



I-405 BRICKYARD TO SR527 IMPROVEMENT PROJECT

## JUANITA CREEK FISH PASSAGE

### STRUCTURAL DESIGN CALCULATION REPORT

FISH PASSAGE EAST PORTAL

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# **Part 1**

## **I-405, Brickyard to SR 527 Improvement Project**

### **Juanita Creek Fish Passage**

#### **East Portal Walls Permanent Structures Design**

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# 1. INTRODUCTION

**Scope of the Report:** This report was prepared by AECOM and corresponds to the design of the permanent support of the wingwalls and headwalls to access the Juanita Creek Fish Passage Tunnel of I-405, Brickyard to SR 527 Improvement Project, as shown in Figure 1.

This report comprises the East Portal which is designed as tie-back soldier pile walls with a cast in place concrete fascia. The Preliminary design drawings of the Juanita Creek Fish Passage Portals, which present the design based on the analyses documented in this report, are provided in Appendix A.

**Exclusion:** The design of the final lining as well as the tunnel excavation sequence and temporary support of the headwalls are not part of the scope of this report and are submitted separately.

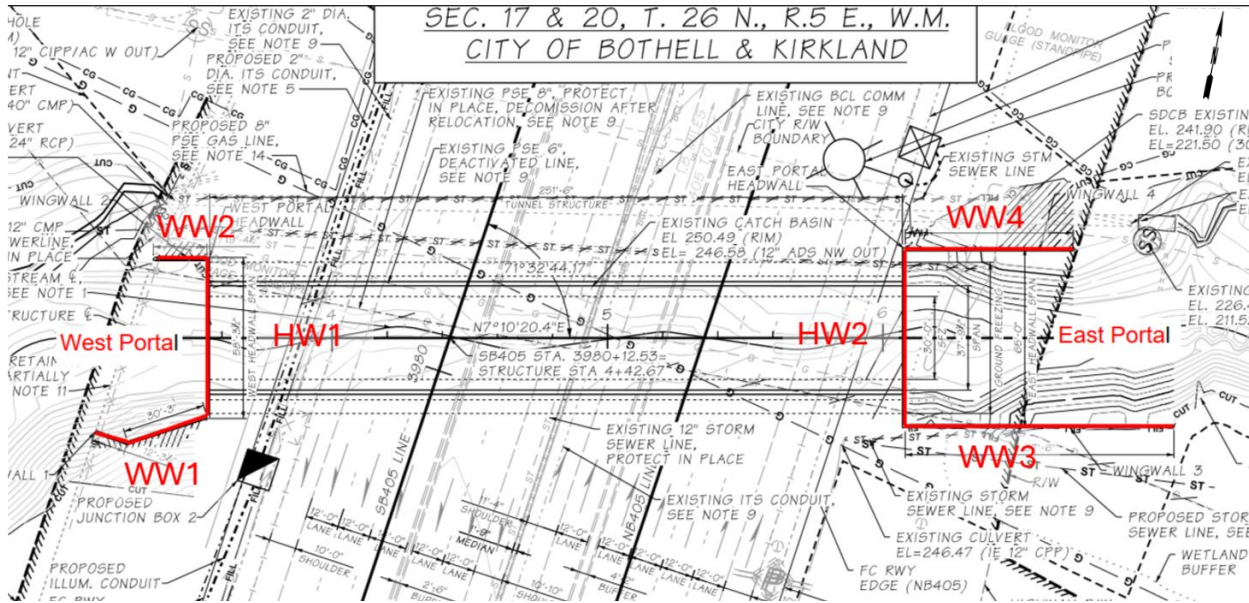


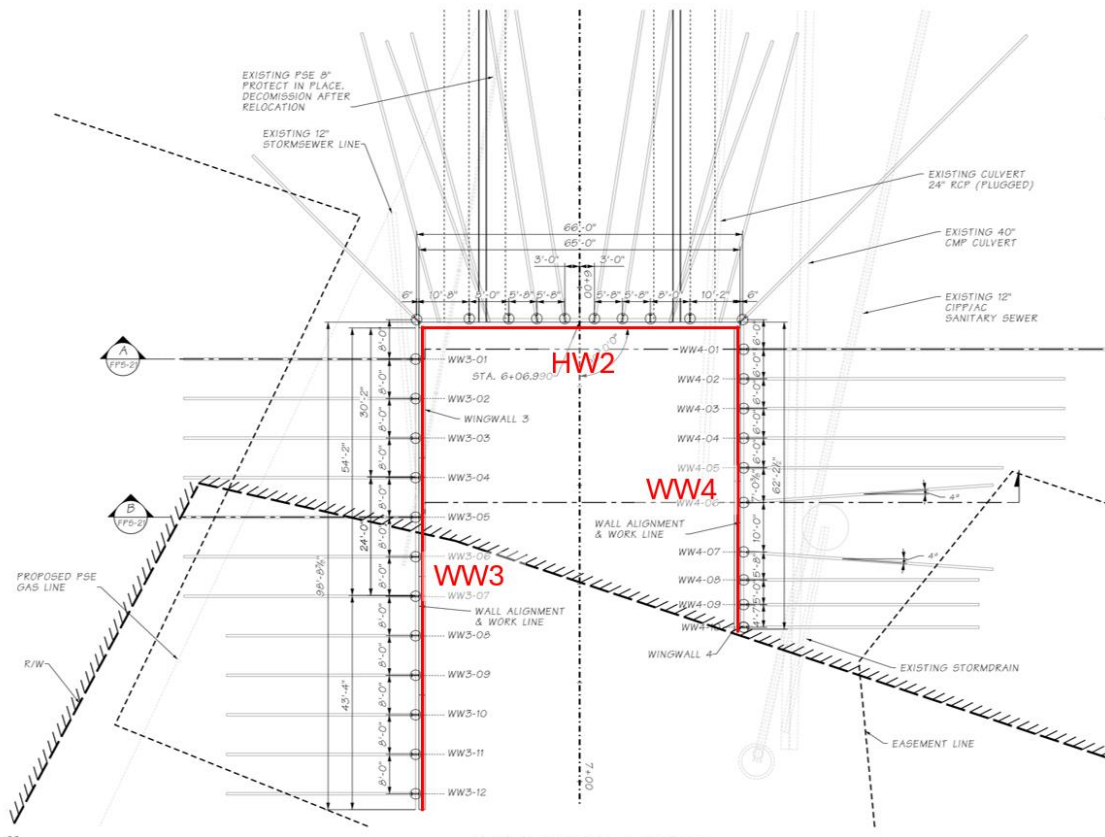
Figure 1 Juanita Creek fish passage location plan

**Design verifications deferred:** The following design items are not included in the preliminary engineering calculation report and will be included in the final design submission:

- Geotechnical capacity of the pile embedment for vertical (axial) force
- Tieback pocket / cover plates.

## 1.1. Description of design for East Portal

The East Portal at Juanita Creek Fish passage comprises permanent walls for Wingwall 3 (WW3), Wingwall 4 (WW4) and Headwall 2 (HW2). These walls are designed as soldier pile walls with temporary lagging, and permanent ground anchors. The permanent wall facing is formed by a reinforced, cast-in place concrete fascial wall. The presence of nearby utilities, including the existing stream culvert, has driven the portal location and walls configuration, in particular in terms of the permanent ground anchors layout. Figure 2 shows the plan view of the East Portal.



**Figure 2 East portal walls. Location plan**

**Wingwall 3 (WW3):** The total length of Wingwall 3 is 98'- 8" and it has a variable height of excavation in front of the wall ranging from 31ft to 42ft. Depending on the maximum height of each wall section, 2 to 3 rows of permanent tie-back anchors will be installed. The permanent fascia wall is 1' – 2" thick.

**Wingwall 4 (WW4):** The total length of Wingwall 4 is 62'- 2", with a variable excavation height in front of the wall ranging from 34 ft to 42 ft. Depending on the maximum height of each wall section, 1 to 3 rows of permanent tie-back anchors will be installed. The permanent fascia wall is 1' – 2" thick.

**Headwall 2 (HW2):** The headwall spans 68' – 7", between both wingwalls. This headwall width allows for sufficient room for the temporary works of the SEM tunnel to be performed (e.g. ground freezing works). This structure is being designed to be permanently supported by ground anchors and the soldier piles. The headwall also relies on lateral support provided by the tunnel liner, at its interface with the tunnel liner, and by the lateral wingwalls. The permanent fascia wall is 1' – 2" thick.

The East Portal is classified as a non-visible structure; hence, Type 1 Aesthetics apply, with no requirements for finishing nor wall capping.

## 2. DESIGN CRITERIA

### 2.1. Design Standards and Technical Requirements

This report was prepared based on the design requirements listed below and the data provided in the RFP by the Washington State Department of Transportation (WSDOT):

- AASHTO LRFD Bridge Design Specifications, 9<sup>th</sup> Edition, 2020
- AWS D1.1 Structural Steel Welding Code
- AISC Steel Construction Manual, 15th Ed.
- ACI 318-20 Building Code Requirements for Structural Concrete
- WSDOT Geotechnical Design Manual. – M 46-03.16, February 2022.
- WSDOT Bridge Design Manual M 23-50.21, June 2022, Chapter 8
- WSDOT Standard Plans M 21-01 October 2023
- FHWA General Engineering Circular No. 4 “Ground Anchors and Anchored Systems”, June 1999 (GEC4).
- I-405 / Brickyard to SR-527. Improvement Design-Build Project. Design Criteria for Bridges and Other Structures. December 2023.
- Interstate-405 - Urban Design Criteria, December 2022.

### 2.2. Project Inputs

General Inputs to this design include:

- Soil and Rock Properties for Design, I-405, Brickyard to SR 527 Improvement Project King and Snohomish Counties, Washington. Geoengineers, 2023.
- Final Geotechnical Engineering Report Design Package #9. I-405, Brickyard to SR 527 Improvement Plan King and Snohomish Counties, Washington. Terracon, January 2025.
- RFP Appendix H-08 I-405 MP 21.94 Juanita Creek (988602): Preliminary Hydraulic Design Report.

### 2.3. Assumptions

The following table summarizes the assumptions taken on this design package.

**Table 1 List of assumptions**

Item	Assumption
Geotechnical design parameters	The design is based on the geotechnical parameters presented in Final Geotechnical Engineering Report Design Package #9 dated January 2025
Drained conditions	Assumed the soils behaved in drained conditions, with no pore water pressure build up nor undrained shear strength mobilization.

Item	Assumption
Utilities location	The location of the utilities is assumed to be accurate from as-built information available.
Utilities inactive or to be dismantled	Utilities in direct clashing with the portal walls are to be dismantled, diverted as required, and can be drilled according to Contractor's methods. Utilities currently inactive can also be drilled through during piling or tie-back works.
Construction sequence	The design of the headwall considers that the temporary condition does not produce loads larger than the permanent condition.
Temporary excavation	An additional excavation of 3 ft is considered to accommodate ground freezing works related equipment.
Construction tolerances	Pile location: 1 inch. Pile verticality: 0.5 %
Construction loads	250 psf as per section 15-7.3.3 in the GDM WSDOT
Fascia bottom level	Scour assumed to impact the fascia wingwalls. Fascia bottom level driven by tunnel footing elevation.

## 2.4. Major Constraints

Major constraints which have affected the design are summarized in Table 2.

**Table 2 Major Constraints**

Constraint	Impact to design
<ul style="list-style-type: none"> <li>- Existing 24" RCP culvert</li> <li>- Existing 40" CMP culvert</li> <li>- Existing 30" CMP culvert</li> <li>- Existing 18" CMP culvert</li> <li>- SDCB Existing Manhole</li> </ul>	In the northern area, four utilities run parallel to wingwall 4. The arrangement of the tie-back anchors of this wall has been designed to avoid any interference with these utilities.

### 3. GEOTECHNICAL CONDITIONS

#### 3.1. Geological setting

The site is located within the Puget Lowland, an elongated basin that has been filled with a complex sequence of glacial and nonglacial sediments. Surficial deposits are mapped on the USGS MF-1747 Bothell Quadrangle as several units of continental glacial drift deposited during the Vashon Glaciation. At the Juanita Creek location these glacial deposits have been eroded and subsequently infilled with Quaternary alluvium.

For this project, the soils were classified utilizing Engineering Stratigraphic Units (ESU).

According to the geological investigation, the following Engineering Stratigraphic Units can be identified at the project site:

- **ESU 1B (Fill):** Existing Fill: Granular, Cohesionless, Loose to Very Dense. Existing fill soils within the I-405 roadway prism consisting of sand with variable silt and gravel content, with some areas of silty fill. Fill soils may locally include cobbles and boulders.
- **ESU 2A:** Alluvium: This ESU generally consists of unconsolidated, stratified clay, silt, and significant organic matter. There may also be sand and gravel near the base of this ESU.
- **ESU 5 (Advance Outwash (Qva)):** This ESU generally consists of medium dense to very dense silty sand and gravel with variable silt content and some silt layers. Cobbles and boulders may also be encountered within this ESU.
- **ESU 6B (Transitional Beds (Qtb)):** undisturbed. This ESU generally consists of very stiff to hard silt and clay with some interbedded granular material. Where significant thickness of soils with a clay fraction less than 20% are present, these sublayers will be identified but will still be considered part of ESU 6B.

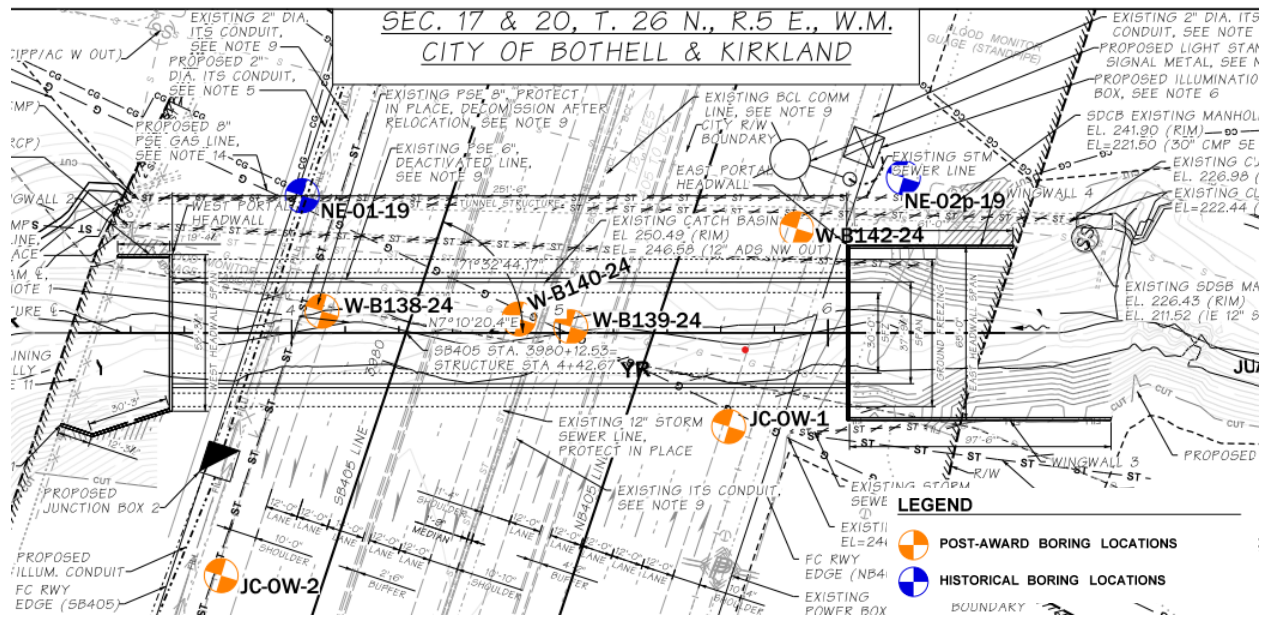
A detailed description of the geological setting as well as the correlations used to estimate the parameters are discussed in the Geotechnical Engineering Report (GER) [Terracon, 2025].

#### 3.2. Available Geotechnical Data

The design has been carried out based on available geotechnical site investigation information in the proximity to the proposed structure comprising logs of boreholes together with laboratory testing on recovered samples of soil – refer to Terracon, 2025. The representative boreholes for this project are shown in **Table 3**

**Table 3 Summary of geotechnical investigation points**

Borehole ID	Completion Date	Easting (X)	Northing (Y)	Ground Elevation Corrected to NAVD88 [ft]	Depth below existing ground level [ft]	GW depth [ft]
NE-01-19	-	-	-	248.9	57.4	34.2
NE-02p-19	-	-	-	241	79.8	17.2
W-B138-24	2/23/2024	1635070.4	598337.8	250.5	76.5	34.0
W-B139-24	1/23/2024	1635162.4	598350.1	250.6	101.5	33.0
W-B140-24	1/25/2024	1635142.9	598349.2	250.7	101.0	34.0



**Figure 3 Geotechnical investigation points at Juanita Creek Fish Passage (extracted from Terracon, 2025)**

### 3.3. Geotechnical Design Parameters

The engineering properties for each of the units provided in **Table 4** are included in the GER and are based on the correlations and typical values described in the Soil and Rock Properties for Design (Geoengineers 2023).

