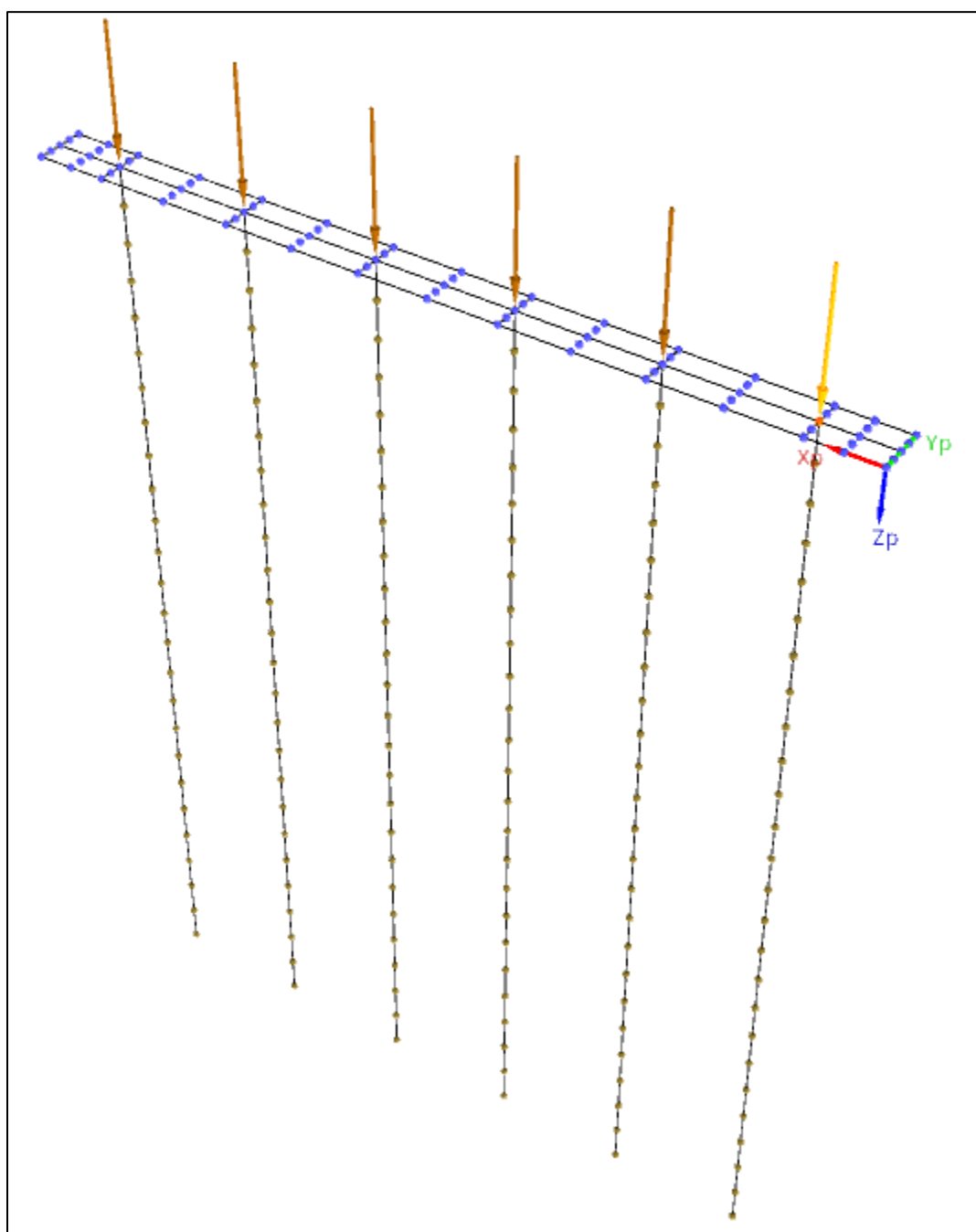
| Soil Set | Tip Model           | Shear Modulus (ksi) | Poisson's Ratio | Nominal Tip Resistance (ksf) |
|----------|---------------------|---------------------|-----------------|------------------------------|
| 1        | Driven Pile (McVay) | 3.92                | 0.22            | 1600.00                      |



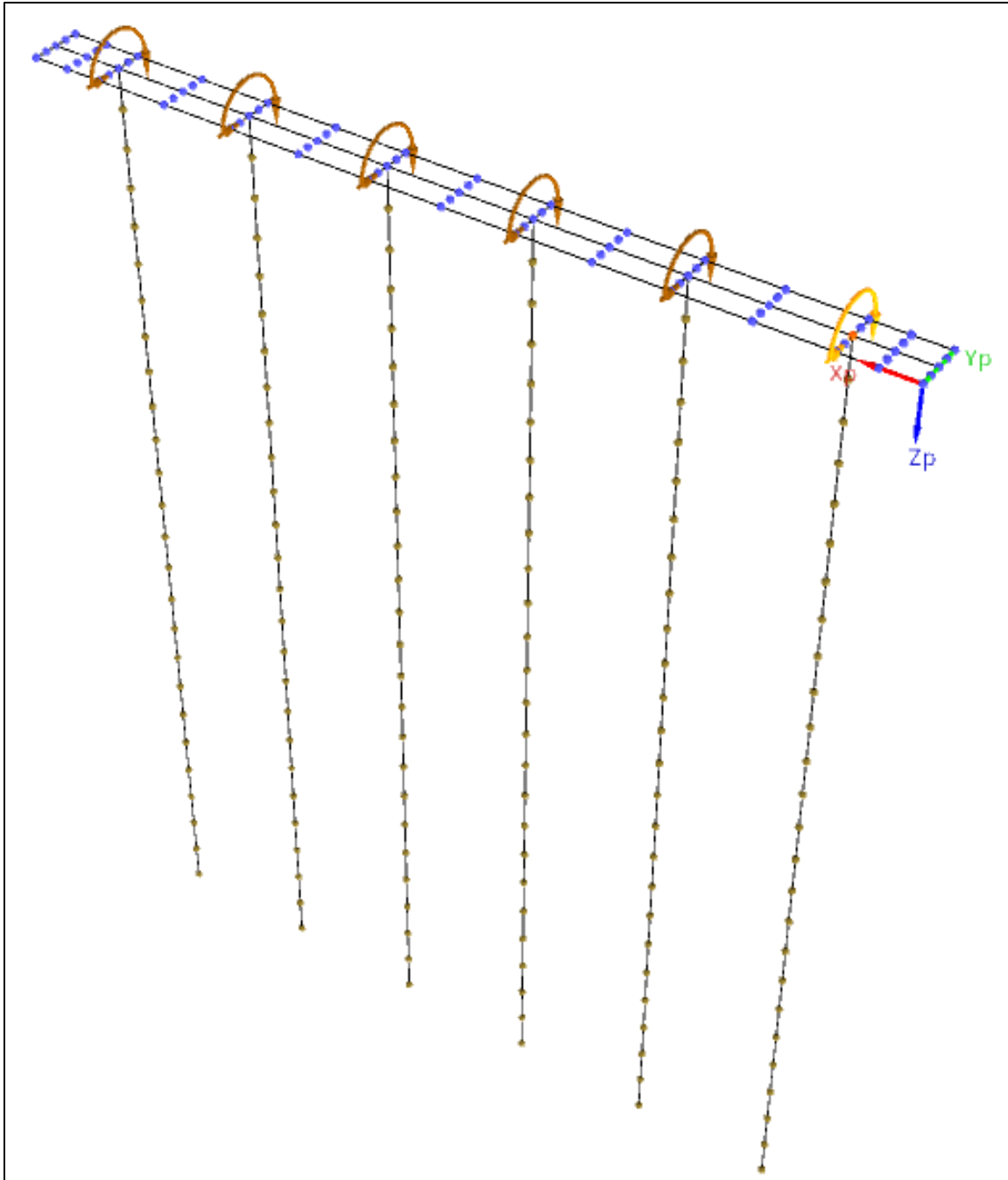
**Figure A4.4.1** Abutment 1 Pile Cap Geometry