**Table 4: Engineering Properties for Juanita Creek Fish Passage (after GER)**

Parameter	Streambed Sediments	ESU 1B	ESU 2A	ESU 5	ESU 6B
Total Unit Weight [pcf]	130	110	110	135	130
Buoyant Unit Weight [pcf]	68	48	48	73	68
Soil Friction Angle [deg]	36	34	34	40	36
Corrected SPT, $N_{1(60)}$ [blows/ft]	-	42	14	86	94
Active Earth Pressure Coeff. Level Ground	0.23	0.25	0.25	0.20	0.23
At-Rest Earth Pressure Coeff. Level Ground	0.41	0.44	0.44	0.36	0.41
Seismic Active Earth Pressure Coeff. <sup>2</sup> , Level Ground	0.42	0.45	0.45	0.37	0.42
Active Earth Pressure Coeff. Ground Sloping at 4H:1V	-	0.30	0.30	0.23	-
At-Rest Earth Pressure Coefficient, Ground Sloping at 4H:1V	-	0.55	0.55	0.44	-
Seismic Active Earth Pressure Coeff. <sup>2</sup> , Ground Sloping at 4H:1V	-	0.64	0.64	0.48	-
Active Earth Pressure Coeff. Ground Sloping at 2H:1V	-	0.40	0.40	0.29	-
At-Rest Earth Pressure Coeff. Ground Sloping at 2H:1V	-	0.64	0.64	0.52	-
Seismic Active Earth Pressure Coeff. <sup>2</sup> , Ground Sloping at 2H:1V	-	1.14	1.14	1.10	-
Passive Earth Pressure Coeff. Level Ground <sup>1</sup>	9.2	7.7	7.7	11.3	9.2
Seismic Passive Earth Pressure Coeff. Level Ground <sup>1,2</sup>	6.4	5.5	5.5	8.9	6.4
LPILE Model	API Sand	API Sand	API Sand	API Sand	API Sand
p-y modulus, above groundwater table [pci]	-	120	120	255	-
p-y modulus, below groundwater table [pci]	95	-	75	145	95
Nominal grout-ground bond strength <sup>3</sup> [psi]	-	18	18	35	27

Parameter	Streambed Sediments	ESU 1B	ESU 2A	ESU 5	ESU 6B
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Notes:

1. Passive pressure and seismic passive pressure may be applied over a width equal to 3 times the soldier pile shaft diameter or the pile spacing, whichever is less. Values shown are nominal (un-factored).
2. Seismic earth pressure coefficients are based on a seismic coefficient of 0.25, corresponding to a site-class adjusted peak ground acceleration of 0.50 and allowing for 1 to 2 inches of permanent displacement following the Safety Evaluation Earthquake (SEE).
3. Bond strength values shown are for gravity-grouted anchors.

### 3.4. Groundwater Conditions

The Design Groundwater Elevation (DGWE) at Juanita Creek Fish Passage have been presented in the GER, Terracon 2025. The values are summarized in **Table 5** below.

**Table 5: Design Groundwater Elevation for Juanita Creek Fish Passage. East Portal**

Structure	DGWE [ft]
Headwall 2	217.1
Wingwall 3 (East end)	220.1
Wingwall 3 (West end)	217.1
Wingwall 4 (East end)	219.0
Wingwall 4 (West end)	217.1

### 3.5. Pseudo-Static Ground Acceleration

As per indicated in the GER, a site-class adjusted peak ground acceleration of 0.501g has been considered at the location of the project. Allowance for 1 to 2 inches of permanent displacement following the Safety Evaluation Earthquake (SEE) is anticipated.

For the pseudo-static analysis carried out, a horizontal acceleration coefficient (Kh) is applied to the models. According to AASHTO Chapter 11.6.5.2.2 if the wall is capable of lateral displacement of 1 to 2 inches or more during the design seismic event then Kh may be reduced to 0.5\*PGA.

A summary of the seismic design parameters assumed in the design is provided in **Table 6**.

**Table 6: Seismic design parameters**

Structure ID	Site Class	Return Period [yr]	PGA [g]	Kh [g]
Juanita Creek Fish Passage.	C	975	0.501	0.25

## 4. DESIGN METHODOLOGY

### 4.1. Design approach

The structure was designed in compliance with the AASHTO LRFD Bridge Design Specifications for retaining walls and anchored systems. The methodology follows the Load and Resistance Factor Design framework, ensuring stability, serviceability, and durability under factored load combinations. Based on this, the limit states considered in the design are:

- Strength limit state: Strength 1
- Service limit state: Service 1
- Extreme event limit state: Extreme 1

The dynamic conditions for the Extreme 1 are modelled following:

- Mononobe-Okabe pseudo static approach for earth pressure calculations
- Explicit acceleration input in finite-element software (Plaxis 2D)

The Service 1 is verified when deflections of the soldier pile wall are less than 1 inch.

### 4.2. Software

The following software have used to perform the design analysis:

**Table 7: Software used in the design analysis**

Software	Version
Plaxis 2D	2024
PYWall	2022
SAP2000	V25

In-house Excel spreadsheets are used to process the results, derive the maximum forces and undertake the design verification.

### 4.3. Load Combinations and Factors

The limit states load combinations, and load factors used for structural design are in accordance with WSDOT BDM Section 8 and the AASHTO LRFD Table 3.4.1-1. Load combinations for the structural design of retaining walls shall be as presented below in **Table 8**:

**Table 8: Load combinations and load factors**

Limit state	DC	EH	ES	WA	LS
Strength 1	1.25	Active: 1.5 AEP: 1.35	1.5	1.0	1.75
Extreme 1	1.0	1.0	1.0	1.0	1.0
Service 1	1.0	1.0	1.0	1.0	1.0

The Plaxis models adopted a working stress approach where the soil parameters, structural properties and permanent loads were not factored. Live loads are factored by  $1.75/1.5 = 1.17$ , so to account for the larger load factor required on live loads. Then, the structural forces obtained from the analyses are factorized by 1.5 (as per the active pressure load factor) to obtain the Strength 1 design structural forces.

The global stability is also assessed. These analyses are undertaken in Plaxis, where the global stability is estimated by reducing the strength of the entire soil and rock by a common factor until failure occurs - decreasing the resisting forces and increasing the stabilizing forces simultaneously, referred as  $c/\phi$  reduction method. This factor of safety is then defined by that factor of failure (Msf). According to Chapter 7.4 of the WSDOT GDM, the required FoS for global stability are as indicated in Table 10:

**Table 9. Required Global Stability Factor of Safety Adopted for Retention Design**

Wall Condition	Target Factor of Safety (Msf) (PLAXIS $\phi/c$ Reduction Method)
Permanent static condition	1.3
Temporary static condition	1.25
Temporary pseudo-static condition	1.1

## 4.4. Analysis procedure

### 4.4.1. Wingwalls analysis

The wingwalls are designed following a Soil Structure Interaction (SSI) analysis, using finite element modelling (FEM) software Plaxis 2D to check the following:

- Global Stability (Factor of Safety) of the structure.
  - o Design of the soldier piles size and tie-back anchors support.
  - o Minimum depth of embedment
- Structural elements:
  - o Structural forces within the soldier piles and tie-backs.
  - o Deflection and settlement of the piles
- Settlement and deformations of any adjacent utility at the back of the wall.

Calculation scenarios covering construction stages, long-term condition and seismic loading are considered.

The results obtained from these models are then verified for:

- Soldier piles bending moment and shear capacity.
- Deflections limitation

An additional cross check is undertaken in PYWALL: Two design sections are modelled, one for each wingwall, and their results are compared against the same design sections in Plaxis 2D.

The permanent fascia is designed using in-house spreadsheets. For specific areas, the fascia is modelled in SAP2000, so the relevant moments and shear forces are obtained. Earth pressures are calculated and used as input for the fascia design at the wingwalls. For further details refer to APPENDIX D:  
Fascia structural calculations.

#### 4.4.2. Headwall analysis

The headwall is designed in SAP2000, where the fascia wall, the soldier piles and the tie-backs are modeled. Earth pressures are derived for the headwall's geometry and tie-backs configuration, from which also loadings in the tie-backs are obtained. Apparent earth pressure loading is calculated for both the static case and dynamic case

The earth pressures are used in the SAP2000 model as acting directly over the fascia elements. The tie-backs are pre-stressed to load equivalent to the lock off load. However, the pre-stress applied to the tie-backs is adjusted to verify the deformations of the wall are within the limits defined.

The results obtained from this model are then verified for:

- Soldier piles bending moment and shear capacity.
- Deflections limitation

For further details refer to APPENDIX D:  
Fascia structural calculations.

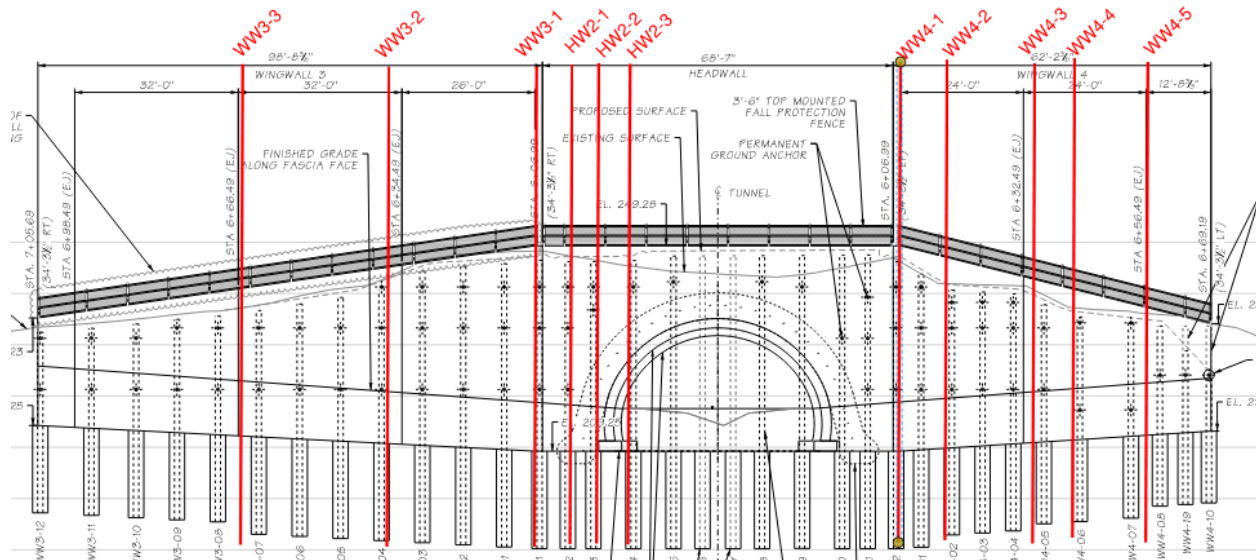
### 4.5. Design Sections

The following sections shown in Table 7 are identified as relevant to capture the structure geometry and changes in wall elevation and soldier piles and tie-backs layout

**Table 10: Design sections**

Design sections ID		Station [ft]	Retained height [ft]
Wingwall 3	WW3-1	6+06.99 to 6+38.36 Lt	42'
	WW3-2	6+38.36 to 6+62.36 Lt	36'-2"
	WW3-3	6+62.36 to 7+05.69 Lt	31' - 1"
Wingwall 4	WW4-1	6+06.99 to 6+15.49 Rt	42'
	WW4-2	6+15.49 to 6+33.49 Rt	39'-6"
	WW4-3	6+33.49 to 6+39.19 Rt	34'-7"
	WW4-4	6+39.19 to 6+56.36 Rt	32'-10"
	WW4-5	6+56.36 to 6+69.19 Rt	28'-5"
Headwall 2	HW2-1	6+06.99	42'
	HW2-2	6+06.99	42'
	HW2-3	6+06.99	42'

Note that the retained height is taken from finish grade to the bottom of the fascia. In the temporary condition, an additional excavation of 3 ft is considered to accommodate ground freezing works related equipment.



**Figure 4 Elevation view with design sections location**

## 4.6. Design Ground Profile

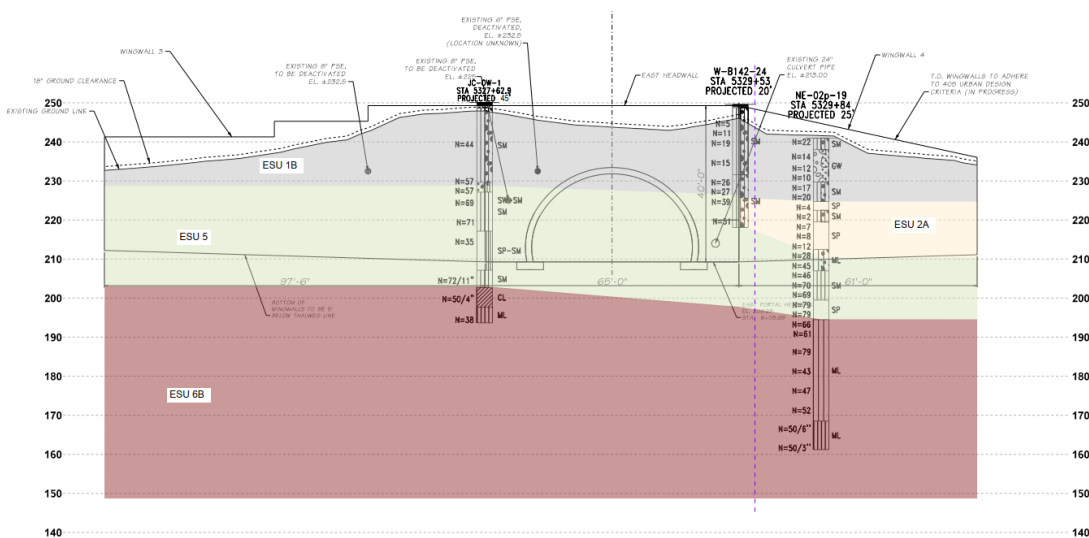
Geological long sections along the work line of the tunnel portals were developed using the project geological model interpreted from the available geotechnical data, as presented in Section 3. The generalized ground profiles adopted for the design sections are summarized in Table 8. **Error! Reference source not found.**

**Table 11: Design ground profiles**

Retaining Wall Section	Engineering Stratigraphic Units. Top of layer elevation (FAMSL)				Top of Wall Level <sup>(1)</sup>
	1B	2A	5	6B	
WW3-1	248.9	NA	226.0	192.5	249.25
WW3-2	248.9	NA	226.0	192.5	245.30
WW3-3	238.0	NA	226.0	192.5	241.45
WW4-1	248.9	225.3	210.2	194.2	249.1
WW4-2	242.0	225.3	210.2	194.2	246.1
WW4-3	241.5	225.3	210.2	194.2	240.6
WW4-4	238.1	225.3	210.2	194.2	240.6
WW4-5	235.8	225.3	210.2	194.2	236.6
HW2		225.3	210.2	194.2	249.1

Note:

1. Considered from top of Fascia wall



**Figure 5 Geotechnical profile (extracted from Terracon, 2025)**

## 5. STRUCTURAL DESIGN

### 5.1. Soldier pile walls

The excavation support for the portal structure consists of a soldier pile wall system, designed to resist lateral earth pressures through a combination of steel piles, tie-backs, and horizontal lagging.

The system consists of vertical W-type steel beams (soldier piles) installed at regular intervals with tie-backs to resist lateral earth pressures. These piles are embedded in drilled hole, (3' – 3" diameter), which are backfilled with 4000 psi concrete below excavation limit. The minimum embedment depth into competent soil is designed to provide sufficient structural resistance to lateral, vertical, and overturning forces.

Lateral soil pressures are transferred to the soldier piles through horizontal lagging. During excavation, temporary timber planks are installed incrementally. For permanent conditions, a cast-in-place concrete fascia will be installed to ensure long-term durability and structural integrity.

The soldier piles were designed to resist the flexural, axial, and shear loads obtained from the analyses. The piles consist of wide-flange sections made of ASTM A992 steel, with a specified yield strength of 50 ksi. To facilitate the attachment and structural support of the concrete fascia, welded studs will be installed to the flange faces of the soldier piles.

Due to the height of the walls, permanent tie-back anchors are required to control deflection and provide additional lateral support. These anchors will be installed in multiple rows at specific locations and angles through prefabricated pockets within the soldier piles as excavation progresses.

The prefabricated pockets for the anchor's installation are constructed with a HSS pipe sleeve passing through the center of the pile section. This pipe sleeve is welded to the web at the top and bottom, and cover plates attached to the outside of each flange. The pipe wall thickness and the cover plate thickness are to be sized to replace and reinforce the soldier pile web and flanges removed by the tie-back hole.

The steel section and spacing for the soldier piles in each design section are summarized in **Error! Reference source not found.** Refer to drawings in **APPENDIX A: Preliminary Design Drawings** for further details.

**Table 12. Soldier piles section and spacing**

Design section	Soldier Pile Section	Pile Spacing [ft]
WW3-1	W21X101	8
WW3-2	W21X101	8
WW3-3	W21X101	8
WW4-1	W21X101	6

Design section	Soldier Pile Section	Pile Spacing [ft]
WW4-2	W21X101	6
WW4-3	W21X101	6
WW4-4	W21X101	Variable
WW4-5	W24X104	Variable
HW2-1	W21X101	5
HW2-2	W21X101	5
HW2-3	W21X101	6

### 5.1.1. Soldier piles capacity verification

From the results obtained in the analyses, the steel pile sections are verified to meet:

- Flexural capacity as per AASHTO LRFD (6.10.6.2):

The moment capacity is calculated as:

$$\Phi_f M_p = \Phi_f S_x F_y$$

Where:

- $\Phi_f$  is the flexural resistance factor (after article 6.5.4.2)
- $M_n$  is the nominal flexural resistance based on the elastic moment.
- $S_x$  is the elastic section modulus.
- $F_y$  is the steel yield stress.

- Shear capacity as per AASHTO LRFD Article 6.10.9

The shear capacity is calculated as:

$$\Phi_v V_p = \Phi_{vf} 0.58 F_{yw} D t_w$$

Where:

- $\Phi_v$  is the shear resistance factor (after article 6.5.4.2)
- $V_p$  is the plastic shear force.
- $D$  is the clear web height.
- $t_w$  is the web thickness.
- $F_y$  is the steel yield stress for the web.

## 5.2. Permanent Tie-back

Tie-back are used in conjunction with soldier pile walls to provide stability during the excavation and permanent lateral support of the portals. These tie-back transfer lateral forces from the wall to the surrounding soil, using high-strength, low-relaxation, multi-strand steel tendons grouted into a pre-drilled borehole. The permanent ground anchor consists of a bond zone (grouted length), a free length (unbonded), and an anchor head that connects to the soldier pile. The design and installation process involves drilling through the prefabricated pockets within the soldier piles. The bond zone will be located beyond the potential failure plane as per AASHTO Figure 11.9.1-1 in Section 11.9.

The location and inclination of the tie-backs in the headwall and Wingwall 4 is driven by the presence of utilities. The tie-backs are located to leave a minimum distance of 3 ft to the nearby assets.

**Table 13** summarizes the tie-backs solution implemented for each wall section analyzed.

**Table 13. Geometry characteristics of the permanent tie-back**

Design section	No. Rows	Inclination angle [°]
WW3-1	3	30/30/30
WW3-2	2	30/30
WW3-3	2	30/30
WW4-1	3	15/15/40
WW4-2	3	15/15/40
WW4-3	2	15/45
WW4-4	2	25/45
WW4-5	1	25
HW2-1	3	25 / 25 /30
HW2-2	2	25 / 25
HW2-3	1	20

## 5.3. Permanent concrete fascia

The concrete fascia spans horizontally between soldier piles and is connected to each pile by regularly spaced welded studs in both wingwalls. The concrete fascia will be continuous across

the face in the soldier piles between expansion joints, resulting in multi-span conditions for design. The spacing of expansion joints are generally 24 feet.

Concrete compressive strength for the fascia is 4000 psi. Reinforcement steel bars will be uncoated, grade 60, compliant with ASTM A706.

The fascia walls are designed with a minimum thickness of 1'-2", for both headwall and wingwalls. Reinforcements will not continue through expansion joints, which will be filled with expansion filler. The mats of bars in each face are maintained parallel to each other. The welded studs in tension are to be evaluated considering steel strength, pullout, and concrete breakout failure modes.

There is no specific requirement for the finishing of the fascia.

For further details on the analysis, refer to **APPENDIX D: Fascia structural calculations.**

#### **5.4. Durability**

The assumed rate for the section loss due to corrosion in steel pile sections is 0.00075 in/yr for a non-marine aggressive soil condition. Based on a design of 75-year life span of the structure, the total corrosion allowance for all the pile section would be 0.1125 inches. This allowance is considered for the entire perimeter of the soldier pile section and the different steel elements associated with these piles.

The permanent ground anchor will have double corrosion protection.

The reinforced concrete fascia will have a minimum rebar cover of 2".

## 6. GEOTECHNICAL DESIGN

### 6.1. Earth pressure

For the design sections and using the ground parameters recommended by the geotechnical engineer, earth pressure diagrams were computed. For the static condition the apparent earth pressure distribution was applied to the wall as indicated in AASHTO LRFD 3.11.5.7. For the verification in seismic conditions the Mononobe-Okabe method was considered for the estimation of the seismic active earth pressure coefficient,  $K_{AE}$  as shown in AASHTO LRFD A11.3.1.

These diagrams were used for the verification of the permanent fascia and the analysis of the permanent condition of the headwall. For the wingwalls, earth pressures acting on the soldier piles, as well as tie-back loads, were computed directly on the Plaxis 2D models.

From the apparent earth pressure calculated, tie-back loads are derived following the tributary area method as described in AASHTO LRFD 11.9.5.1. These loads are used to inform the pre-stress load (i.e. lock off loads) for the SAP 2000 model of the headwall.





### 6.2. Geotechnical Design in Plaxis

The geotechnical design undertaken in Plaxis 2D has considered the following:

- The soil units were modelled as Mohr-Coulomb model.
- The structural elements such as soldier pile walls were modelled as plate elements.
- The equivalent stiffness per linear foot was calculated considering the diameter and spacing of the piles.
- The unbonded length of the tie-back anchors was modelled as node-to-node anchor elements with the axial stiffness defined in terms of the number of strands for each anchor.
- The anchor bond length is modelled as an embedded beam element defined by the drilling diameter and the grout-ground bond strength.
- To allow for a long-term reduction of the steel section due to corrosion the pile flexural and axial stiffness (EA, EI) were adjusted accordingly as indicated in Section 5.4.

The properties for the design of the soil materials (**Table 14** and **Table 15**), plates (**Table 16**) and anchors (**Table 17** and **Table 18**) considered in the Plaxis 2D calculations are summarized in the tables below.





**Table 14. Soil properties**

Identification number		1	2	3	4
Identification		ESU 1B	ESU 2A	ESU 5	ESU 6B
Soil model		Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Drainage type		Drained	Drained	Drained	Drained
Colour					
Comments					
y_unsat	lbf/ft <sup>3</sup>	110,0	110,0	135,0	130,0
y_sat	lbf/ft <sup>3</sup>	110,0	110,0	135,0	130,0
e_init		0,5000	0,5000	0,5000	0,5000
n_init		0,3333	0,3333	0,3333	0,3333
E'_ref	lbf/ft <sup>2</sup>	725,0E3	150,0E3	12,98E6	8,540E6
v (nu)		0,2900	0,2400	0,3900	0,4000
G_ref	lbf/ft <sup>2</sup>	281,0E3	60,48E3	4,667E6	3,050E6
E_oed	lbf/ft <sup>2</sup>	950,1E3	176,8E3	25,88E6	18,30E6
E'_inc	lbf/ft <sup>2</sup> /ft	0,000	0,000	0,000	0,000
y_ref	ft	0,000	0,000	0,000	0,000
V_s	ft/s	286,7	133,0	1055	869,0
V_p	ft/s	527,2	227,4	2484	2129
Identification number		1	2	3	4
c'_ref	lbf/ft <sup>2</sup>	1,000	1,000	1,000	1,000
φ' (phi)	°	34,00	33,00	40,00	36,00
ψ (psi)	°	0,000	0,000	0,000	0,000
c'_inc	lbf/ft <sup>2</sup> /ft	0,000	0,000	0,000	0,000
y_ref	ft	0,000	0,000	0,000	0,000
Tension cut-off		True	True	True	True
Tensile strength	lbf/ft <sup>2</sup>	0,000	0,000	0,000	0,000
Determination		v-undrained definition	v-undrained definition	v-undrained definition	v-undrained definition
v_u definition method		Direct	Direct	Direct	Direct
v_u, equivalent (nu)		0,4950	0,4950	0,4950	0,4950
Skempton B		0,9795	0,9840	0,9577	0,9532
K_w, ref/n	lbf/ft <sup>2</sup>	27,43E6	5,932E6	445,5E6	289,7E6
Classification type		Standard	Standard	Standard	Standard
Soil class (Standard)		Coarse	Coarse	Coarse	Coarse
< 2 μm	%	10,00	10,00	10,00	10,00
2 μm - 50 μm	%	13,00	13,00	13,00	13,00
50 μm - 2 mm	%	77,00	77,00	77,00	77,00
Use defaults		False	False	False	False
k_x	ft/day	0,000	0,000	0,000	0,000
k_y	ft/day	0,000	0,000	0,000	0,000
Void ratio dependency		False	False	False	False

**Table 15. Soil properties (continued from previous)**

Identification number		1	2	3	4
c_k		1000E12	1000E12	1000E12	1000E12
n_init		0,3333	0,3333	0,3333	0,3333
-ψ_unsat	ft	32,81E3	32,81E3	32,81E3	32,81E3
c_s	kJ/lb/K	0,000	0,000	0,000	0,000
λ_s	kW/ft/K	0,000	0,000	0,000	0,000
ρ_s	lb/ft <sup>3</sup>	162,3	162,3	162,3	162,3
Thermal expansion type		Isotropic	Isotropic	Isotropic	Isotropic
α_sv	1/K	0,000	0,000	0,000	0,000
Phase change		False	False	False	False
D_v	ft <sup>2</sup> /day	0,000	0,000	0,000	0,000
f_Tv		0,000	0,000	0,000	0,000
Stiffness determination		Derived	Derived	Derived	Derived
Strength determination		Manual	Manual	Manual	Manual
R_inter		0,6700	0,6700	0,6700	0,6700
Consider gap closure		True	True	True	True
Cross permeability		Impermeable	Impermeable	Impermeable	Impermeable
Drainage conductivity, dk	ft <sup>3</sup> /day/ft	0,000	0,000	0,000	0,000
R_thermal	ft <sup>2</sup> K/kW	0,000	0,000	0,000	0,000
K_0 determination		Automatic	Automatic	Automatic	Automatic
K_0,x		0,4408	0,4554	0,3572	0,4122
K_0,z		0,4408	0,4554	0,3572	0,4122

**Table 16. Plate element properties**

Identification number		1	2	3	4
Identification		Pile (W18x55)_6ft_100%EI&EA	Pile (W18x55)_6ft_corrosion_EI&EA	Pile (W18x55)_8ft_100%EI&EA	Pile (W18x55)_8ft_corrosion_EI&EA
Material type		Elastic	Elastic	Elastic	Elastic
Colour					
Comments					
w	lbf/ft/ft	6,670	6,670	5,000	5,000
Prevent punching		False	False	False	False
Isotropic		True	True	True	True
EA_1	lbf/ft	78,30E6	62,64E6	58,73E6	46,98E6
EA_2	lbf/ft	78,30E6	62,64E6	58,73E6	46,98E6
E_1	lbf/ft <sup>2</sup>	36,59E6	29,28E6	27,45E6	21,96E6
E_2	lbf/ft <sup>2</sup>	36,59E6	29,28E6	27,45E6	21,96E6
EI	lbf ft <sup>2</sup> /ft	29,87E6	23,89E6	22,40E6	17,92E6
v (nu)		0,3000	0,3000	0,3000	0,3000
d	ft	2,140	2,139	2,140	2,139
c	kJ/lb/K	0,000	0,000	0,000	0,000
λ	kW/ft/K	0,000	0,000	0,000	0,000
ρ	lb/ft <sup>3</sup>	0,000	0,000	0,000	0,000
α	1/K	0,000	0,000	0,000	0,000
A_eff,T	ft <sup>2</sup>	0,000	0,000	0,000	0,000

**Table 17. Node-to-node anchor element properties**

Identification number		1	2	3	4
Identification		Anchor_5strands_6ft	Anchor_3strands_6ft	Anchor_4strands_6ft	Anchor_4strands_8ft
Material type		Elastic	Elastic	Elastic	Elastic
Colour		■	■	■	■
Comments					
L_spacing	ft	6,000	6,000	6,000	8,000
EA	lbf	31,40E6	18,80E6	25,00E6	25,00E6
c	kJ/lb/K	0,000	0,000	0,000	0,000
$\lambda$	kW/ft/K	0,000	0,000	0,000	0,000
$\rho$	lb/ft <sup>3</sup>	0,000	0,000	0,000	0,000
$\alpha$	1/K	0,000	0,000	0,000	0,000
A_eff,T	ft <sup>2</sup>	0,000	0,000	0,000	0,000

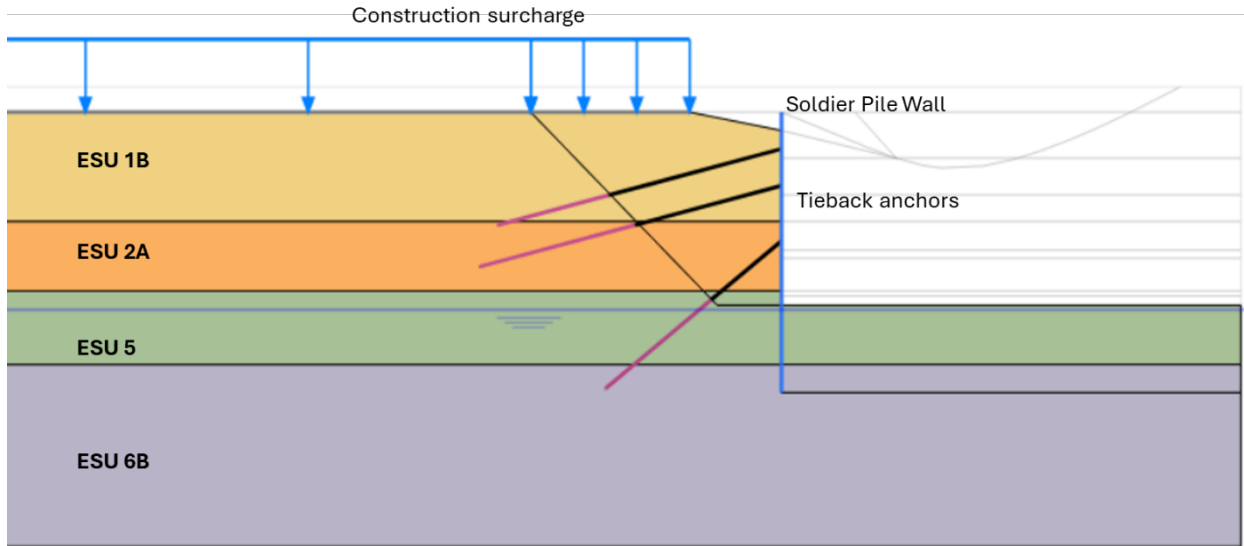
**Table 18. Embedded beam row element properties**

Identification number		1	2	3	4	5
Identification		Bond_6ft_2A	Bond_6ft_5 & 6B	Bond_6ft_2A&5_1/2	Bond_8ft_2A	Bond_8ft_5 & 6B
Material type		Elastic	Elastic	Elastic	Elastic	Elastic
Colour		■	■	■	■	■
Comments						
$\gamma$	lbf/ft <sup>3</sup>	12,73	12,73	12,73	12,73	12,73
L_spacing	ft	6,000	6,000	6,000	8,000	8,000
Cross section type		Predefined	Predefined	Predefined	Predefined	Predefined
Predefined cross section type		Solid circular beam	Solid circular beam	Solid circular beam	Solid circular beam	Solid circular beam
Diameter	ft	0,5000	0,5000	0,5000	0,5000	0,5000
A	ft <sup>2</sup>	0,1963	0,1963	0,1963	0,1963	0,1963
I	ft <sup>4</sup>	3,068E-3	3,068E-3	3,068E-3	3,068E-3	3,068E-3
E	lbf/ft <sup>2</sup>	522,1E6	522,1E6	522,1E6	522,1E6	522,1E6
Axial skin resistance		Linear	Linear	Linear	Linear	Linear
T_skin, start, max	lbf/ft	8000	12,00E3	10,20E3	8000	12,00E3
T_skin, end, max	lbf/ft	8000	12,00E3	10,20E3	8000	12,00E3
Lateral resistance		Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
F_max	lbf	0,000	0,000	0,000	0,000	0,000
Default values		True	True	True	True	True