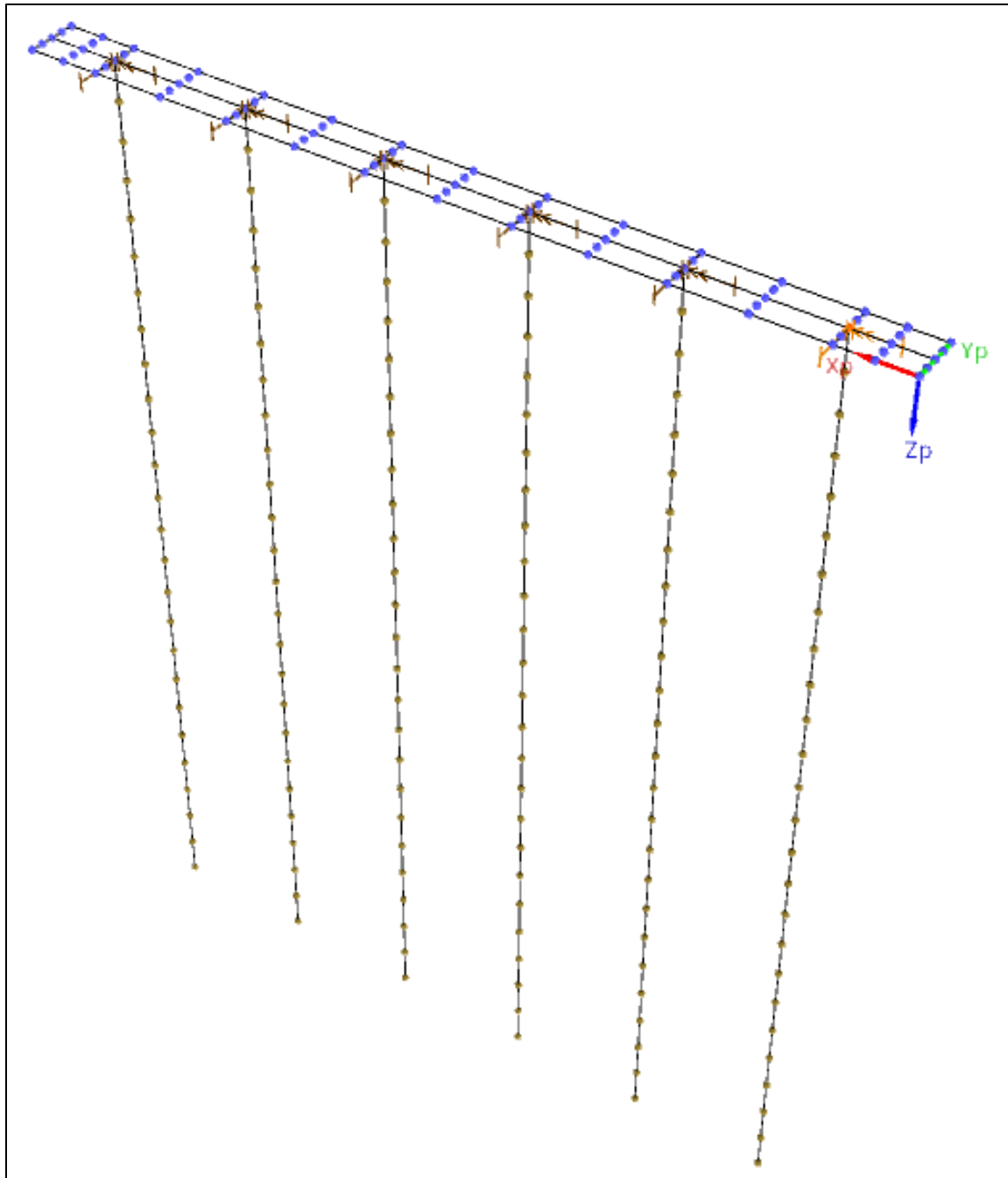
**Figure A4.4.2** Abutment 2 Pile Cap Geometry



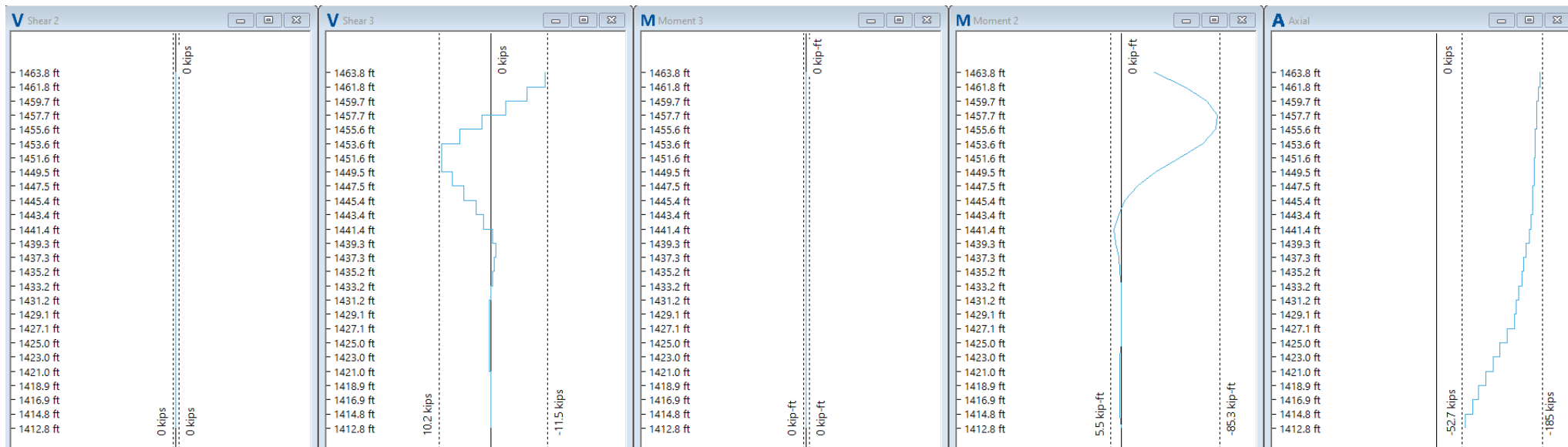
**Figure A4.5.1** Strength 1 Axial Loading



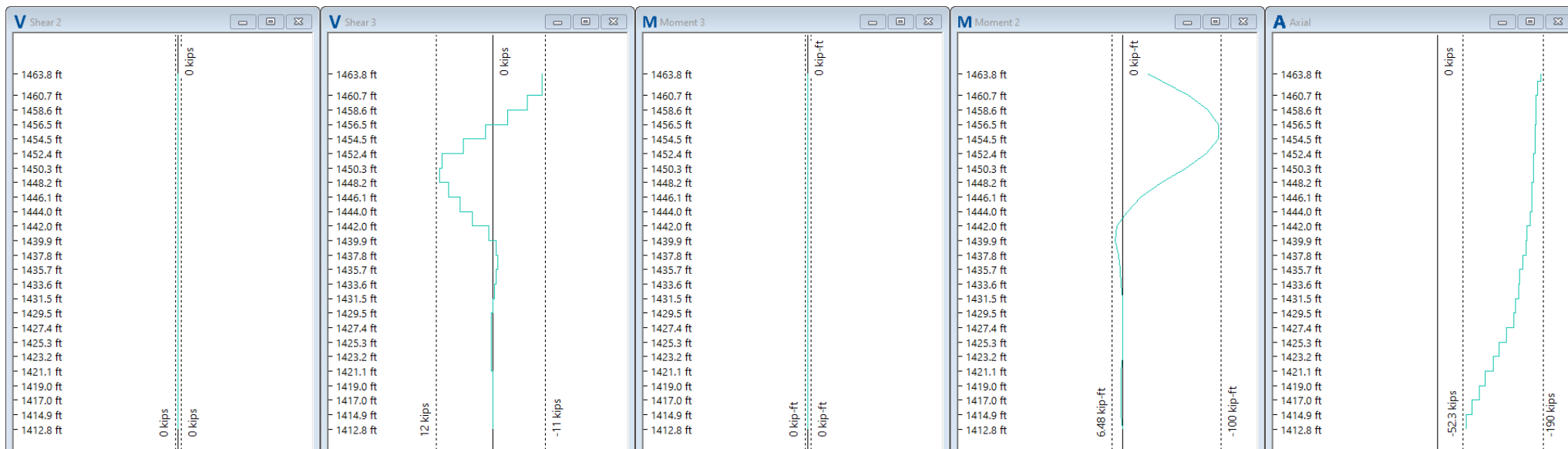
**Figure A4.5.2** Strength 1 Lateral and Moment Loading



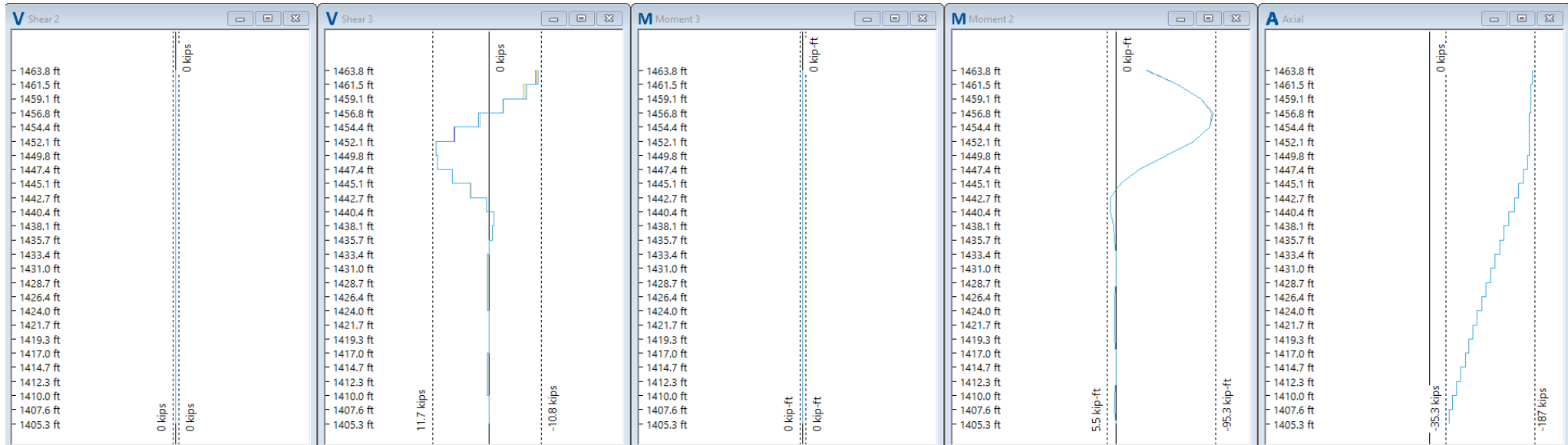
**Figure A4.5.3** Strength Displacement Loading