### 6.2.1. Calculation Scenarios

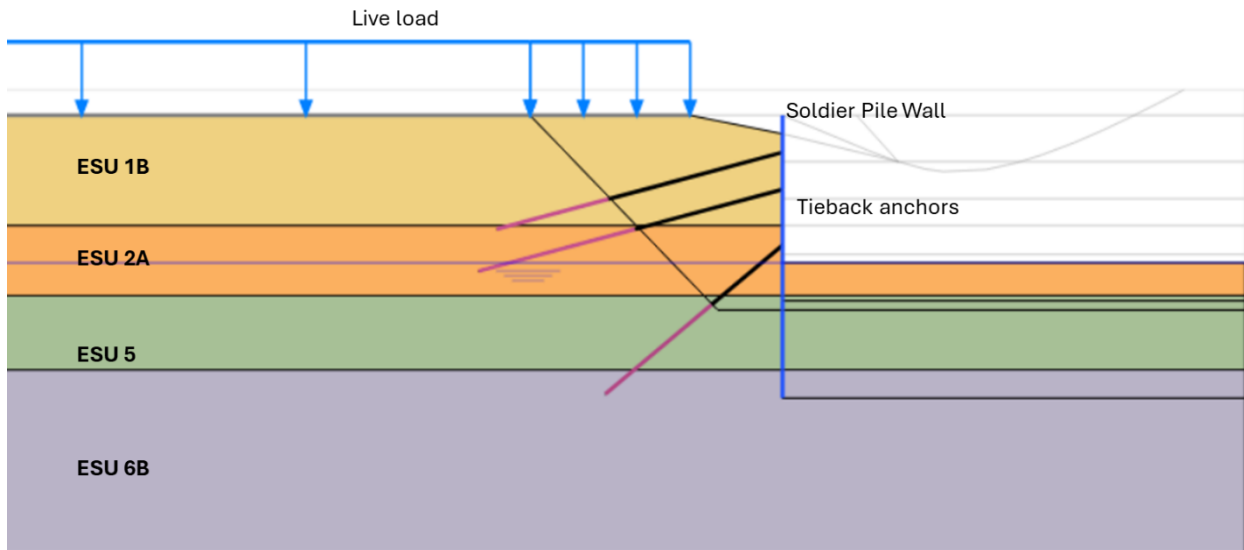
The construction stages for the soldier pile wall were evaluated explicitly in Plaxis 2D and the following design scenarios were considered for every design section.

- **Scenario C1 - Construction stage + construction surcharge:** maximum depth of excavation which corresponds to the height of the wall in each calculation section plus an additional 3 ft.



**Figure 6- Design scenario C1 for section WW4.1.**

- **Scenario O1 – Long term Operational case + Live load:** Wall height from top of wall to final grade level. W Beam section reduced to account for corrosion. The ground water level corresponds to the 100yr WSE level.



**Figure 7- Design scenario O1 for section WW4.1.**

- **Scenario O2 – Long term Operational case + Live load:** Wall height from top of wall to final grade level. W Beam section reduced to account for corrosion. The ground water level corresponds to the 100yr WSE level at the stream side and to weep holes level on the retained side.

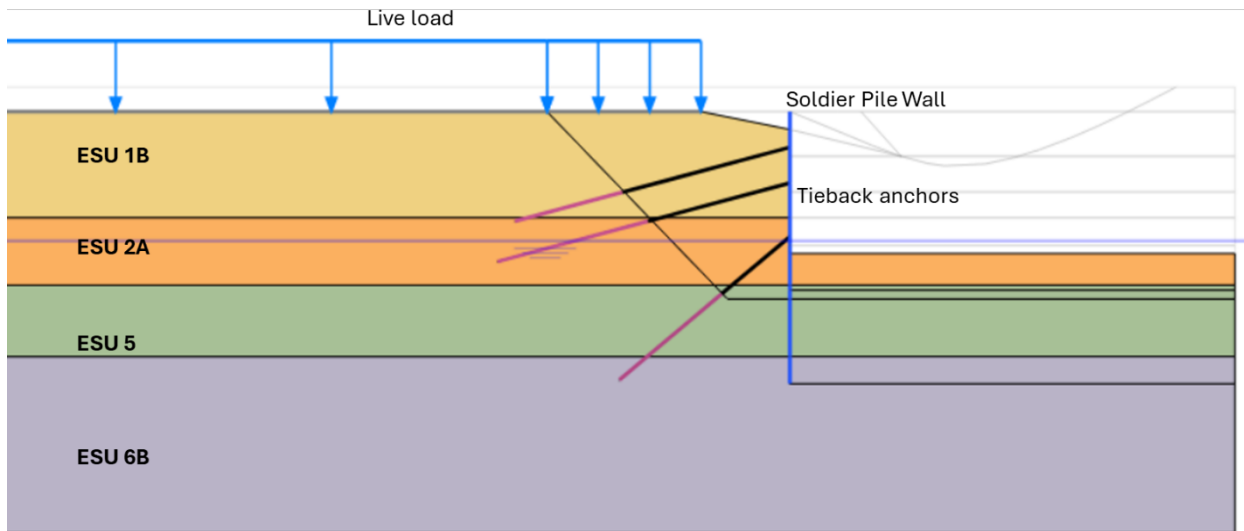


Figure 8- Design scenario O2 for section WW4.1.

- **Scenario A1 – Extreme 1. Long term. Earthquake:** Wall height from top of wall to final grade level. W Beam section reduced to account for corrosion. The ground water level corresponds to the 100yr WSE level. Pseudo-static horizontal acceleration of 0.25g.

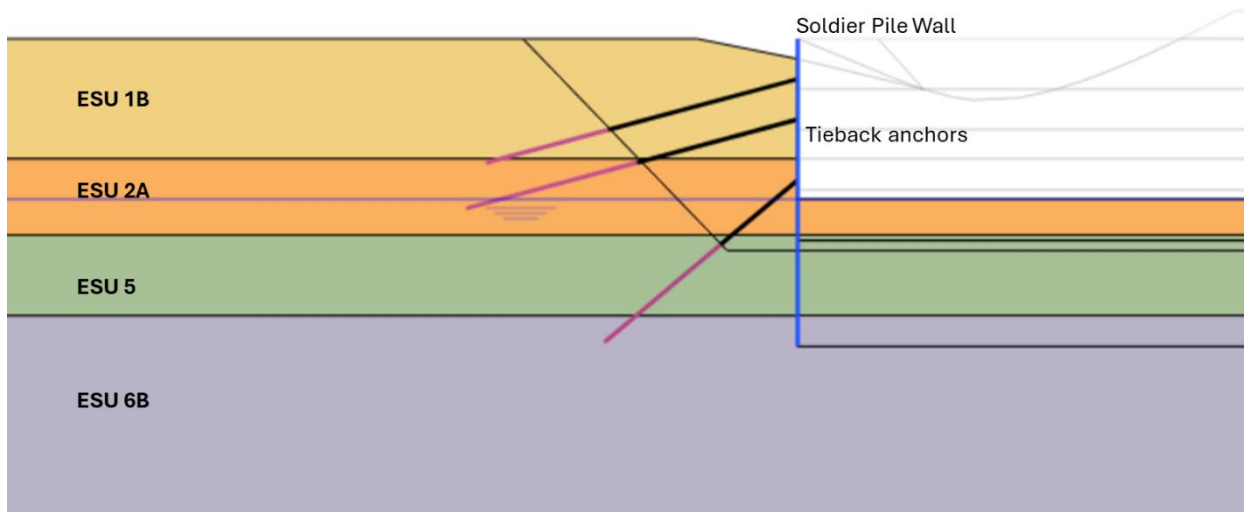


Figure 9- Design scenario A1 for section WW4.1.

### 6.3. Pywall analyses

The Pywall models have included the same design ground profile, pile length, section and spacing, excavation geometry, loads, and tie-backs layout as the Plaxis 2D models to be compared with. The calculation scenario compared corresponds to the maximum excavation depth.

The soil properties input are unit weight, angle of shearing resistance, and k modulus for the p-y curves. For soil layers below the groundwater level (i.e. ESU 6B), submerged properties are used. The p-y model set for the soil layers is API sand, as per GER recommendations.

The pile section properties are obtained directly from the software for standard AISC sections.

The earth pressure option is set to generate trapezoidal distribution pressure for anchored walls as per FHWA. The p-y curves are also set to be generated based on the k modulus values provided.

Tie-backs are modelled with the same unbonded length and pre-stress as in Plaxis 2D model.

### 6.4. Design groundwater

In the calculation models the Design Ground Water Elevation (DGWE) has been considered at the following levels depending on the condition:

- Temporary construction conditions: The DGWE is at the level of maximum excavation.
- Long-term permanent conditions. Two scenarios are considered:
  - The DGWE is at the 100yr WSE level, equal at both sides of the wall.
  - The DGWE is at the 100yr WSE level in the stream side, and at weep hole level on the earth side.

## 7. DESIGN ANALYSIS AND RESULTS

### 7.1. Earth Pressure

The apparent earth pressure is calculated for the relevant sections. An envelope of the results obtained is taken and these results obtained are used in the fascia analyses. In the following **Table 19**, the design pressures considered in Strength 1, Extreme 1 and Service 1, for all the structures are shown.

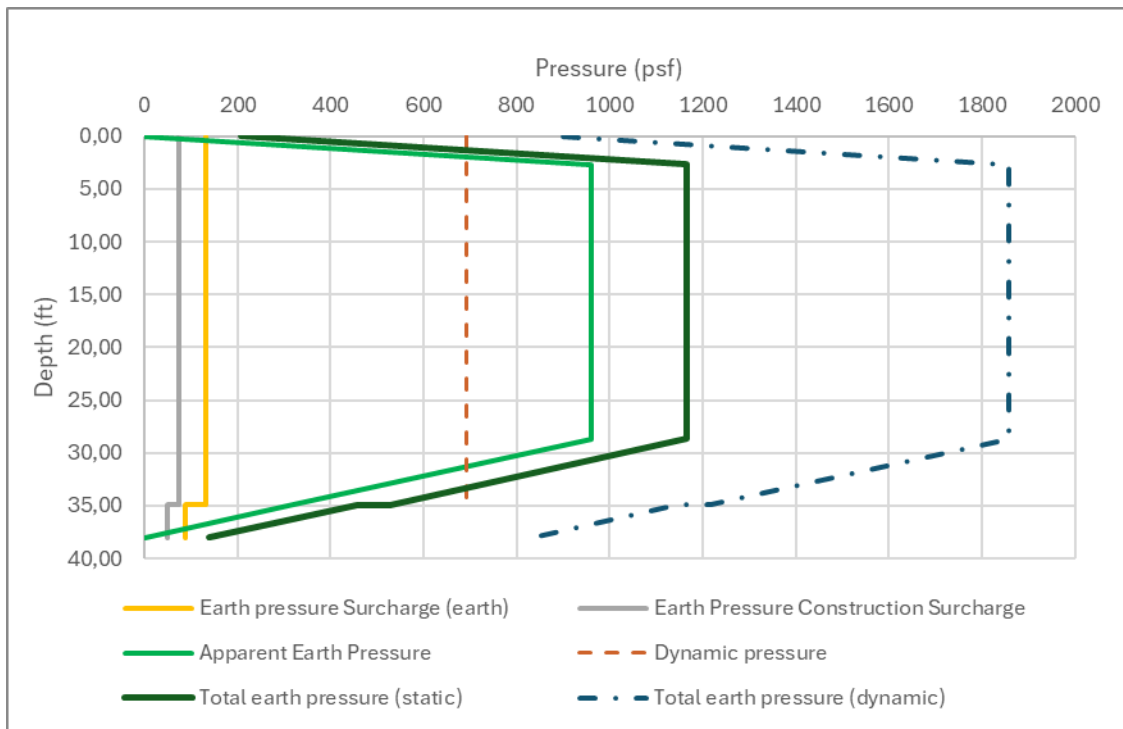
**Table 19 Pressures considered in the fascia design**

Structure	Loading case	Limit state		
		Strength I	Extreme I	Service I
Wingwall 3	AEP	1397 psf	1710 psf	1035 psf
	ES	342 psf	228 psf	228 psf

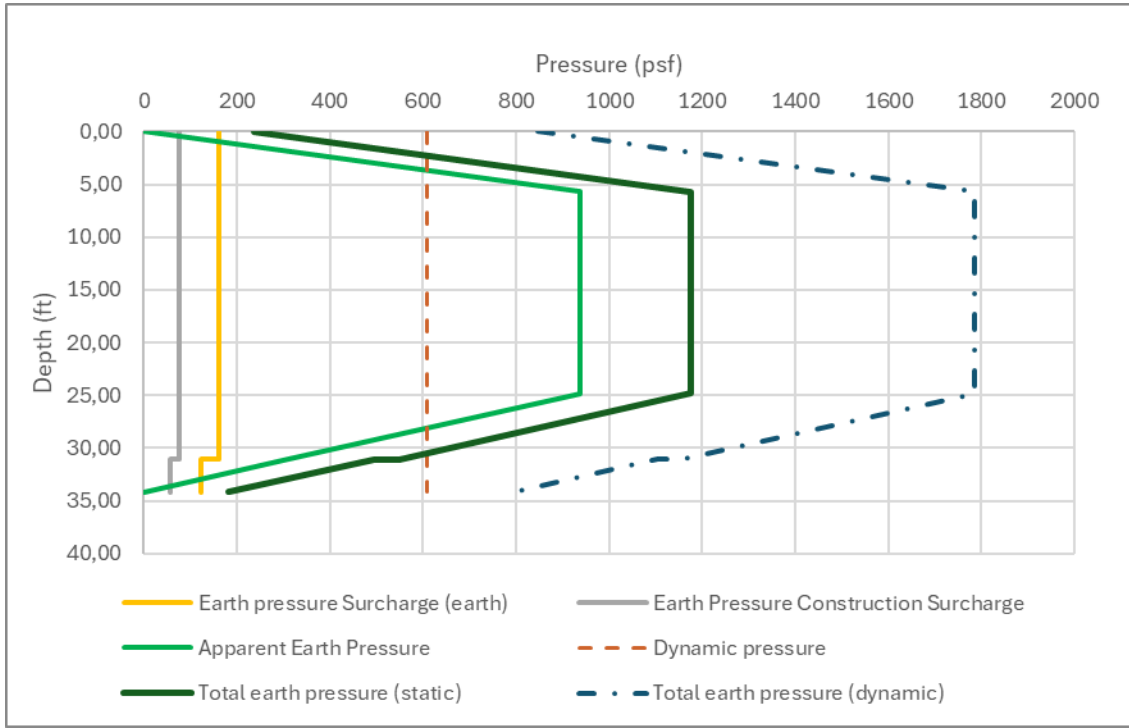
Structure	Loading case	Limit state		
		Strength I	Extreme I	Service I
	LS	131 psf	75 psf	75 psf
Wingwall 4	AEP	1295 psf	1651 psf	959 psf
	ES	198 psf	132 psf	132 psf
	LS	131 psf	75 psf	75 psf
Headwall 2	AEP	1505 psf	1723 psf	1115 psf
	LS	131 psf	75 psf	75 psf

### 7.1.1. Earth pressure diagrams

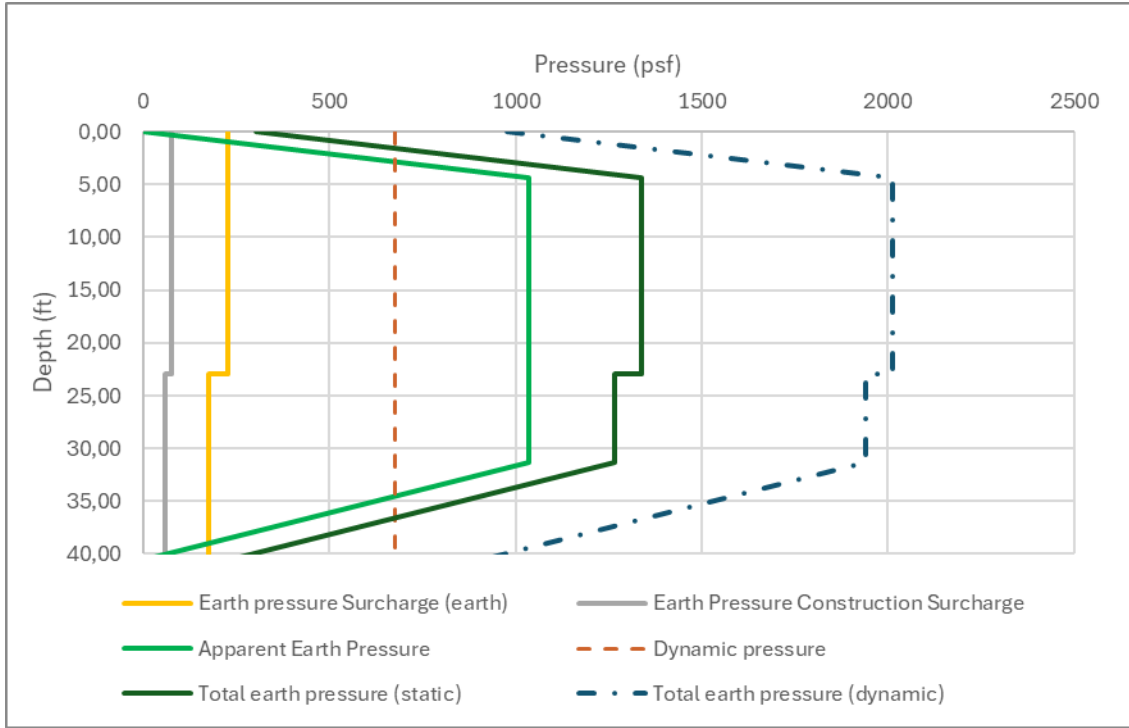
The following figures show the calculated earth pressure diagrams (unfactored) following the trapezoidal earth pressure distribution and the tie-back layout.



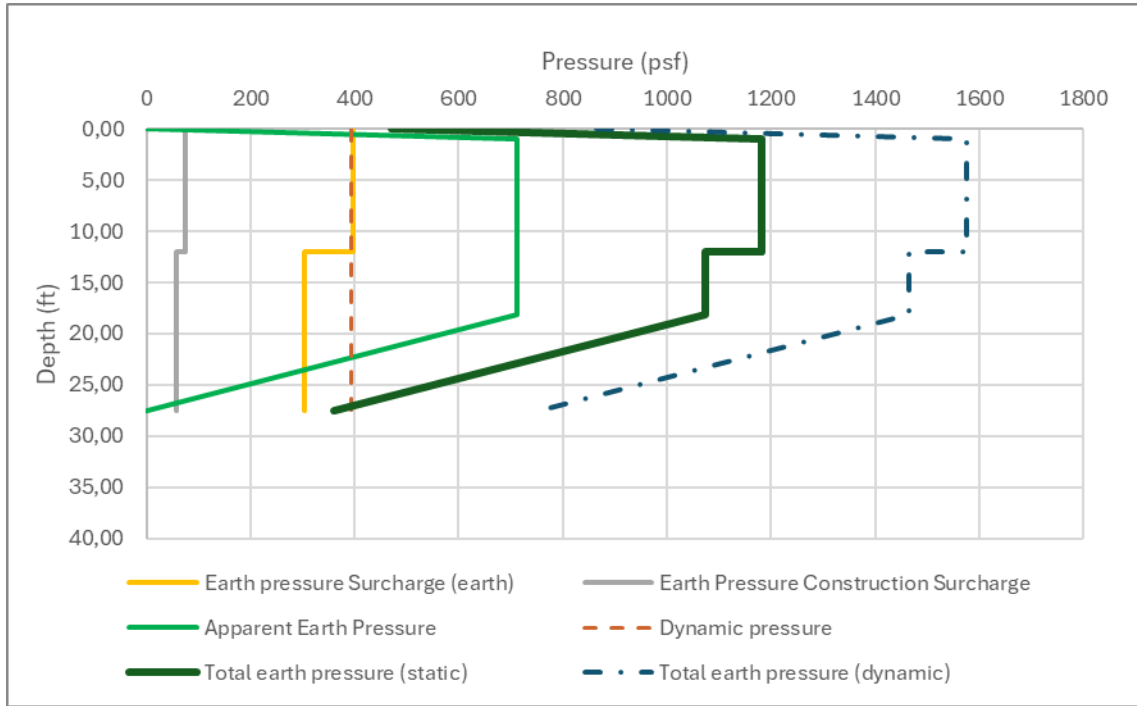
**Figure 10: Earth pressure diagrams. Section 4-1**



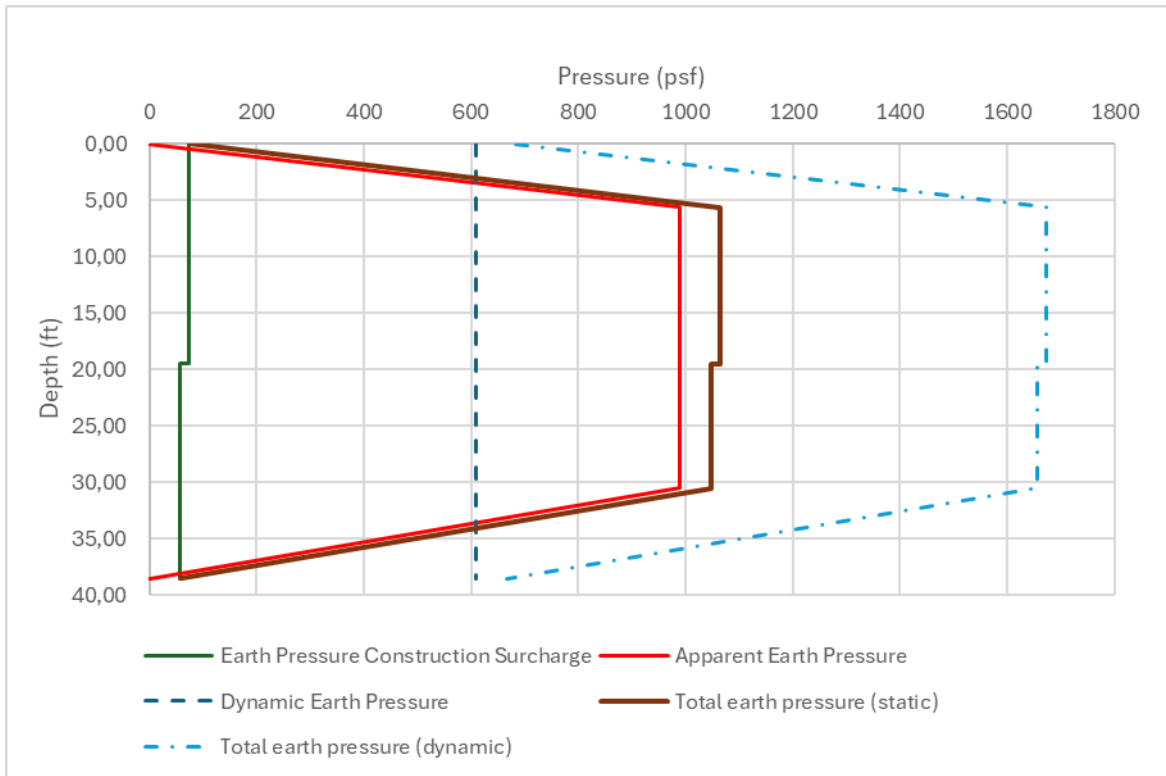
**Figure 11: Earth pressure diagrams. Section 4-2**



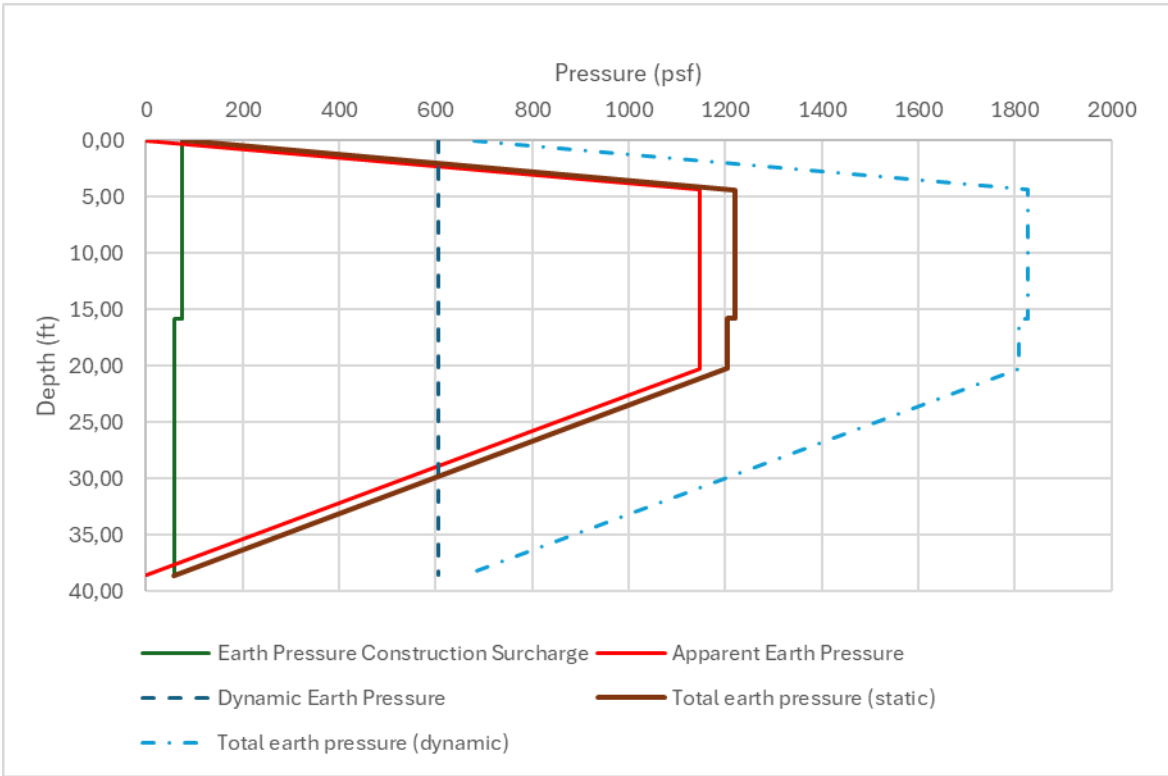
**Figure 12: Earth pressure diagrams. Section 3-1**



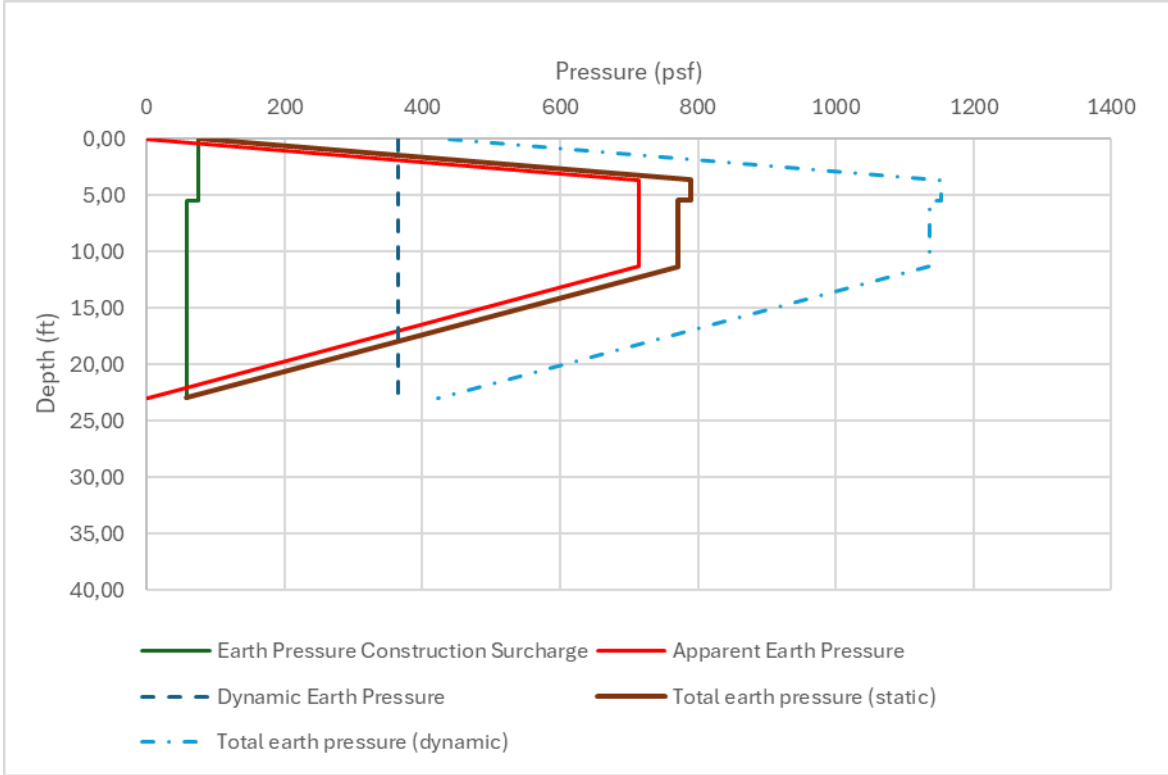
**Figure 13: Earth pressure diagrams. WW3-2**



**Figure 14: Earth pressure diagrams. HW2-1**



**Figure 15: Earth pressure diagrams. HW2-2**



**Figure 16: Earth pressure diagrams. HW2-3**

### 7.1.2. Tie-back loads from trapezoidal earth pressure

Tie-back loads are calculated for the headwall design sections, as presented in tables below. In these tables the following notation refer to:

- $t_h$  is the horizontal load per ft.
- $T_h$  is the horizontal force at the tie-back as  $t_h * spacing$
- $T_{anchor}$  is the force at the tie-back as  $T_h / \cos(\alpha)$

Tie-back spacing and angle ( $\alpha$ ) follow values presented in **Table 12** and **Table 13** respectively.