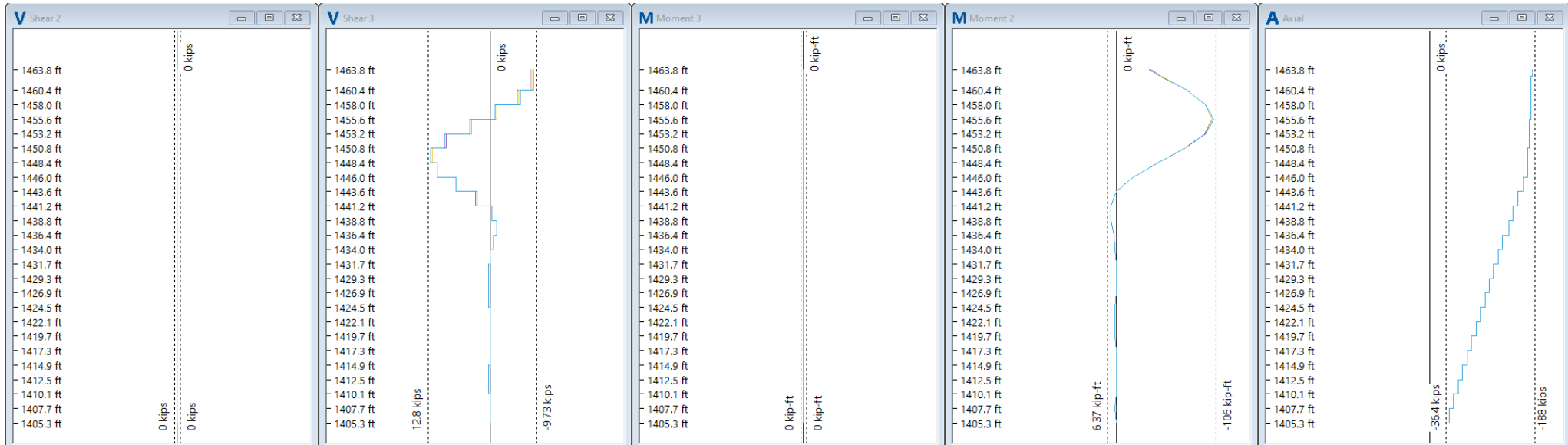
**Figure A4.6.1** Abutment 1 Strength 1 Non-Scour Output Forces



**Figure A4.6.2** Abutment 1 Strength 1 Scour Output Forces



**Figure A4.6.3** Abutment 2 Strength 1 Non-Scour Output Forces



**Figure A4.6.4** Abutment 2 Strength 1 Scour Output Forces

**Table A4.7.1** Abutment 1 Non Scour Output Forces and Deflections

| Load Case    | Shear x (k) | Shear y (k) | Mom x (kft) | Mom y (kft) | Axial (k) | Disp x (in) | Disp y (in) | Rotate x (rad) |
|--------------|-------------|-------------|-------------|-------------|-----------|-------------|-------------|----------------|
| Strength I   | 0.00        | -11.53      | -85.32      | 0.00        | 184.58    | 0.00        | 0.95        | 0.011          |
| Strength II  | 0.00        | -10.94      | -78.06      | 0.00        | 174.91    | 0.00        | 0.86        | 0.010          |
| Strength III | 0.00        | -5.44       | -20.80      | 0.00        | 143.03    | 0.00        | 0.19        | 0.000          |
| Strength IV  | 0.00        | -5.39       | -20.85      | 0.00        | 169.65    | 0.00        | 0.19        | 0.000          |
| Strength V   | 0.39        | -12.25      | -65.50      | 2.37        | 175.17    | 0.00        | 0.75        | 0.008          |
| Service I    | 0.35        | -10.61      | -49.98      | 2.02        | 135.41    | 0.00        | 0.54        | 0.006          |
| Service II   | 0.00        | -9.93       | -63.51      | 0.00        | 142.55    | 0.00        | 0.69        | 0.008          |
| Service III  | 0.00        | -12.62      | -46.06      | 0.00        | 135.19    | 0.00        | 0.52        | 0.005          |
| Service IV   | 0.00        | -5.52       | -20.92      | 0.00        | 135.07    | 0.00        | 0.19        | 0.000          |

**Table A4.7.2** Abutment 1 Scour Output Forces and Deflections

| Load Case    | Shear x (k) | Shear y (k) | Mom x (kft) | Mom y (kft) | Axial (k) | Disp x (in) | Disp y (in) | Rotate x (rad) |
|--------------|-------------|-------------|-------------|-------------|-----------|-------------|-------------|----------------|
| Strength I   | 0.00        | 12.00       | -99.97      | 0.00        | 189.60    | 0.00        | 1.38        | 0.014          |
| Strength II  | 0.00        | 10.15       | -86.68      | 0.00        | 180.10    | 0.00        | 1.15        | 0.012          |
| Strength III | 0.00        | -4.08       | -18.99      | 0.00        | 148.20    | 0.00        | 0.19        | 0.000          |
| Strength IV  | 0.00        | -4.04       | -19.03      | 0.00        | 174.90    | 0.00        | 0.19        | 0.000          |
| Strength V   | 0.35        | -9.97       | -73.76      | 2.45        | 180.37    | 0.01        | 1.01        | 0.010          |
| Service I    | 0.33        | -9.16       | -54.91      | 2.19        | 140.55    | 0.01        | 0.70        | 0.007          |
| Service II   | 0.00        | -9.68       | -67.08      | 0.00        | 147.40    | 0.00        | 0.90        | 0.009          |
| Service III  | 0.00        | -8.05       | -54.41      | 0.00        | 140.30    | 0.00        | 0.66        | 0.007          |
| Service IV   | 0.00        | -3.85       | -18.32      | 0.00        | 140.30    | 0.00        | 0.19        | 0.000          |

**Table A4.7.3** Abutment 2 Non Scour Output Forces and Deflections

| Load Case    | Shear x (k) | Shear y (k) | Mom x (kft) | Mom y (kft) | Axial (k) | Disp x (in) | Disp y (in) | Rotate x (rad) |
|--------------|-------------|-------------|-------------|-------------|-----------|-------------|-------------|----------------|
| Strength I   | 0.00        | 11.71       | -95.27      | 0.00        | 186.99    | 0.00        | 1.24        | 0.013          |
| Strength II  | 0.00        | 10.72       | -88.67      | 0.00        | 174.91    | 0.00        | 1.09        | 0.012          |
| Strength III | 0.00        | -4.74       | -19.85      | 0.00        | 135.28    | 0.00        | 0.19        | 0.000          |
| Strength IV  | 0.00        | -4.70       | -19.90      | 0.00        | 159.49    | 0.00        | 0.19        | 0.000          |
| Strength V   | 0.39        | 9.17        | -75.15      | 2.59        | 175.20    | 0.01        | 0.91        | 0.010          |
| Service I    | 0.29        | -9.40       | -49.08      | 1.82        | 135.99    | 0.00        | 0.60        | 0.006          |
| Service II   | 0.00        | -10.18      | -61.82      | 0.00        | 144.72    | 0.00        | 0.80        | 0.008          |
| Service III  | 0.00        | -8.69       | -48.80      | 0.00        | 135.78    | 0.00        | 0.58        | 0.006          |
| Service IV   | 0.00        | -4.74       | -19.85      | 0.00        | 135.78    | 0.00        | 0.19        | 0.000          |

**Table A4.7.4** Abutment 2 Scour Output Forces and Deflections

| Load Case          | Shear x (k) | Shear y (k) | Mom x (kft)   | Mom y (kft) | Axial (k)     | Disp x (in) | Disp y (in) | Rotate x (rad) |
|--------------------|-------------|-------------|---------------|-------------|---------------|-------------|-------------|----------------|
| Strength I         | 0.00        | 12.76       | 106.14        | 0.00        | 187.50        | 0.00        | 1.48        | 0.015          |
| Strength II        | 0.00        | 11.32       | -93.79        | 0.00        | 175.60        | 0.00        | 1.30        | 0.013          |
| Strength III       | 0.00        | -3.57       | -17.83        | 0.00        | 135.80        | 0.00        | 0.19        | 0.000          |
| Strength IV        | 0.00        | -3.53       | -17.88        | 0.00        | 160.10        | 0.00        | 0.19        | 0.000          |
| Strength V         | 0.38        | -10.06      | -81.46        | 2.74        | 175.91        | 0.01        | 1.13        | 0.011          |
| Service I          | 0.35        | -9.09       | -55.18        | 2.46        | 136.58        | 0.01        | 0.76        | 0.007          |
| <b>Service II*</b> | <b>0.00</b> | <b>8.84</b> | <b>-73.27</b> | <b>0.00</b> | <b>145.10</b> | <b>0.00</b> | <b>0.99</b> | <b>0.010</b>   |
| Service III        | 0.00        | -8.20       | -54.93        | 0.00        | 136.30        | 0.00        | 0.70        | 0.007          |
| Service IV         | 0.00        | -3.57       | -17.84        | 0.00        | 136.30        | 0.00        | 0.19        | 0.000          |

\*Service II governs for deflection, <1.0 inch/rz

## Integral Abutment Design Worksheet (See IAB Manual 2010 Appendix B Design Example)

Project Name: Mount Holly ER P23-1(334)

FB-Pier Corresponding File Name: \Abutment 1 STR I.in

Analysis By: A. Arles 06/06/2025

Piles Oriented for Weak Axis Bending

### Pile Size Inputs:

Pile := HP 14x117 ▾

$$b_f = 14.9 \text{ in} \quad t_f = 0.805 \text{ in} \quad t_w = 0.805 \text{ in} \quad d = 14.9 \text{ in} \quad k_o = 1.5 \text{ in} \quad A_s = 34.4 \text{ in}^2$$

$$S_y = 59.5 \text{ in}^3 \quad Z_y = 91.4 \text{ in}^3 \quad r_y = 3.59 \text{ in}$$

$$S_x = 172 \text{ in}^3 \quad Z_x = 194 \text{ in}^3 \quad r_x = 5.96 \text{ in}$$

$$D_c := \frac{d}{2}$$

Dc = depth of web in compression

$$t := d - 2 \cdot k_o = 11.9 \text{ in} \quad \lambda_f := \frac{b_f}{2 \cdot t_f} = 9.255 \quad \lambda_w := \frac{t}{t_w} = 14.783$$

$$F_y := 50 \cdot \text{ksi}$$

$$E := 29000 \cdot \text{ksi}$$

### FB-Pier Inputs:

Muy refers to moment about the y-axis of the pile.

$$P_u := 184.6 \cdot \text{kip}$$

$$M_{uy_{top}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{uy_{2nd}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{top}} := 85.33 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{2nd}} := 5.4955 \cdot \text{kip} \cdot \text{ft}$$

$$l_{by_{top}} := 0.1 \cdot \text{in}$$

$$l_{by_{2nd}} := 0.1 \cdot \text{in}$$

$$V_u := 12 \cdot \text{kip}$$

$$l_{bx_{top}} := 244.8 \cdot \text{in}$$

$$l_{bx_{2nd}} := 122.4 \cdot \text{in}$$

Resistance Factors

$$\phi_{cl} := 0.50$$

For lower zone of the pile

$\phi_{cu} := 0.70$  For the upper zone of the pile

$\phi_f := 1.0$  For the upper zone of the pile

$R_h := 1.0$  AASHTO C6.10.1.10.1  $C_b := 1.0$  AASHTO C6.10.8.2.3

$R_b := 1.0$  AASHTO C6.10.1.10.2

$Q := 1.0$  use 1 for nonslender elements AASHTO C6.9.4.1.1

Nominal Axial Pile Resistance  
(Check Pile Size chosen)

$$R_n := \frac{P_u}{\phi_c l} \quad R_n = 369.2 \text{ kip}$$

$$A_{sreq} := \frac{R_n}{(0.8 \cdot F_y)} \quad A_{sreq} = 9.23 \text{ in}^2$$

Check if Area Required is less  
than chosen pile area:

$$A_{sreq} < A_s = 1 \quad \text{(Should see 1)}$$

Elastic Flexural Buckling Resistance

( $k_{top} = 1.2$  first, 2.1 if hinge forms)

$$k_{top} := 1.2$$

$$k_{2nd} := 1.0$$

Calculate Column Slenderness Factors

$$\lambda_{top} := \left( \frac{k_{top} \cdot l_{by_{top}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{top} = 1.952 \cdot 10^{-7}$$

Check:

$$\lambda_{top} < 2.25 = 1 \quad \text{(Should see 1)}$$

$$\lambda_{2nd} := \left( \frac{k_{2nd} \cdot l_{by_{2nd}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{2nd} = 1.355 \cdot 10^{-7}$$

$$\lambda_{2nd} < 2.25 = 1 \quad \text{(Should see 1)}$$

Calculate Nominal Flexural Resistance

$$\lambda_f = 9.255$$

Flange Slenderness

$$\lambda_{pf} := 0.38 \cdot \sqrt{\frac{E}{F_y}} \quad \lambda_{pf} = 9.152$$

Compact Flange

AASHTO 6.12.2.2.1-4

$$\lambda_{rf} := 0.56 \cdot \sqrt{\frac{E}{0.7 \cdot F_y}}$$

$$\lambda_{rf} = 16.12$$

Noncompact Flange

AASHTO 6.12.2.2.1-5

Strong Axis Flexure

$$F_n := \left( 1 - \left( 1 - 0.7 \cdot \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(\lambda_f - \lambda_{pf})}{(\lambda_{rf} - \lambda_{pf})} \right) \cdot R_h \cdot R_b \cdot F_y = 49.778 \text{ ksi}$$

AASHTO 6.10.8.2.2-2

Lateral Torsional Buckling

$$r_t := \frac{b_f}{\sqrt{12 \cdot \left( 1 + \frac{1 \cdot D_c \cdot t_w}{3 \cdot b_f \cdot t_f} \right)}} = 3.982 \text{ in}$$

AASHTO 6.10.8.2.2-9

$$L_p := 1.0 \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 7.992 \text{ ft}$$

$$L_r := \pi \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 25.108 \text{ ft}$$

$$F_{ntop} := \left\| \begin{array}{l} \text{if } lbx_{top} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{top} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{top} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{top} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{top}}{r_t} \right)^2} \right\| \end{array} \right\|$$

AASHTO 6.10.8.2.3

$$F_{ntop} = 50 \text{ ksi}$$

$$F_{nc2nd} := \left\| \begin{array}{l} \text{if } lbx_{2nd} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{2nd} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{2nd} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{2nd} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{2nd}}{r_t} \right)^2} \right\| \end{array} \right\| = 50 \text{ ksi}$$

$$F_{nc2nd} = 50 \text{ ksi}$$

$$F_{ctop} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$F_{c2nd} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$M_{nxtop} := F_{ctop} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{nx2nd} := F_{c2nd} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rxtop} := \phi f \cdot M_{nxtop} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rx2nd} := \phi f \cdot M_{nx2nd} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

#### Weak Axis Flexure

$$M_{ny} := \left\| \begin{array}{l} \text{if } \lambda_{pf} < \lambda_f < \lambda_{rf} \\ \left\| \left( 1 - \left( 1 - \frac{S_y}{Z_y} \right) \cdot \left( \frac{\lambda_f - \lambda_{pf}}{0.45 \cdot \sqrt{\frac{E}{F_y}}} \right) \right) \cdot F_y \cdot Z_y \right\| \\ \text{if } \lambda_f \leq \lambda_{pf} \\ \left\| Z_y \cdot F_y \right\| \end{array} \right\|$$

AASHTO 6.12.2.2.1-2

$$M_{ny} = 4554.83 \text{ in} \cdot \text{kip}$$

#### Calculate Flexural Resistance

$$M_{ry} := \phi f \cdot M_{ny}$$

$$M_{ry} = 4554.8 \text{ in} \cdot \text{kip}$$

#### Strong Axis Compression

AASHTO 6.9.4.2.1

AASHTO 6.9.4.1.2-1

$$P_{extop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lbx_{top}}{rx}\right)^2} = (4.053 \cdot 10^3) \text{ kip}$$

$$P_{ex2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lbx_{2nd}}{rx}\right)^2} = (2.334 \cdot 10^4) \text{ kip}$$

$$P_o := Q \cdot F_y \cdot A_s = (1.72 \cdot 10^3) \text{ kip}$$

$$P_{nxtop} := \left\| \begin{array}{l} \text{if } \frac{P_{extop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{extop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{extop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{extop} \right\| \end{array} \right\|$$

$$P_{nxtop} = 1440.08 \text{ kip}$$

$$P_{nx2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ex2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ex2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ex2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ex2nd} \right\| \end{array} \right\|$$

$$P_{nx2nd} = 1667.77 \text{ kip}$$

$$P_{eytop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lby_{top}}{ry}\right)^2} = (8.812 \cdot 10^9) \text{ kip}$$

$$P_{ey2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lby_{2nd}}{ry}\right)^2} = (1.269 \cdot 10^{10}) \text{ kip}$$

## Nominal Structural Pile Resistance

$$P_{nytop} := \left\| \begin{array}{l} \text{if } \frac{P_{eytop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{eytop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{eytop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{eytop} \right\| \end{array} \right\|$$

$$P_{nytop} = 1720 \text{ kip}$$

$$P_{ny2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ey2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ey2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ey2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ey2nd} \right\| \end{array} \right\|$$

$$P_{ny2nd} = 1720 \text{ kip}$$

$$P_{nbot} := 0.66^{0.0} \cdot F_y \cdot A_s$$

$$P_{nbot} = 1720 \text{ kip}$$

## Factored Structural Pile Resistance

$$P_{rytop} := \phi cu \cdot P_{nytop}$$

$$P_{rytop} = 1204 \text{ kip}$$

$$P_{ry2nd} := \phi cu \cdot P_{ny2nd}$$

$$P_{ry2nd} = 1204 \text{ kip}$$

$$P_{rxtop} := \phi cu \cdot P_{nxtop}$$

$$P_{rxtop} = 1008.05 \text{ kip}$$

$$P_{rx2nd} := \phi c u \cdot P_{ny2nd}$$

$$P_{rx2nd} = 1204 \text{ kip}$$

$$P_{rbot} := \phi c l \cdot P_{nbot}$$

$$P_{rbot} = 860 \text{ kip}$$

$$P_{rtop} := \min(P_{rxtop}, P_{rytop}) = (1.008 \cdot 10^3) \text{ kip}$$

$$P_{r2nd} := \min(P_{rx2nd}, P_{ry2nd}) = (1.204 \cdot 10^3) \text{ kip}$$

Check to make sure pile size is not too big:

$$\frac{P_u}{P_{rtop}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{r2nd}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{rbot}} < 1 = 1$$

(Should see 1)

Check Moment that will cause plastic hinge

$$M_p := \frac{9}{8} \cdot \left(1 - \frac{P_u}{P_{rtop}}\right) \cdot M_{ry}$$

$$M_p = 4185.8 \text{ in}\cdot\text{kip}$$

$$M_p = 348.8 \text{ ft}\cdot\text{kip}$$

$$M u y_{top} > M_p = 0$$

(Should see 1)

Since the Applied moment exceeds the moment that would create a plastic hinge, it can be assumed that the pile head has plastically deformed.