**Table 20 Tie-back loads (factored) for design section HW2-1**

	T1	T2	T3	T1 dyn	T2 dyn	T3 dyn
$t_h$ (lb / ft)	14558.1	12929.5	15851.2	17174.2	14178.5	17380.5
$T_h$ (lb)	74246.3	65940.3	80841.2	87588.3	72310.2	88640.7
$T_{anchor}$ (lb)	81921.7	72757.0	93347.4	96643.0	79785.5	102353.5

**Table 21 Tie-back loads (factored) for design section HW2-2**

	T1	T2	T1 dyn	T2 dyn
$t_h$ (lb / ft)	11336.3	26022.1	12833.4	27402.7
$T_h$ (lb)	57814.9	132713	65450.2	139753.6
$T_{anchor}$ (lb)	63791.7	146432	72216.3	154201

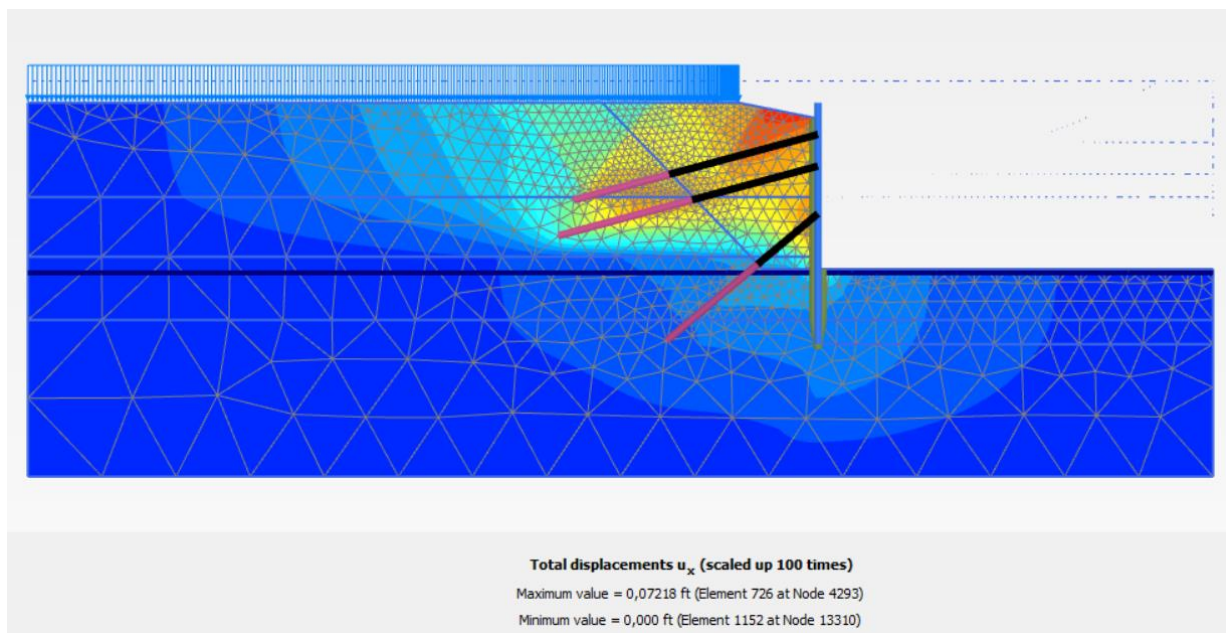
**Table 22 Tie-back loads (factored) for design section HW2-3**

	T1	T1 dyn
$t_h$ (lb / ft)	12988.7	13428.1
$T_h$ (lb)	77932.2	80568.7
$T_{anchor}$ (lb)	82933.7	85739.4

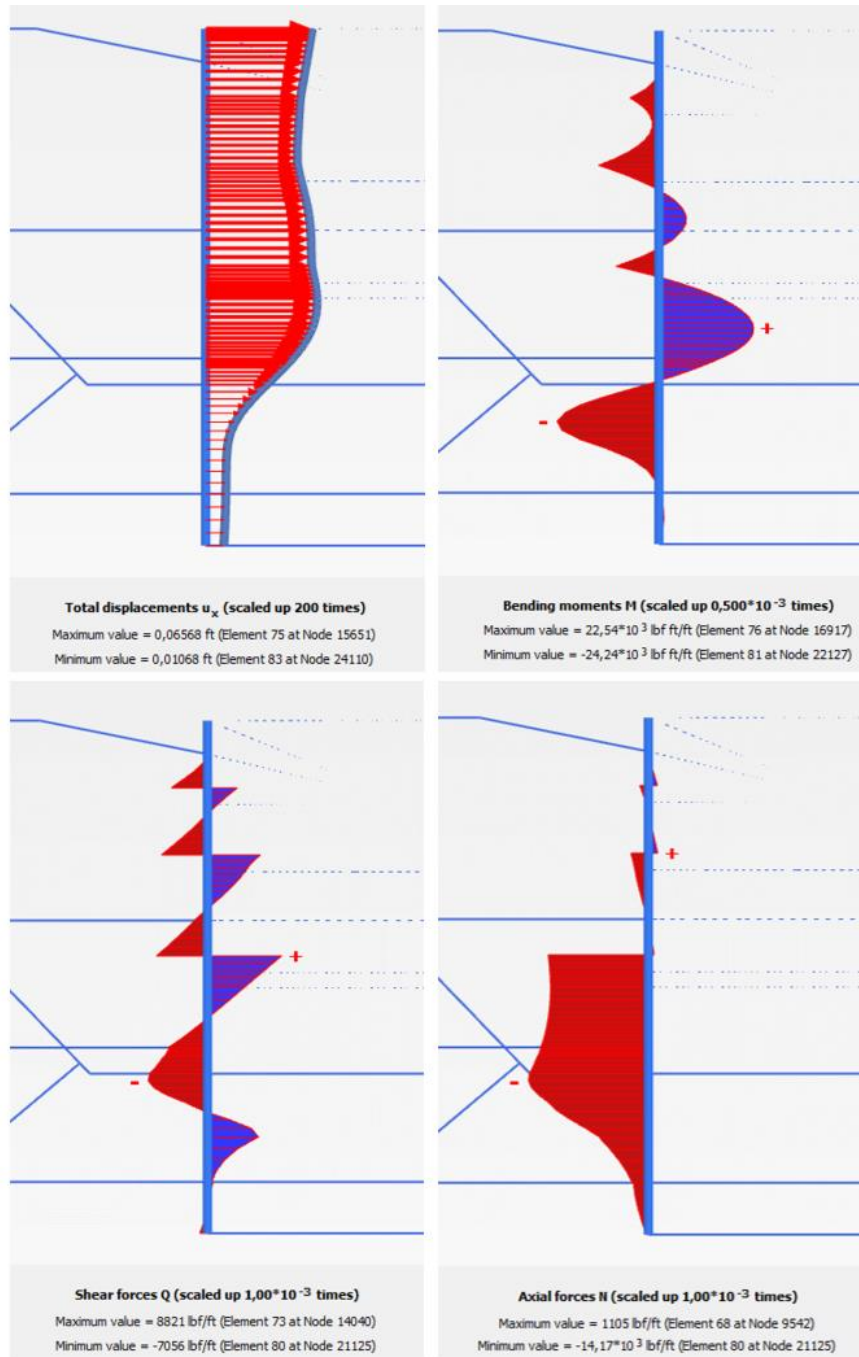
### 7.3. Geotechnical design of wingwalls

Results from the analysis in Plaxis 2D are presented in **APPENDIX B: Plaxis 2D model calculations**. Figures 14 to 16 illustrate the characteristic output of each calculation model that can be found in the appendix.

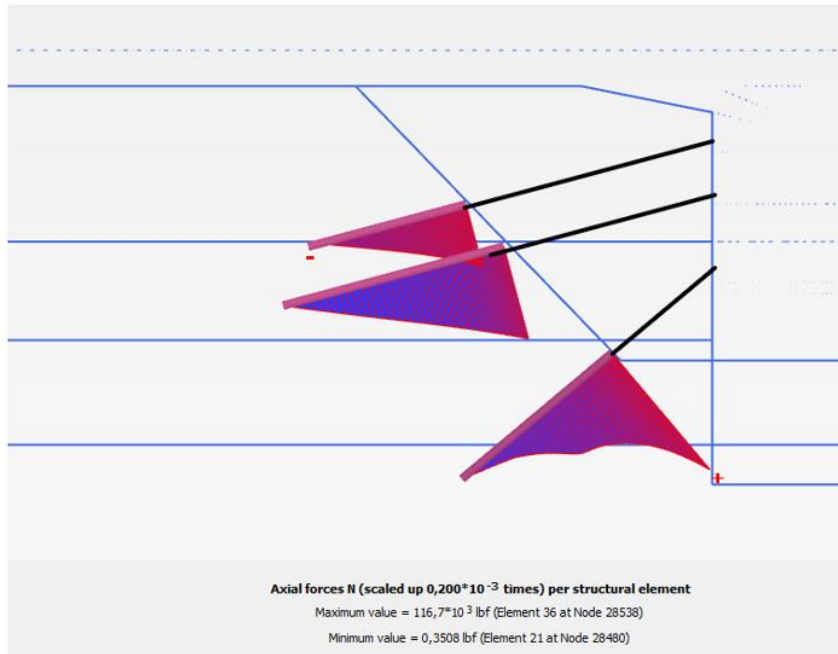
The axial forces, shear forces, and bending moments have been factored by a multiplier of 1.5 to obtain the factored loads, ensuring the design captures the load factoring principles. Since the lateral capacity governs the design, the axial capacity has been adequately addressed through the pile embedment. Additionally, the temporary factor of safety (FOS) considers the results for all construction and extreme event stages, including the seismic assessment, providing a comprehensive evaluation of the structure's stability throughout its various stages. The estimated horizontal deflection values at top of the walls are within the 1-inch limit.



**Figure 17- Total displacements  $U_x$ . Design scenario C1 for section WW4.1.**



**Figure 18- Total displacements  $U_x$  and forces along the wall plate. Design scenario C1 for section WW4.1.**



Structural element ▲	Node ▲	Local number ▲	X ▲ [ft]	Y ▲ [ft]	N ▲ [10 <sup>3</sup> lbf]	N <sub>min</sub> ▲ [lbf]	N <sub>max</sub> ▲ [10 <sup>3</sup> lbf]
NodeToNodeAnchor_1_1	9542	1	100,000	78,500	73,272	0,000	76,506
Element 2-2 (Node-to-node anchor)	28481	2	68,124	69,959	73,272	0,000	76,506
NodeToNodeAnchor_2_1	14040	1	100,000	66,500	116,713	0,000	116,713
Element 3-3 (Node-to-node anchor)	28538	2	84,679	53,644	116,713	0,000	116,713

**Figure 19- Axial Forces along tie-backs' bond length. Design scenario C1 for section WW4.1.**

### 7.3.1. Summary of wingwalls' analyses in Plaxis 2D

**Table 23** below shows a summary of pile dimensions, minimum embedment length, maximum forces and deformations. The estimated horizontal deflection values at top of the walls are within the 1-inch limit.

**Table 23 Summary table of calculation results**

Plaxis Model ID	Station [ft]	Soldier pile section <sup>1)</sup>	Max. Retained Height <sup>(1)</sup>	Min. Pile Embedment Length	Max factored Axial Force	Max factored Shear Force	Max factored Bending Moment	Lateral Wall Deflection	Temp.case FoS (seismic)	Temp.case FoS (max. excavation)	Permanent cases FoS (long-term)
		[-]	[ft]	[ft]	[kips]	[kips]	[in kips]	[in]	[-]	[-]	[-]
WW3-1	6+06.99 to 6+38.36 Lt	W21x101	42'	19	361	76	2290	0.8	1.1	1.6	1.6
WW3-2	6+38.36 to 6+62.36 Lt	W21x101	36'-2"	19	251	101	3622	1.0	1.1	1.7	1.8
WW3-3	6+62.36 to 7+05.69 Lt	W21x101	31' - 1"	17	157	60	1548	0.3	1.1	1.9	2.0
WW4-1	6+06.99 to 6+15.49 Rt	W21x101	42'	19	222	92	3002	0.9	1.1	1.6	2.5
WW4-2	6+15.49 to 6+33.49 Rt	W21x101	39'-6"	17	240	88	2283	0.7	1.1	1.9	2.6
WW4-3	6+33.49 to 6+39.19 Rt	W21x101	34'-7"	16	200	74	2368	1.0	1.1	1.7	1.7
WW4-4	6+39.19 to 6+56.36 Rt	W21x101	32'-10"	16	164	61	2614	1.0	1.2	1.6	1.8
WW4-5	6+56.36 to 6+69.19 Rt	W24x104	28'-5"	14	64	75	4015	0.8	1.2	1.9	2.8

Note:

- 1) Considered from top of wall to maximum depth of excavation.

### 7.3.2. Plaxis 2D vs. PYWALL comparison

**Table 24** and **Table 25** below compare Pywall and Plaxis 2D models outcomes for two design sections, one for wingwall 3 and one for wingwall 4. Note forces figures are unfactored.

**Table 24 Summary table of PYWALL vs Plaxis 2D results for wingwall 3**

Results	Pywall (wingwall 3)	Plaxis 2D (design section WW3-1)	Results difference
Maximum deflection (in)	1,3	0,5	0,8
Maximum bending moment (in – kips)	1469	1375	94
Maximum Shear (kips)	46	49	-3
Level 1 tie-back load (kips)	99	62	37
Level 2 tie-back load (kips)	128	89	39
Level 3 tie-back load (kips)	143	95	48

**Table 25 Summary table of PYWALL vs Plaxis 2D results for wingwall 4**

Results	Pywall (wingwall 4)	Plaxis 2D (design section WW4-1)	Results difference
Maximum deflection (in)	0,40	0,7	-0,3
Maximum bending moment (in – kips)	1352	2521	-1169
Maximum Shear (kips)	52	40	12
Level 1 tie-back load (kips)	55	49	6
Level 2 tie-back load (kips)	82	74	8
Level 3 tie-back load (kips)	140	117	23

It is noted that for wingwall 3, Pywall yields to a higher maximum deflections (1.3 in vs 0.5 in), while the bending moments (1469 in–kips vs 1375 in–kips) and shear (46 kips vs 49 kips) are within the same magnitude as the ones obtained in Plaxis 2D. Additionally, tie-back loads at all three levels are consistently higher in Pywall by 37, 39, and 48 kips respectively. In contrast,

wingwall 4 exhibits a reversal in some trends: Pywall predicts lower maximum deflection (0.40 in vs 0.7 in), although the difference is minor in this case; and a lower bending moment (1352 in–kips vs 2521 in–kips) than Plaxis, even though its maximum shear (52 kips vs 40 kips) is higher. The tie-back loads in this case are still larger in Pywall, however the difference obtained is lower than in Wingwall 3.

These differences suggest that the two modeling approaches may be capturing different aspects of the structural behavior, particularly in terms of moment distribution and deflection characteristics, which could be attributed to variations in their underlying assumptions or computational methodologies. However, the results are deemed comparable, and both models provide a similar picture of the structure conditions.

Thus, the results obtained from Plaxis 2D design following finite element methods are validated against the results obtained from a PYWALL with a p-y and trapezoidal pressure approach.

## 7.4. Soldier piles

The results obtained from the Plaxis 2D (wingwalls) and SAP 2000 (headwall) analyses are used to verify the steel section capacity to bending moment and shear.

### 7.4.1. Section geometrical properties

The slenderness of the proposed sections is checked to verify the compact sections formulation can be used. The following tables summarize the check undertaken:

**Table 26. Geometrical properties check for flange (flexural)**

Section	Width bf (in)	Flange thickness tf (in)	$bf/(2*tf)$	Flange slenderness limit (6.12.2.2.1c-4)	Compact flange?
W 21 x 101	12.29	0.8	7.68	9.15	Ok
W 24 x 104	12.75	0.75	8.50	9.15	Ok

**Table 27. Geometrical properties check for web (shear)**

Section	D (in)	tw (in)	D/tw	Slenderness limit (6.10.9.3.2-4)	Compact web?	C
W 21 x 101	19.8	0.5	39.6	60.31	Ok	1.0
W 24 x 104	22.6	0.5	45.2	60.31	Ok	1.0

Therefore, the sections are considered as compact, and the capacity calculations will be done in accordance with that.

#### 7.4.2. Section resistance

Properties and factors used in the section resistance analysis:

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

$$\Phi_f = 1$$

$$\Phi_v = 1$$

$$C = 1$$

**Table 28. Moment resistance for the soldier pile sections**

Section	S (in <sup>3</sup> )	M <sub>p</sub> (in-kips)	Factored M (in-kips)
W 21 x 101	227	18160	18160
W 24 x 104	258	20640	20640

**Table 29. Shear resistance for the soldier pile sections**

Section	D* <i>t</i> w	V <sub>p</sub> (kips)	V <sub>n</sub> (kips)	Factored V (kips)
W 21 x 101	9.9	287.1	287.1	287.1
W 24 x 104	11.3	327.7	327.7	327.7

#### 7.4.3. Bending moment verification

**Table 30. Bending moment verification for soldier piles**

Design section	Soldier Pile Section	Flexural resistance (in kips)	Factored bending moment, M <sub>u</sub> (in kips)	Check
WW3-1	W21X101	11350	2290	Ok
WW3-2	W21X101	11350	3622	Ok
WW3-3	W21X101	11350	1548	Ok
WW4-1	W21X101	11350	3002	Ok
WW4-2	W21X101	11350	2283	Ok
WW4-3	W21X101	11350	2368	Ok

Design section	Soldier Pile Section	Flexural resistance (in kips)	Factored bending moment, Mu (in kips)	Check
WW4-4	W21X101	11350	2614	Ok
WW4-5	W24X104	12900	4015	Ok
HW2-1	W21X101	11350	1560	Ok
HW2-2	W21X101	11350	1560	Ok
HW2-3	W21X101	11350	1560	Ok

The W-beam sections used in each design section satisfy the bending moment verification.

### 7.3.1. Shear force verification

**Table 31. Shear force verification for soldier piles**

Design section	Soldier Pile Section	Shear resistance (ft-lb)	Factored shear force, Vu (ft-lb)	Check
WW3-1	W21X101	287.1	76	Ok
WW3-2	W21X101	287.1	101	Ok
WW3-3	W21X101	287.1	60	Ok
WW4-1	W21X101	287.1	92	Ok
WW4-2	W21X101	287.1	88	Ok
WW4-3	W21X101	287.1	74	Ok
WW4-4	W21X101	287.1	61	Ok
WW4-5	W24X104	327.7	75	Ok
HW2-1	W21X101	287.1	36	Ok
HW2-2	W21X101	287.1	36	Ok
HW2-3	W21X101	287.1	36	Ok

The W-beam sections used in each design section satisfy the shear force verification.