Now, make sure the 2nd segment DOES NOT develop a plastic hinge. A plastic hinge in this segment will cause the pile to fail!

$$I_{top} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{rtop}} \geq 0.2 \\ \left\| \frac{P_u}{P_{rtop}} + \frac{8}{9} \cdot \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{rtop}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{rtop}} + \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \end{array} \right\|$$

AASHTO 6.9.2.2-2

AASHTO 6.9.2.2-1

$$I_{top} = 0.211$$

$$I_{2nd} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{r2nd}} \geq 0.2 \\ \left\| \frac{P_u}{P_{r2nd}} + \frac{8}{9} \cdot \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{r2nd}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{r2nd}} + \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \end{array} \right\|$$

$$I_{2nd} = 0.085$$

$$I_{bot} := \frac{P_u}{P_{rbot}} = 0.215$$

$$I_{2nd} < 1 = 1$$

(Should see 1)

$$I_{bot} < 1 = 1$$

(Should see 1)

Now Check for Shear

$$\phi_v := 1.0$$

$$k_v := 1.2 \quad \text{AISC Steel Manual, G7}$$

$$C_v := 1.0$$

$$A_w := 2 \cdot b_f \cdot t_f \quad A_w = 23.989 \text{ in}^2$$

$$V_n := 0.6 \cdot F_y \cdot A_w \cdot C_v \quad V_n = 719.67 \text{ kip}$$

$$V_r := \phi_v \cdot V_n \quad V_r = 719.67 \text{ kip}$$

$$\frac{V_u}{V_r} < 1 = 1 \quad \text{(Should see 1)}$$

## Integral Abutment Design Worksheet (See IAB Manual 2010 Appendix B Design Example)

Project Name: Mount Holly ER P23-1(334)

FB-Pier Corresponding File Name: \Abutment 1 STR I scour.in

Analysis By: A. Arles 06/06/2025

Piles Oriented for Weak Axis Bending

### Pile Size Inputs:

Pile := HP 14x117 ▾

$$b_f = 14.9 \text{ in} \quad t_f = 0.805 \text{ in} \quad t_w = 0.805 \text{ in} \quad d = 14.9 \text{ in} \quad k_o = 1.5 \text{ in} \quad A_s = 34.4 \text{ in}^2$$

$$S_y = 59.5 \text{ in}^3 \quad Z_y = 91.4 \text{ in}^3 \quad r_y = 3.59 \text{ in}$$

$$S_x = 172 \text{ in}^3 \quad Z_x = 194 \text{ in}^3 \quad r_x = 5.96 \text{ in}$$

$$D_c := \frac{d}{2}$$

Dc = depth of web in compression

$$t := d - 2 \cdot k_o = 11.9 \text{ in} \quad \lambda_f := \frac{b_f}{2 \cdot t_f} = 9.255 \quad \lambda_w := \frac{t}{t_w} = 14.783$$

$$F_y := 50 \cdot \text{ksi}$$

$$E := 29000 \cdot \text{ksi}$$

### FB-Pier Inputs:

Muy refers to moment about the y-axis of the pile.

$$P_u := 189.6 \cdot \text{kip}$$

$$M_{uy_{top}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{uy_{2nd}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{top}} := 99.97 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{2nd}} := 6.47 \cdot \text{kip} \cdot \text{ft}$$

$$l_{by_{top}} := 0.1 \cdot \text{in}$$

$$l_{by_{2nd}} := 0.1 \cdot \text{in}$$

$$V_u := 12 \cdot \text{kip}$$

$$l_{bx_{top}} := 261.96 \cdot \text{in}$$

$$l_{bx_{2nd}} := 124.32 \cdot \text{in}$$

Resistance Factors

$$\phi_{cl} := 0.50$$

For lower zone of the pile

$$\phi_{cu} := 0.70$$

For the upper zone of the pile

$$\phi_f := 1.0$$

For the upper zone of the pile

$$R_h := 1.0$$

AASHTO C6.10.1.10.1

$$C_b := 1.0$$

AASHTO C6.10.8.2.3

$$R_b := 1.0$$

AASHTO C6.10.1.10.2

$$Q := 1.0$$

use 1 for nonslender elements

AASHTO C6.9.4.1.1

Nominal Axial Pile Resistance  
(Check Pile Size chosen)

$$R_n := \frac{P_u}{\phi_c l}$$

$$R_n = 379.2 \text{ kip}$$

$$A_{sreq} := \frac{R_n}{(0.8 \cdot F_y)}$$

$$A_{sreq} = 9.48 \text{ in}^2$$

Check if Area Required is less  
than chosen pile area:

$$A_{sreq} < A_s = 1 \quad \text{(Should see 1)}$$

Elastic Flexural Buckling Resistance

(k\_top = 1.2 first, 2.1 if hinge forms)

$$k_{top} := 1.2$$

$$k_{2nd} := 1.0$$

Calculate Column Slenderness Factors

$$\lambda_{top} := \left( \frac{k_{top} \cdot l_{by_{top}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right)$$

$$\lambda_{top} = 1.952 \cdot 10^{-7}$$

Check:

$$\lambda_{top} < 2.25 = 1 \quad \text{(Should see 1)}$$

$$\lambda_{2nd} := \left( \frac{k_{2nd} \cdot l_{by_{2nd}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right)$$

$$\lambda_{2nd} = 1.355 \cdot 10^{-7}$$

$$\lambda_{2nd} < 2.25 = 1 \quad \text{(Should see 1)}$$

Calculate Nominal Flexural Resistance

$$\lambda_f = 9.255$$

Flange Slenderness

$$\lambda_{pf} := 0.38 \cdot \sqrt{\frac{E}{F_y}}$$

$$\lambda_{pf} = 9.152$$

Compact Flange

AASHTO 6.12.2.2.1-4

$$\lambda_{rf} := 0.56 \cdot \sqrt{\frac{E}{0.7 \cdot F_y}}$$

$$\lambda_{rf} = 16.12$$

Noncompact Flange

AASHTO 6.12.2.2.1-5

Strong Axis Flexure

$$F_n := \left( 1 - \left( 1 - 0.7 \cdot \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(\lambda_f - \lambda_{pf})}{(\lambda_{rf} - \lambda_{pf})} \right) \cdot R_h \cdot R_b \cdot F_y = 49.778 \text{ ksi}$$

AASHTO 6.10.8.2.2-2

Lateral Torsional Buckling

$$r_t := \frac{b_f}{\sqrt{12 \cdot \left( 1 + \frac{1 \cdot D_c \cdot t_w}{3 \cdot b_f \cdot t_f} \right)}} = 3.982 \text{ in}$$

AASHTO 6.10.8.2.2-9

$$L_p := 1.0 \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 7.992 \text{ ft}$$

$$L_r := \pi \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 25.108 \text{ ft}$$

$$F_{ntop} := \left\| \begin{array}{l} \text{if } lbx_{top} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{top} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{top} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{top} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{top}}{r_t} \right)^2} \right\| \end{array} \right\|$$

AASHTO 6.10.8.2.3

$$F_{ntop} = 50 \text{ ksi}$$

$$F_{nc2nd} := \left\| \begin{array}{l} \text{if } lbx_{2nd} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{2nd} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{2nd} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{2nd} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{2nd}}{r_t} \right)^2} \right\| \end{array} \right\| = 50 \text{ ksi}$$

$$F_{nc2nd} = 50 \text{ ksi}$$

$$F_{ctop} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$F_{c2nd} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$M_{nxtop} := F_{ctop} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{nx2nd} := F_{c2nd} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rxtop} := \phi f \cdot M_{nxtop} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rx2nd} := \phi f \cdot M_{nx2nd} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

#### Weak Axis Flexure

$$M_{ny} := \left\| \begin{array}{l} \text{if } \lambda_{pf} < \lambda_f < \lambda_{rf} \\ \left\| \left( 1 - \left( 1 - \frac{S_y}{Z_y} \right) \cdot \left( \frac{\lambda_f - \lambda_{pf}}{0.45 \cdot \sqrt{\frac{E}{F_y}}} \right) \right) \cdot F_y \cdot Z_y \right\| \\ \text{if } \lambda_f \leq \lambda_{pf} \\ \left\| Z_y \cdot F_y \right\| \end{array} \right\|$$

AASHTO 6.12.2.2.1-2

$$M_{ny} = 4554.83 \text{ in} \cdot \text{kip}$$

#### Calculate Flexural Resistance

$$M_{ry} := \phi f \cdot M_{ny}$$

$$M_{ry} = 4554.8 \text{ in} \cdot \text{kip}$$

#### Strong Axis Compression

AASHTO 6.9.4.2.1

AASHTO 6.9.4.1.2-1

$$P_{extop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lbx_{top}}{rx}\right)^2} = (3.539 \cdot 10^3) \text{ kip}$$

$$P_{ex2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lbx_{2nd}}{rx}\right)^2} = (2.263 \cdot 10^4) \text{ kip}$$

$$P_o := Q \cdot F_y \cdot A_s = (1.72 \cdot 10^3) \text{ kip}$$

$$P_{nxtop} := \left\| \begin{array}{l} \text{if } \frac{P_{extop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{extop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{extop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{extop} \right\| \end{array} \right\|$$

$$P_{nxtop} = 1403.43 \text{ kip}$$

$$P_{nx2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ex2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ex2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ex2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ex2nd} \right\| \end{array} \right\|$$

$$P_{nx2nd} = 1666.14 \text{ kip}$$

$$P_{eytop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lby_{top}}{ry}\right)^2} = (8.812 \cdot 10^9) \text{ kip}$$

$$P_{ey2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lby_{2nd}}{ry}\right)^2} = (1.269 \cdot 10^{10}) \text{ kip}$$

## Nominal Structural Pile Resistance

$$P_{nytop} := \left\| \begin{array}{l} \text{if } \frac{P_{eytop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{eytop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{eytop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{eytop} \right\| \end{array} \right\|$$

$$P_{nytop} = 1720 \text{ kip}$$

$$P_{ny2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ey2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ey2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ey2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ey2nd} \right\| \end{array} \right\|$$

$$P_{ny2nd} = 1720 \text{ kip}$$

$$P_{nbot} := 0.66^{0.0} \cdot F_y \cdot A_s$$

$$P_{nbot} = 1720 \text{ kip}$$

## Factored Structural Pile Resistance

$$P_{rytop} := \phi cu \cdot P_{nytop}$$

$$P_{rytop} = 1204 \text{ kip}$$

$$P_{ry2nd} := \phi cu \cdot P_{ny2nd}$$

$$P_{ry2nd} = 1204 \text{ kip}$$

$$P_{rxtop} := \phi cu \cdot P_{nxtop}$$

$$P_{rxtop} = 982.4 \text{ kip}$$

$$P_{rx2nd} := \phi c u \cdot P_{ny2nd}$$

$$P_{rx2nd} = 1204 \text{ kip}$$

$$P_{rbot} := \phi c l \cdot P_{nbot}$$

$$P_{rbot} = 860 \text{ kip}$$

$$P_{rtop} := \min(P_{rxtop}, P_{rytop}) = 982.402 \text{ kip}$$

$$P_{r2nd} := \min(P_{rx2nd}, P_{ry2nd}) = (1.204 \cdot 10^3) \text{ kip}$$

Check to make sure pile size is not too big:

$$\frac{P_u}{P_{rtop}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{r2nd}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{rbot}} < 1 = 1$$

(Should see 1)

Check Moment that will cause plastic hinge

$$M_p := \frac{9}{8} \cdot \left(1 - \frac{P_u}{P_{rtop}}\right) \cdot M_{ry}$$

$$M_p = 4135.2 \text{ in}\cdot\text{kip}$$

$$M_p = 344.6 \text{ ft}\cdot\text{kip}$$

$$M_{uytop} > M_p = 0$$

(Should see 1)

Since the Applied moment exceeds the moment that would create a plastic hinge, it can be assumed that the pile head has plastically deformed.

Now, make sure the 2nd segment DOES NOT develop a plastic hinge. A plastic hinge in this segment will cause the pile to fail!

$$I_{top} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{rtop}} \geq 0.2 \\ \left\| \frac{P_u}{P_{rtop}} + \frac{8}{9} \cdot \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{rtop}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{rtop}} + \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \end{array} \right\|$$

AASHTO 6.9.2.2-2

AASHTO 6.9.2.2-1

$$I_{top} = 0.237$$

$$I_{2nd} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{r2nd}} \geq 0.2 \\ \left\| \frac{P_u}{P_{r2nd}} + \frac{8}{9} \cdot \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{r2nd}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{r2nd}} + \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \end{array} \right\|$$

$$I_{2nd} = 0.088$$

$$I_{bot} := \frac{P_u}{P_{rbot}} = 0.22$$

$$I_{2nd} < 1 = 1$$

(Should see 1)

$$I_{bot} < 1 = 1$$

(Should see 1)

Now Check for Shear

$$\phi_v := 1.0$$

$$k_v := 1.2 \quad \text{AISC Steel Manual, G7}$$

$$C_v := 1.0$$

$$A_w := 2 \cdot b_f \cdot t_f \quad A_w = 23.989 \text{ in}^2$$

$$V_n := 0.6 \cdot F_y \cdot A_w \cdot C_v \quad V_n = 719.67 \text{ kip}$$

$$V_r := \phi_v \cdot V_n \quad V_r = 719.67 \text{ kip}$$

$$\frac{V_u}{V_r} < 1 = 1 \quad \text{(Should see 1)}$$

## Integral Abutment Design Worksheet (See IAB Manual 2010 Appendix B Design Example)

Project Name: Mount Holly ER P23-1(334)

FB-Pier Corresponding File Name: \Abutment 2 STR 1.in

Analysis By: A. Arles 06/06/2025

Piles Oriented for Weak Axis Bending

### Pile Size Inputs:

Pile := HP 14x117 ▾

$$b_f = 14.9 \text{ in} \quad t_f = 0.805 \text{ in} \quad t_w = 0.805 \text{ in} \quad d = 14.9 \text{ in} \quad k_o = 1.5 \text{ in} \quad A_s = 34.4 \text{ in}^2$$

$$S_y = 59.5 \text{ in}^3 \quad Z_y = 91.4 \text{ in}^3 \quad r_y = 3.59 \text{ in}$$

$$S_x = 172 \text{ in}^3 \quad Z_x = 194 \text{ in}^3 \quad r_x = 5.96 \text{ in}$$

$$D_c := \frac{d}{2}$$

Dc = depth of web in compression

$$t := d - 2 \cdot k_o = 11.9 \text{ in} \quad \lambda_f := \frac{b_f}{2 \cdot t_f} = 9.255 \quad \lambda_w := \frac{t}{t_w} = 14.783$$

$$F_y := 50 \cdot \text{ksi}$$

$$E := 29000 \cdot \text{ksi}$$

### FB-Pier Inputs:

Muy refers to moment about the y-axis of the pile.

$$P_u := 186.99 \cdot \text{kip}$$

$$M_{uy_{top}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{uy_{2nd}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{top}} := 95.27 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{2nd}} := 5.45 \cdot \text{kip} \cdot \text{ft}$$

$$l_{by_{top}} := 0.1 \cdot \text{in}$$

$$l_{by_{2nd}} := 0.1 \cdot \text{in}$$

$$V_u := 11.71 \cdot \text{kip}$$

$$l_{bx_{top}} := 252.72 \cdot \text{in}$$

$$l_{bx_{2nd}} := 112.32 \cdot \text{in}$$

Resistance Factors

$$\phi_{cl} := 0.50$$

For lower zone of the pile

$\phi_{cu} := 0.70$  For the upper zone of the pile

$\phi_f := 1.0$  For the upper zone of the pile

$R_h := 1.0$  AASHTO C6.10.1.10.1  $C_b := 1.0$  AASHTO C6.10.8.2.3

$R_b := 1.0$  AASHTO C6.10.1.10.2

$Q := 1.0$  use 1 for nonslender elements AASHTO C6.9.4.1.1

Nominal Axial Pile Resistance  
(Check Pile Size chosen)

$$R_n := \frac{P_u}{\phi_{cl}} \quad R_n = 373.98 \text{ kip}$$

$$A_{sreq} := \frac{R_n}{(0.8 \cdot F_y)} \quad A_{sreq} = 9.35 \text{ in}^2$$

Check if Area Required is less  
than chosen pile area:

$$A_{sreq} < A_s = 1 \quad \text{(Should see 1)}$$

Elastic Flexural Buckling Resistance

(k\_top = 1.2 first, 2.1 if hinge forms)

$$k_{top} := 1.2$$

$$k_{2nd} := 1.0$$

Calculate Column Slenderness Factors

$$\lambda_{top} := \left( \frac{k_{top} \cdot l_{by_{top}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{top} = 1.952 \cdot 10^{-7}$$

Check:

$$\lambda_{top} < 2.25 = 1 \quad \text{(Should see 1)}$$

$$\lambda_{2nd} := \left( \frac{k_{2nd} \cdot l_{by_{2nd}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{2nd} = 1.355 \cdot 10^{-7}$$

$$\lambda_{2nd} < 2.25 = 1 \quad \text{(Should see 1)}$$

Calculate Nominal Flexural Resistance

$$\lambda_f = 9.255$$

Flange Slenderness

$$\lambda_{pf} := 0.38 \cdot \sqrt{\frac{E}{F_y}} \quad \lambda_{pf} = 9.152$$

Compact Flange

AASHTO 6.12.2.2.1-4

$$\lambda_{rf} := 0.56 \cdot \sqrt{\frac{E}{0.7 \cdot F_y}}$$

$$\lambda_{rf} = 16.12$$

Noncompact Flange

AASHTO 6.12.2.2.1-5

Strong Axis Flexure

$$F_n := \left( 1 - \left( 1 - 0.7 \cdot \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(\lambda_f - \lambda_{pf})}{(\lambda_{rf} - \lambda_{pf})} \right) \cdot R_h \cdot R_b \cdot F_y = 49.778 \text{ ksi}$$

AASHTO 6.10.8.2.2-2

Lateral Torsional Buckling

$$r_t := \frac{b_f}{\sqrt{12 \cdot \left( 1 + \frac{1 \cdot D_c \cdot t_w}{3 \cdot b_f \cdot t_f} \right)}} = 3.982 \text{ in}$$

AASHTO 6.10.8.2.2-9

$$L_p := 1.0 \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 7.992 \text{ ft}$$

$$L_r := \pi \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 25.108 \text{ ft}$$

$$F_{ntop} := \left\| \begin{array}{l} \text{if } lbx_{top} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{top} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{top} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{top} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{top}}{r_t} \right)^2} \right\| \end{array} \right\|$$

AASHTO 6.10.8.2.3

$$F_{ntop} = 50 \text{ ksi}$$

$$F_{nc2nd} := \left\| \begin{array}{l} \text{if } lbx_{2nd} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{2nd} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{2nd} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{2nd} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{2nd}}{r_t} \right)^2} \right\| \end{array} \right\| = 50 \text{ ksi}$$

$$F_{nc2nd} = 50 \text{ ksi}$$

$$F_{ctop} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$F_{c2nd} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$M_{nxtop} := F_{ctop} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{nx2nd} := F_{c2nd} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rxtop} := \phi f \cdot M_{nxtop} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rx2nd} := \phi f \cdot M_{nx2nd} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

#### Weak Axis Flexure

$$M_{ny} := \left\| \begin{array}{l} \text{if } \lambda_{pf} < \lambda_f < \lambda_{rf} \\ \left\| \left( 1 - \left( 1 - \frac{S_y}{Z_y} \right) \cdot \left( \frac{\lambda_f - \lambda_{pf}}{0.45 \cdot \sqrt{\frac{E}{F_y}}} \right) \right) \cdot F_y \cdot Z_y \right\| \\ \text{if } \lambda_f \leq \lambda_{pf} \\ \left\| Z_y \cdot F_y \right\| \end{array} \right\|$$