## 7.4. Tie-backs

**Table 32** summarizes the tie-back loads implemented for each wall section analyzed.

**Table 32. Design for permanent tie-back anchors**

Design section	No. Rows	Inclination [°]	Unbonded Length	Factored Design Load [kip]
WW3-1	3	30/30/30	30/25/18	90/128/138
WW3-2	2	30/30	25/18	153/152
WW3-3	2	30/30	25/18	77/107
WW4-1	3	15/15/40	39/33/20	83/116/176
WW4-2	3	15/15/40	35/31/19	80/113/168
WW4-3	2	15/45	30/18	114/158
WW4-4	2	25/45	30/15	114/143
WW4-5	1	25	20	132
HW2-1	3	25 / 25 /30	37/32/25	97/80/102
HW2-2	2	25 / 25	39/35	72/154
HW2-3	1	30	40	86

Lock-off load shall be at least 60% of the Factored Design Load. As per WSDOT GDM, the bonded length is to be determined by the ground anchors contractor based on the Factored Design Load.

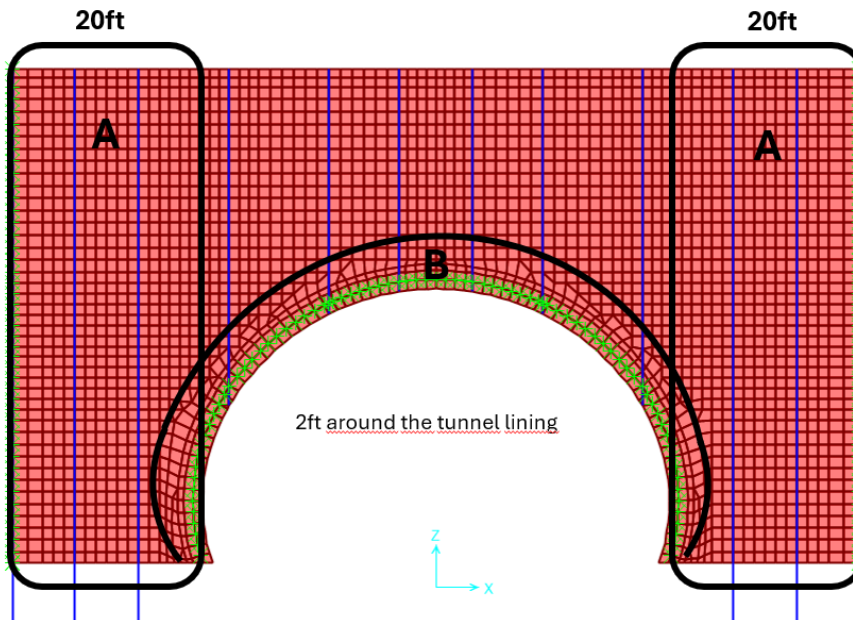
## 7.5. Fascia wall

Strength I limit state, and Extreme I limit state controlled the structural design at wingwalls. Serviceability criteria governed the determination of the thickness of the headwall, based on the maximum allowable deflection. The Service I load combination is utilized to evaluate deformation and crack control. Crack control is achieved by limiting the steel stress and spacing of reinforcement in accordance with the BDS.

From the analysis results the following sizing and reinforcements are obtained:

- The Wingwall 3 concrete fascia has been designed with an 8.00 ft span (panel length), 14-inch thickness with a flexural reinforcement of #4 at 8" spacing on both faces without shear reinforcement.
- The Wingwall 4 concrete fascia has been designed with a maximum 10.00 ft span (panel length), 14-inch thickness with a flexural reinforcement of #4 at 8" spacing on both faces without shear reinforcement.
- The headwall's fascia reinforcement comprises:
  - #5@6" horizontal direction in both outer and inner faces.
  - Additional #5@6" in horizontal direction in areas in outer face for fascia at both sides of the tunnel (zone A).

- #4@6" in vertical direction in both outer and inner faces.
- Additional #4@6" in both vertical and horizontal directions, in a 2-ft wide band around the tunnel interface (zone B).
- Additional located reinforcements will be needed in the tie-back locations (to be provided in final design submission).



**Figure 20- Additional reinforcement zones for East Portal Headwall**

Refer to **APPENDIX**  
Fascia structural calculations for further details on the analysis results.

**D:**

## 8. CONCLUSIONS

The proposed portal structure—comprising a soldier pile wall with permanent ground anchors, concrete fascia, head wall, and wing walls—has been designed to meet the functional, safety, and durability requirements of the Washington Department of Transportation. Key conclusions include:

### 1. Structural Stability

- The system satisfies AASHTO LRFD Strength I and Extreme Event I limit states, with the soldier piles satisfying both flexural and shear forces verifications.
- Global stability analyses in Plaxis 2D confirmed no critical failure surfaces occurred on Strength I and Extreme Event I limit states, with FoS obtained above 1.6 and 1.1, respectively.

### 2. Serviceability

- Lateral wall deflection remains below the 1.0-inch thresholds, ensuring minimal impact on adjacent assets.
- Tie-backs are designed with double corrosion protection and corrosion section reduction was also accounted for the soldier piles, meeting WSDOT service life criteria ( $\geq 75$  years).

### 3. Seismic Resilience

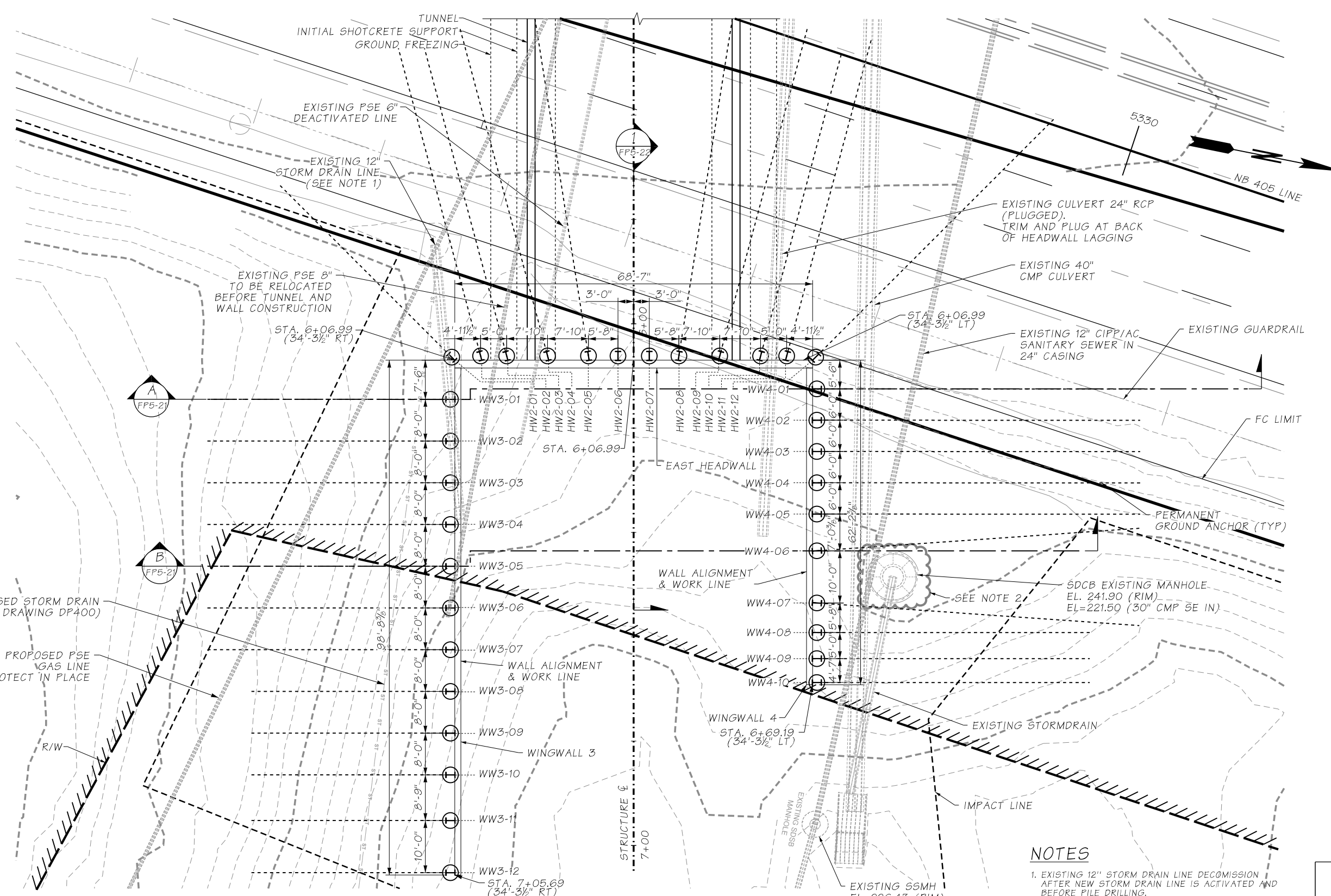
- Dynamic analyses in Plaxis 2D demonstrated acceptable post-earthquake performance, with tie-back loads within the capacity and deflections under the threshold of 1.0 inch.

The analytical approach has been adapted to the structure's requirements and constraints, combining PLAXIS for global and soil-structure interaction and SAP2000 for the headwall analysis, providing robust results. Cross-verification against AASHTO LRFD ensured efficient design outcomes, particularly for:

- Soldier Piles: W21x101 sections at 5 ft to 8 ft spacing, and locally W24x104 sections, validated for flexure and buckling.
- Concrete Fascia: 14-inch-thick reinforced concrete, meeting deflections and crack control criteria.

# **APPENDIX A: Preliminary Design Drawings**

C.S. 1757 ~ PROJ. NO. 9727 ~ NORTHWEST REGION ~ I-405 MP 21.94 ~ JUANITA CREEK AT I-405 FISH PASSAGE



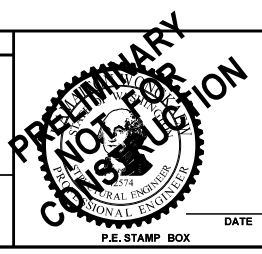
**EAST PORTAL LAYOUT**  
SCALE 1"=20'

- NOTES**
- EXISTING 12" STORM DRAIN LINE DECOMMISSION AFTER NEW STORM DRAIN LINE IS ACTIVATED AND BEFORE PILE DRILLING.
  - UNDERGROUND SIZE AND PIPE CONNECTION FROM AND TO THIS MANHOLE ARE NOT CONFIRMED. THE CONTRACTOR SHALL BE MINDFUL OF POTENTIAL CLASHES WITH UNFORESEEN MANHOLE AND/OR DUCTS DURING ANCHORS INSTALLATION.

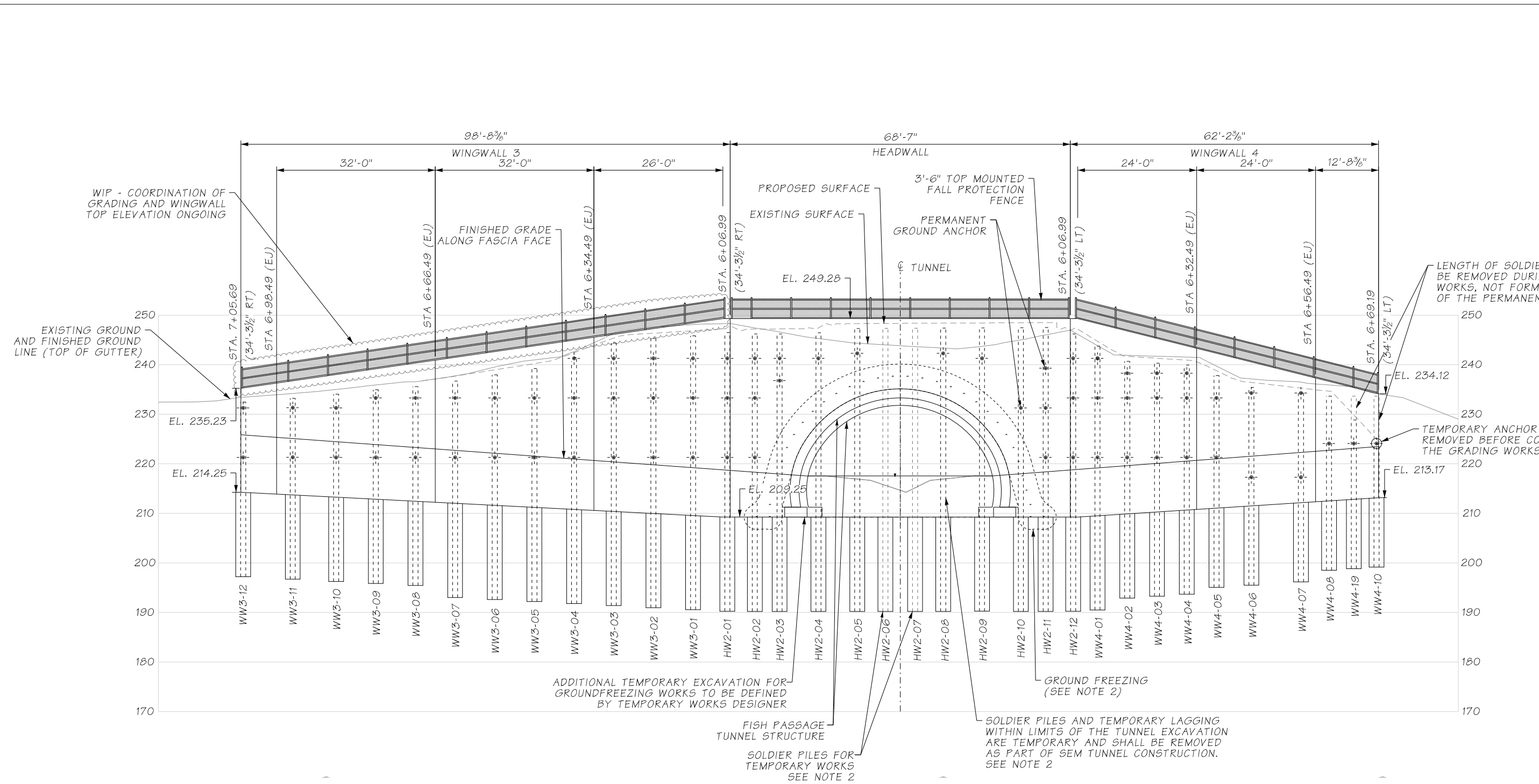
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DESIGNED BY	I RIVERO		
ENTERED BY	S SANCHEZ		
CHECKED BY	M WONGKAEW		
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REGIONAL ADM.	L HODGSON	REVISION	DATE BY
REGION NO.	10	STATE	WASH
FED.AID PROJ.NO.			
JOB NUMBER	22AB17		
CONTRACT NO.	9727		
LOCATION NO.	XL5446		



I-405 BRICKYARD TO SR527 IMPROVEMENT PROJECT	PLAN REF NO FP5-17
JUANITA CREEK FISH PASSAGE STRUCTURE EAST PORTAL WALL LAYOUT	SHEET XX OF SHEETS



**ELEVATION - EAST PORTAL**  
SCALE 1"=100'

**NOTES**

- UNLESS OTHERWISE NOTED, THE SOLDIER PILES, TIEBACKS, WALER BEAMS AND REINFORCED CONCRETE FASCIA WALL SHOWN ON THIS SHEET REPRESENT THE PERMANENT (FINAL) CONDITION.
- REFER TO PLANS PREPARED BY BRIERLEY ASSOCIATES FOR THE SEM TUNNEL AND ADDITIONAL REQUIREMENTS FOR THE PORTAL WALL IN THE TEMPORARY CONDITIONS.
- FASCIA SHALL HAVE ARCHITECTURAL FINISH TYPE 1, NOT VISIBLE AESTHETICS. NO WALL CAP NOR ASHLAR FINISH REQUIRED. THE TUNNEL FINAL LINER SHALL EXTEND OUT TO THE EXTERIOR FACE OF THE HEADWALL AND DOES NOT REQUIRE FORMLINER FINISH.