AASHTO 6.12.2.2.1-2

$$M_{ny} = 4554.83 \text{ in} \cdot \text{kip}$$

#### Calculate Flexural Resistance

$$M_{ry} := \phi f \cdot M_{ny}$$

$$M_{ry} = 4554.8 \text{ in} \cdot \text{kip}$$

#### Strong Axis Compression

AASHTO 6.9.4.2.1

AASHTO 6.9.4.1.2-1

$$P_{extop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lbx_{top}}{rx}\right)^2} = (3.803 \cdot 10^3) \text{ kip}$$

$$P_{ex2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lbx_{2nd}}{rx}\right)^2} = (2.772 \cdot 10^4) \text{ kip}$$

$$P_o := Q \cdot F_y \cdot A_s = (1.72 \cdot 10^3) \text{ kip}$$

$$P_{nxtop} := \left\| \begin{array}{l} \text{if } \frac{P_{extop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{extop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{extop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{extop} \right\| \end{array} \right\|$$

$$P_{nxtop} = 1423.35 \text{ kip}$$

$$P_{nx2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ex2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ex2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ex2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ex2nd} \right\| \end{array} \right\|$$

$$P_{nx2nd} = 1675.91 \text{ kip}$$

$$P_{eytop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lby_{top}}{ry}\right)^2} = (8.812 \cdot 10^9) \text{ kip}$$

$$P_{ey2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lby_{2nd}}{ry}\right)^2} = (1.269 \cdot 10^{10}) \text{ kip}$$

## Nominal Structural Pile Resistance

$$P_{nytop} := \left\| \begin{array}{l} \text{if } \frac{P_{eytop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{eytop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{eytop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{eytop} \right\| \end{array} \right\|$$

$$P_{nytop} = 1720 \text{ kip}$$

$$P_{ny2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ey2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ey2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ey2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ey2nd} \right\| \end{array} \right\|$$

$$P_{ny2nd} = 1720 \text{ kip}$$

$$P_{nbot} := 0.66^{0.0} \cdot F_y \cdot A_s$$

$$P_{nbot} = 1720 \text{ kip}$$

## Factored Structural Pile Resistance

$$P_{rytop} := \phi cu \cdot P_{nytop}$$

$$P_{rytop} = 1204 \text{ kip}$$

$$P_{ry2nd} := \phi cu \cdot P_{ny2nd}$$

$$P_{ry2nd} = 1204 \text{ kip}$$

$$P_{rxtop} := \phi cu \cdot P_{nxtop}$$

$$P_{rxtop} = 996.35 \text{ kip}$$

$$P_{rx2nd} := \phi c u \cdot P_{ny2nd}$$

$$P_{rx2nd} = 1204 \text{ kip}$$

$$P_{rbot} := \phi c l \cdot P_{nbot}$$

$$P_{rbot} = 860 \text{ kip}$$

$$P_{rtop} := \min(P_{rxtop}, P_{rytop}) = 996.348 \text{ kip}$$

$$P_{r2nd} := \min(P_{rx2nd}, P_{ry2nd}) = (1.204 \cdot 10^3) \text{ kip}$$

Check to make sure pile size is not too big:

$$\frac{P_u}{P_{rtop}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{r2nd}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{rbot}} < 1 = 1$$

(Should see 1)

Check Moment that will cause plastic hinge

$$M_p := \frac{9}{8} \cdot \left(1 - \frac{P_u}{P_{rtop}}\right) \cdot M_{ry}$$

$$M_p = 4162.5 \text{ in}\cdot\text{kip}$$

$$M_p = 346.9 \text{ ft}\cdot\text{kip}$$

$$M u y_{top} > M_p = 0$$

(Should see 1)

Since the Applied moment exceeds the moment that would create a plastic hinge, it can be assumed that the pile head has plastically deformed.

Now, make sure the 2nd segment DOES NOT develop a plastic hinge. A plastic hinge in this segment will cause the pile to fail!

$$I_{top} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{rtop}} \geq 0.2 \\ \left\| \frac{P_u}{P_{rtop}} + \frac{8}{9} \cdot \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{rtop}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{rtop}} + \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \end{array} \right\|$$

AASHTO 6.9.2.2-2

AASHTO 6.9.2.2-1

$$I_{top} = 0.228$$

$$I_{2nd} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{r2nd}} \geq 0.2 \\ \left\| \frac{P_u}{P_{r2nd}} + \frac{8}{9} \cdot \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{r2nd}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{r2nd}} + \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \end{array} \right\|$$

$$I_{2nd} = 0.086$$

$$I_{bot} := \frac{P_u}{P_{rbot}} = 0.217$$

$$I_{2nd} < 1 = 1$$

(Should see 1)

$$I_{bot} < 1 = 1$$

(Should see 1)

Now Check for Shear

$$\phi_v := 1.0$$

$$k_v := 1.2 \quad \text{AISC Steel Manual, G7}$$

$$C_v := 1.0$$

$$A_w := 2 \cdot b_f \cdot t_f \quad A_w = 23.989 \text{ in}^2$$

$$V_n := 0.6 \cdot F_y \cdot A_w \cdot C_v \quad V_n = 719.67 \text{ kip}$$

$$V_r := \phi_v \cdot V_n \quad V_r = 719.67 \text{ kip}$$

$$\frac{V_u}{V_r} < 1 = 1 \quad \text{(Should see 1)}$$

## Integral Abutment Design Worksheet (See IAB Manual 2010 Appendix B Design Example)

Project Name: Mount Holly ER P23-1(334)

FB-Pier Corresponding File Name: \Abutment 2 STR 1 scour.in

Analysis By: A. Arles 06/06/2025

Piles Oriented for Weak Axis Bending

### Pile Size Inputs:

Pile := HP 14x117 ▾

$$b_f = 14.9 \text{ in} \quad t_f = 0.805 \text{ in} \quad t_w = 0.805 \text{ in} \quad d = 14.9 \text{ in} \quad k_o = 1.5 \text{ in} \quad A_s = 34.4 \text{ in}^2$$

$$S_y = 59.5 \text{ in}^3 \quad Z_y = 91.4 \text{ in}^3 \quad r_y = 3.59 \text{ in}$$

$$S_x = 172 \text{ in}^3 \quad Z_x = 194 \text{ in}^3 \quad r_x = 5.96 \text{ in}$$

$$D_c := \frac{d}{2}$$

Dc = depth of web in compression

$$t := d - 2 \cdot k_o = 11.9 \text{ in} \quad \lambda_f := \frac{b_f}{2 \cdot t_f} = 9.255 \quad \lambda_w := \frac{t}{t_w} = 14.783$$

$$F_y := 50 \cdot \text{ksi}$$

$$E := 29000 \cdot \text{ksi}$$

### FB-Pier Inputs:

Muy refers to moment about the y-axis of the pile.

$$P_u := 187.5 \cdot \text{kip}$$

$$M_{uy_{top}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{uy_{2nd}} := 0.1 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{top}} := 106.14 \cdot \text{kip} \cdot \text{ft}$$

$$M_{ux_{2nd}} := 6.32 \cdot \text{kip} \cdot \text{ft}$$

$$l_{by_{top}} := 0.1 \cdot \text{in}$$

$$l_{by_{2nd}} := 0.1 \cdot \text{in}$$

$$V_u := 12.76 \cdot \text{kip}$$

$$l_{bx_{top}} := 270.72 \cdot \text{in}$$

$$l_{bx_{2nd}} := 115.08 \cdot \text{in}$$

Resistance Factors

$$\phi_{cl} := 0.50$$

For lower zone of the pile

$\phi_{cu} := 0.70$  For the upper zone of the pile

$\phi_f := 1.0$  For the upper zone of the pile

$R_h := 1.0$  AASHTO C6.10.1.10.1  $C_b := 1.0$  AASHTO C6.10.8.2.3

$R_b := 1.0$  AASHTO C6.10.1.10.2

$Q := 1.0$  use 1 for nonslender elements AASHTO C6.9.4.1.1

Nominal Axial Pile Resistance  
(Check Pile Size chosen)

$$R_n := \frac{P_u}{\phi_c l} \quad R_n = 375 \text{ kip}$$

$$A_{sreq} := \frac{R_n}{(0.8 \cdot F_y)} \quad A_{sreq} = 9.375 \text{ in}^2$$

Check if Area Required is less  
than chosen pile area:

$$A_{sreq} < A_s = 1 \quad \text{(Should see 1)}$$

Elastic Flexural Buckling Resistance

( $k_{top} = 1.2$  first, 2.1 if hinge forms)

$$k_{top} := 1.2$$

$$k_{2nd} := 1.0$$

Calculate Column Slenderness Factors

$$\lambda_{top} := \left( \frac{k_{top} \cdot l_{by_{top}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{top} = 1.952 \cdot 10^{-7}$$

Check:

$$\lambda_{top} < 2.25 = 1 \quad \text{(Should see 1)}$$

$$\lambda_{2nd} := \left( \frac{k_{2nd} \cdot l_{by_{2nd}}}{r_y \cdot \pi} \right)^2 \cdot \left( \frac{F_y}{E} \right) \quad \lambda_{2nd} = 1.355 \cdot 10^{-7}$$

$$\lambda_{2nd} < 2.25 = 1 \quad \text{(Should see 1)}$$

Calculate Nominal Flexural Resistance

$$\lambda_f = 9.255$$

Flange Slenderness

$$\lambda_{pf} := 0.38 \cdot \sqrt{\frac{E}{F_y}} \quad \lambda_{pf} = 9.152$$

Compact Flange

AASHTO 6.12.2.2.1-4

$$\lambda_{rf} := 0.56 \cdot \sqrt{\frac{E}{0.7 \cdot F_y}}$$

$$\lambda_{rf} = 16.12$$

Noncompact Flange

AASHTO 6.12.2.2.1-5

Strong Axis Flexure

$$F_n := \left( 1 - \left( 1 - 0.7 \cdot \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(\lambda_f - \lambda_{pf})}{(\lambda_{rf} - \lambda_{pf})} \right) \cdot R_h \cdot R_b \cdot F_y = 49.778 \text{ ksi}$$

AASHTO 6.10.8.2.2-2

Lateral Torsional Buckling

$$r_t := \frac{b_f}{\sqrt{12 \cdot \left( 1 + \frac{1 \cdot D_c \cdot t_w}{3 \cdot b_f \cdot t_f} \right)}} = 3.982 \text{ in}$$

AASHTO 6.10.8.2.2-9

$$L_p := 1.0 \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 7.992 \text{ ft}$$

$$L_r := \pi \cdot r_t \cdot \sqrt{\frac{E}{F_y}} = 25.108 \text{ ft}$$

$$F_{ntop} := \left\| \begin{array}{l} \text{if } lbx_{top} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{top} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{top} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{top} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{top}}{r_t} \right)^2} \right\| \end{array} \right\|$$

AASHTO 6.10.8.2.3

$$F_{ntop} = 50 \text{ ksi}$$

$$F_{nc2nd} := \left\| \begin{array}{l} \text{if } lbx_{2nd} \leq L_p \\ \left\| R_h \cdot R_b \cdot F_y \right\| \\ \text{if } L_p < lbx_{2nd} \leq L_r \\ \left\| C_b \cdot \left( \left( 1 - \left( 1 - \frac{F_y}{R_h \cdot F_y} \right) \cdot \frac{(lbx_{2nd} - L_p)}{(L_r - L_p)} \right) \cdot R_h \cdot R_b \cdot F_y \right) \right\| \\ \text{if } lbx_{2nd} > L_r \\ \left\| C_b \cdot R_b \cdot \pi^2 \cdot \frac{E}{\left( \frac{lbx_{2nd}}{r_t} \right)^2} \right\| \end{array} \right\| = 50 \text{ ksi}$$

$$F_{nc2nd} = 50 \text{ ksi}$$

$$F_{ctop} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$F_{c2nd} := \min(F_n, F_{nc2nd}) = 49.778 \text{ ksi}$$

$$M_{nxtop} := F_{ctop} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{nx2nd} := F_{c2nd} \cdot S_x = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rxtop} := \phi f \cdot M_{nxtop} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

$$M_{rx2nd} := \phi f \cdot M_{nx2nd} = (8.562 \cdot 10^3) \text{ in} \cdot \text{kip}$$

#### Weak Axis Flexure

$$M_{ny} := \left\| \begin{array}{l} \text{if } \lambda_{pf} < \lambda_f < \lambda_{rf} \\ \left\| \left( 1 - \left( 1 - \frac{S_y}{Z_y} \right) \cdot \left( \frac{\lambda_f - \lambda_{pf}}{0.45 \cdot \sqrt{\frac{E}{F_y}}} \right) \right) \cdot F_y \cdot Z_y \right\| \\ \text{if } \lambda_f \leq \lambda_{pf} \\ \left\| Z_y \cdot F_y \right\| \end{array} \right\|$$

AASHTO 6.12.2.2.1-2

$$M_{ny} = 4554.83 \text{ in} \cdot \text{kip}$$

#### Calculate Flexural Resistance

$$M_{ry} := \phi f \cdot M_{ny}$$

$$M_{ry} = 4554.8 \text{ in} \cdot \text{kip}$$

#### Strong Axis Compression

AASHTO 6.9.4.2.1

AASHTO 6.9.4.1.2-1

$$P_{extop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lbx_{top}}{rx}\right)^2} = (3.314 \cdot 10^3) \text{ kip}$$

$$P_{ex2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lbx_{2nd}}{rx}\right)^2} = (2.641 \cdot 10^4) \text{ kip}$$

$$P_o := Q \cdot F_y \cdot A_s = (1.72 \cdot 10^3) \text{ kip}$$

$$P_{nxtop} := \left\| \begin{array}{l} \text{if } \frac{P_{extop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{extop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{extop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{extop} \right\| \end{array} \right\|$$

$$P_{nxtop} = 1384.15 \text{ kip}$$

$$P_{nx2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ex2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ex2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ex2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ex2nd} \right\| \end{array} \right\|$$

$$P_{nx2nd} = 1673.75 \text{ kip}$$

$$P_{eytop} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{top} \cdot \frac{lby_{top}}{ry}\right)^2} = (8.812 \cdot 10^9) \text{ kip}$$

$$P_{ey2nd} := \pi^2 \cdot \frac{E \cdot A_s}{\left(k_{2nd} \cdot \frac{lby_{2nd}}{ry}\right)^2} = (1.269 \cdot 10^{10}) \text{ kip}$$

## Nominal Structural Pile Resistance

$$P_{nytop} := \left\| \begin{array}{l} \text{if } \frac{P_{eytop}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{eytop}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{eytop}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{eytop} \right\| \end{array} \right\|$$

$$P_{nytop} = 1720 \text{ kip}$$

$$P_{ny2nd} := \left\| \begin{array}{l} \text{if } \frac{P_{ey2nd}}{P_o} \geq 0.44 \\ \left\| 0.658 \left( \frac{P_o}{P_{ey2nd}} \right) \cdot P_o \right\| \\ \text{if } \frac{P_{ey2nd}}{P_o} < 0.44 \\ \left\| 0.877 \cdot P_{ey2nd} \right\| \end{array} \right\|$$

$$P_{ny2nd} = 1720 \text{ kip}$$

$$P_{nbot} := 0.66^{0.0} \cdot F_y \cdot A_s$$

$$P_{nbot} = 1720 \text{ kip}$$

## Factored Structural Pile Resistance

$$P_{rytop} := \phi cu \cdot P_{nytop}$$

$$P_{rytop} = 1204 \text{ kip}$$

$$P_{ry2nd} := \phi cu \cdot P_{ny2nd}$$

$$P_{ry2nd} = 1204 \text{ kip}$$

$$P_{rxtop} := \phi cu \cdot P_{nxtop}$$

$$P_{rxtop} = 968.91 \text{ kip}$$

$$P_{rx2nd} := \phi c u \cdot P_{ny2nd}$$

$$P_{rx2nd} = 1204 \text{ kip}$$

$$P_{rbot} := \phi c l \cdot P_{nbot}$$

$$P_{rbot} = 860 \text{ kip}$$

$$P_{rtop} := \min(P_{rxtop}, P_{rytop}) = 968.908 \text{ kip}$$

$$P_{r2nd} := \min(P_{rx2nd}, P_{ry2nd}) = (1.204 \cdot 10^3) \text{ kip}$$

Check to make sure pile size is not too big:

$$\frac{P_u}{P_{rtop}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{r2nd}} > 0.2 = 0$$

(Should see 1)

$$\frac{P_u}{P_{rbot}} < 1 = 1$$

(Should see 1)

Check Moment that will cause plastic hinge

$$M_p := \frac{9}{8} \cdot \left(1 - \frac{P_u}{P_{rtop}}\right) \cdot M_{ry}$$

$$M_p = 4132.6 \text{ in}\cdot\text{kip}$$

$$M_p = 344.4 \text{ ft}\cdot\text{kip}$$

$$M_{uytop} > M_p = 0$$

(Should see 1)

Since the Applied moment exceeds the moment that would create a plastic hinge, it can be assumed that the pile head has plastically deformed.

Now, make sure the 2nd segment DOES NOT develop a plastic hinge. A plastic hinge in this segment will cause the pile to fail!

$$I_{top} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{rtop}} \geq 0.2 \\ \left\| \frac{P_u}{P_{rtop}} + \frac{8}{9} \cdot \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{rtop}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{rtop}} + \left( \frac{Mux_{top}}{M_{rxtop}} + \frac{Muy_{top}}{M_{ry}} \right) \right\| \end{array} \right\|$$

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$$I_{top} = 0.246$$

$$I_{2nd} := \left\| \begin{array}{l} \text{if } \frac{P_u}{P_{r2nd}} \geq 0.2 \\ \left\| \frac{P_u}{P_{r2nd}} + \frac{8}{9} \cdot \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \\ \text{if } \frac{P_u}{P_{r2nd}} < 0.2 \\ \left\| \frac{P_u}{2.0 \cdot P_{r2nd}} + \left( \frac{Mux_{2nd}}{M_{rx2nd}} + \frac{Muy_{2nd}}{M_{ry}} \right) \right\| \end{array} \right\|$$

$$I_{2nd} = 0.087$$

$$I_{bot} := \frac{P_u}{P_{rbot}} = 0.218$$

$$I_{2nd} < 1 = 1$$

(Should see 1)

$$I_{bot} < 1 = 1$$

(Should see 1)

Now Check for Shear

$$\phi_v := 1.0$$

$$k_v := 1.2 \quad \text{AISC Steel Manual, G7}$$

$$C_v := 1.0$$

$$A_w := 2 \cdot b_f \cdot t_f \quad A_w = 23.989 \text{ in}^2$$

$$V_n := 0.6 \cdot F_y \cdot A_w \cdot C_v \quad V_n = 719.67 \text{ kip}$$

$$V_r := \phi_v \cdot V_n \quad V_r = 719.67 \text{ kip}$$

$$\frac{V_u}{V_r} < 1 = 1 \quad \text{(Should see 1)}$$