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DESIGNED BY	I RIVERO									XX	
ENTERED BY	S SANCHEZ									OF	
CHECKED BY	M WONGKAEW									SHEETS	
PROJ. ENGR.	J SLAVICEK	REV A - PRELIM DESIGN SUBMITTAL	2/24/25	MW	9727	XL5446					
REGIONAL ADM.	IL HODGSON	REVISION	DATE	BY							

C.S. 1757 ~ PROJ. NO. 9727 ~ NORTHWEST REGION ~ I-405 MP 21.94 ~ JUANITA CREEK AT I-405 FISH PASSAGE

EAST PORTAL SOLDIER PILE SCHEDULE

PILE NO.	STA.	OFFSET (FT)	DRILL HOLE SIZE (m)	P.G.A. ARRANGEMENT TYPE	SOLDIER PILE SECTION	TOP ELEVATION (FT)	(H)	(D)
HW2-01	6+06.99	34'-10½" Rt.	1.0	A	W21X101	246.50	37'-3"	19'-0"
HW2-02	6+06.99	29'-4" Rt.	1.0	HW-A	W21X101	246.19	36'-11"	19'-0"
HW2-03	6+06.99	24'-4" Rt.	1.0	HW-B	W21X101	246.21	36'-11"	19'-0"
HW2-04	6+06.99	16'-6" Rt.	1.0	HW-C	W21X101	246.43	37'-2"	19'-0"
HW2-05	6+06.99	8'-8" Rt.	1.0	HW-D	W21X101	247.28	38'-0"	19'-0"
HW2-06	6+06.99	3'-0" Rt.	1.0	-	W21X101	247.32	38'-1"	19'-0"
HW2-07	6+06.99	3'-0" Lt.	1.0	-	W21X101	247.36	38'-1"	19'-0"
HW2-08	6+06.99	8'-8" Lt.	1.0	HW-E	W21X101	247.39	38'-2"	19'-0"
HW2-09	6+06.99	16'-6" Lt.	1.0	HW-F	W21X101	247.40	38'-2"	19'-0"
HW2-10	6+06.99	24'-4" Lt.	1.0	HW-G	W21X101	247.45	38'-2"	19'-0"
HW2-11	6+06.99	29'-4" Lt.	1.0	HW-H	W21X101	247.49	38'-3"	19'-0"
HW2-12	6+06.99	34'-10½" Lt.	1.0	D	W21X101	246.20	36'-11"	19'-0"
WW3-01	6+14.49	35'-1⅜" Rt.	1.0	A	W21X101	245.83	36'-3"	19'-0"
WW3-02	6+22.49	35'-1⅜" Rt.	1.0	A	W21X101	245.33	35'-4"	19'-0"
WW3-03	6+30.49	35'-1⅜" Rt.	1.0	A	W21X101	244.37	34'-0"	19'-0"
WW3-04	6+38.49	35'-1⅜" Rt.	1.0	B	W21X101	241.41	30'-7"	19'-0"
WW3-05	6+46.49	35'-1⅜" Rt.	1.0	B	W21X101	239.21	28'-0"	19'-0"
WW3-06	6+54.49	35'-1⅜" Rt.	1.0	B	W21X101	237.95	26'-4"	19'-0"
WW3-07	6+62.49	35'-1⅜" Rt.	1.0	B	W21X101	236.68	24'-8"	19'-0"
WW3-08	6+70.49	35'-1⅜" Rt.	1.0	B	W21X101	235.58	23'-2"	17'-0"
WW3-09	6+78.49	35'-1⅜" Rt.	1.0	B	W21X101	234.93	22'-1"	17'-0"
WW3-10	6+86.49	35'-1⅜" Rt.	1.0	C	W21X101	234.04	20'-9"	17'-0"
WW3-11	6+95.24	35'-1⅜" Rt.	1.0	C	W21X101	233.20	19'-6"	17'-0"
WW3-12	7+05.24	35'-1⅜" Rt.	1.0	C	W21X101	232.45	18'-3"	17'-0"
WW4-01	6+12.49	35'-1⅜" Lt.	1.0	D	W21X101	243.73	34'-3"	19'-0"
WW4-02	6+18.49	35'-1⅜" Lt.	1.0	E	W21X101	240.68	30'-9"	17'-0"
WW4-03	6+24.49	35'-1⅜" Lt.	1.0	E	W21X101	240.29	30'-0"	17'-0"
WW4-04	6+30.49	35'-1⅜" Lt.	1.0	E	W21X101	239.92	29'-3"	17'-0"
WW4-05	6+36.49	35'-1⅜" Lt.	1.0	F	W21X101	237.79	26'-9"	16'-0"
WW4-06	6+43.53	35'-1⅜" Lt.	1.0	G	W21X101	235.41	23'-11"	16'-0"
WW4-07	6+53.53	35'-1⅜" Lt.	1.0	G	W21X101	234.28	22'-1"	16'-0"
WW4-08	6+59.19	35'-1⅜" Lt.	1.0	H	W24X104	233.65	21'-2"	14'-0"
WW4-09	6+64.19	35'-1⅜" Lt.	1.0	H	W24X104	228.83 *	16'-0"	14'-0"
WW4-10	6+68.77	35'-1⅜" Lt.	1.0	H	W24X104	224 *	10'-10"	14'-0"

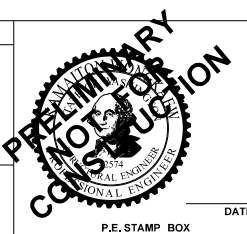
\* TOP ELEVATION FOR SOLDIER PILES IN THE PERMANENT WORKS. IN THE TEMPORARY WORKS CONDITION THE PILE TOP MAY BE AT A HIGHER ELEVATION (REFER TO DRAWING FP5-1B)

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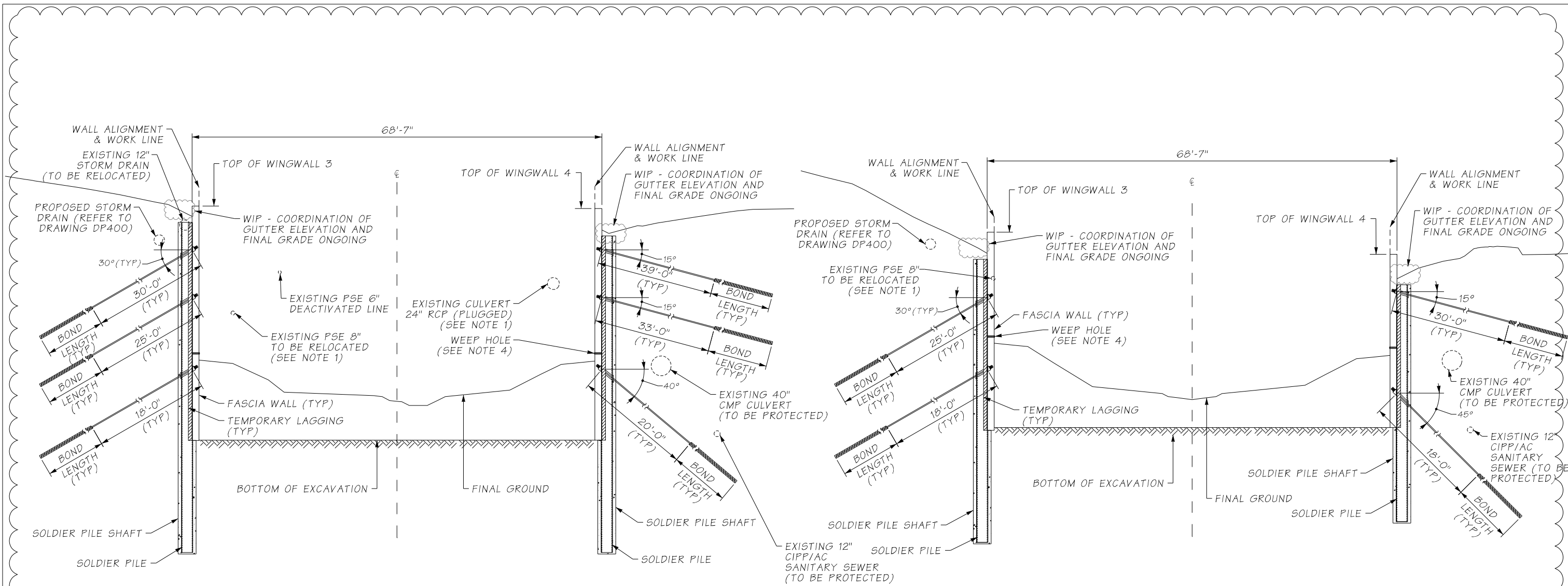
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REGION NO.	10	STATE	WASH
FED.AID PROJ.NO.			
JOB NUMBER	22AB17		
CONTRACT NO.	9727		
LOCATION NO.	XL5446		



I-405	PLAN REF NO
BRICKYARD TO SR527	FP5-19
IMPROVEMENT PROJECT	SHEET XX OF SHEETS
JUANITA CREEK FISH PASSAGE STRUCTURE	
EAST PORTAL WALL. PILE SCHEDULE	

C.S. 1757 ~ PROJ. NO. 9727 ~ NORTHWEST REGION ~ I-405 MP 21.94 ~ JUANITA CREEK AT I-405 FISH PASSAGE



SECTION A  
SCALE 1"=100'

SECTION B  
SCALE 1"=100'

TIEBACK ANCHORS SCHEDULE					
TYPE	NUMBER OF ROWS	ROW ELEVATION	INCLINATION (°)	UNBONDED LENGTH (ft)	FACTORED DESIGN LOAD (kipf)
A [Wingwall 3]	3	241.28/233.28/221.28	30/30/30	30/25/18	90/128/138
B [Wingwall 3]	2	233.28/221.28	30/30	25/18	153/152
C [Wingwall 3]	2	231.28/221.28	30/30	25/18	77/107
D [Wingwall 4]	3	241.28/233.28/221.28	15/15/40	39/33/20	83/116/176
E [Wingwall 4]	3	238.28/233.28/221.28	15/15/40	35/30/19	80/113/168
F [Wingwall 4]	2	233.28/221.28	15/45	30/18	114/158
G [Wingwall 4]	2	234.28/217.28	15/45	30/15	114/143
H [Wingwall 4]	1	224.10	25	17	92

NOTES

- EXISTING UTILITIES THAT ARE ABANDONED IN PLACE AND SHALL BE DECOMMISSIONED. THOSE THAT INTERSECT WITH THE WALL SHALL BE REMOVED TO THE BACK OF THE LAGGING AND PLUGGED.
- LOCK-OFF LOAD SHALL BE 60% OF THE FACTORED DESIGN LOAD.
- CONTRACTOR SHALL DETERMINE THE ANCHOR DIAMETER AND BOND LENGTH, NOT LESS THAN 15 FEET, PER WSDOT SPECIFICATION 6-17.3.
- WEEP HOLES TO FOLLOW WSDOT DETAILS. TO BE LOCATED CENTERED BETWEEN PILES, AT 1FT ELEVATION FROM THE STREAM FINAL GRADE.

WORK IN PROGRESS

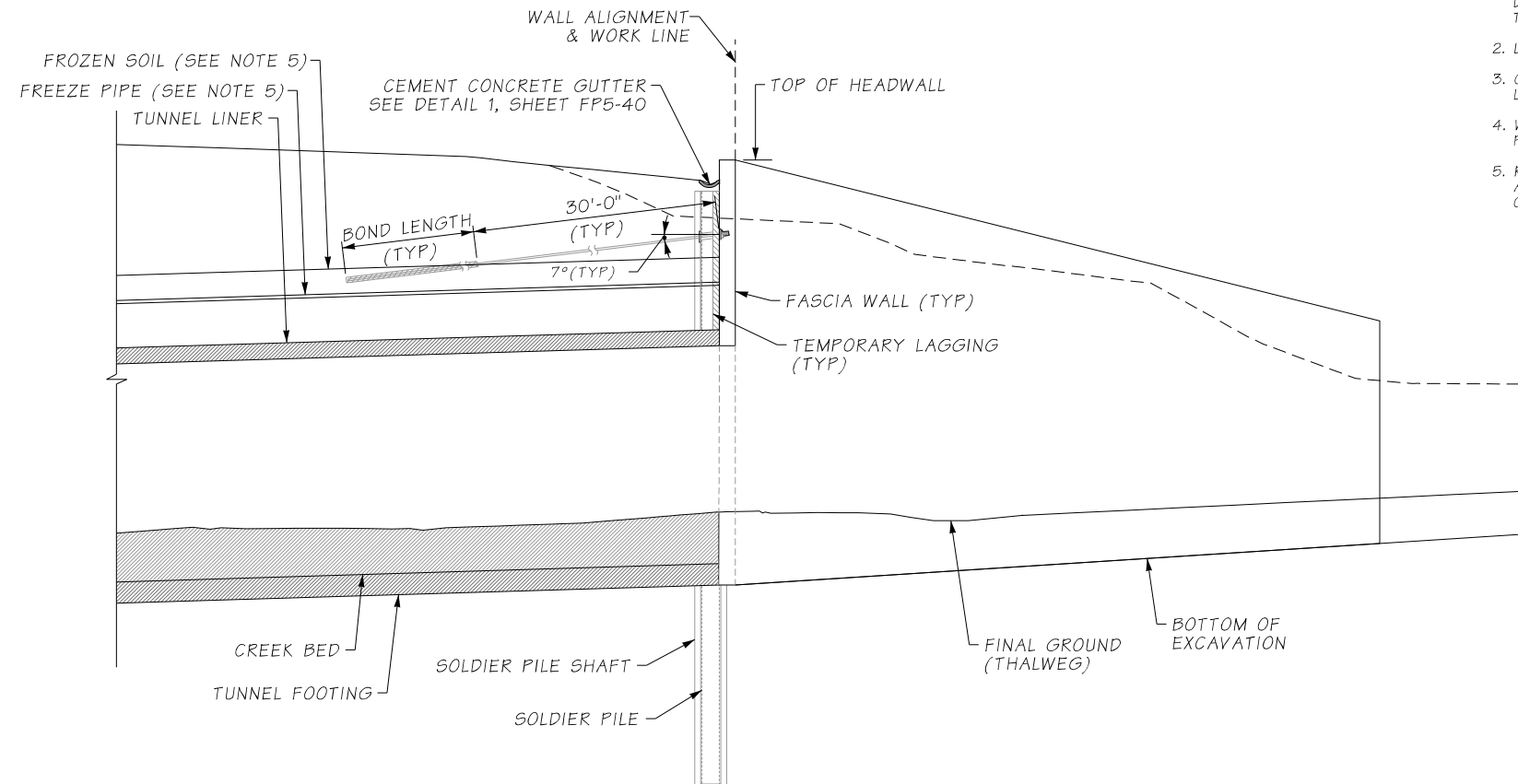
FILE NAME	c:\pwworking\uswaldms06730\C9727_DE_FP5_21.dgn			REGION NO.	STATE	FED.AID PROJ.NO.				<b>I-405</b> <b>BRICKYARD TO SR527</b> <b>IMPROVEMENT PROJECT</b>	PLAN REF NO
TIME	09:29:36			10	WASH						FP5-21
DATE	21/2/2025			JOB NUMBER							SHEET XX OF SHEETS
PLOTTED BY	EscribanoRosilloN			CONTRACT NO.							
DESIGNED BY	I RIVERO			LOCATION NO.							
ENTERED BY	S SANCHEZ										
CHECKED BY	M WONGKAEW										
PROJ. ENGR.	J SLAVICEK	REV A - PRELIM DESIGN SUBMITTAL	2/24/25	MW	9727	XL5446					
REGIONAL ADM.	IL HODGSON	REVISION	DATE	BY							

SR FILE NO. SHEET

C.S. 1757 ~ PROJ. NO. 9727 ~ NORTHWEST REGION ~ I-405 MP 21.94 ~ JUANITA CREEK AT I-405 FISH PASSAGE

**NOTES**

1. EXISTING UTILITIES THAT ARE ABANDONED IN PLACE AND SHALL BE DECOMMISSIONED. THOSE THAT INTERSECT WITH THE WALL SHALL BE REMOVED TO THE BACK OF THE LAGGING AND PLUGGED.
2. LOCK-OFF LOAD SHALL BE 60% OF THE FACTORED DESIGN LOAD.
3. CONTRACTOR SHALL DETERMINE THE ANCHOR DIAMETER AND BOND LENGTH, NOT LESS THAN 15 FEET, PER WSDOT SPECIFICATION 6-17.3.
4. WEEP HOLES TO FOLLOW WSDOT DETAILS. TO BE LOCATED CENTERED BETWEEN PILES, AT 1FT ELEVATION FROM THE STREAM FINAL GRADE.
5. REFER TO PLANS PREPARED BY BRIERLEY ASSOCIATES FOR THE SEM TUNNEL AND ADDITIONAL REQUIREMENTS FOR THE PORTAL WALL IN THE TEMPORARY CONDITIONS.



**SECTION 1**  
SCALE 1"=100'

TIEBACK ANCHORS SCHEDULE					
TYPE	NUMBER OF ROWS	ROW ELEVATION	INCLINATION (°) [HORIZONTAL ANGLE *, VERTICAL ANGLE]	UNBONDED LENGTH (ft)	FACTORED DESIGN LOAD (kipf)
HW-A [Headwall 2]	3	239.28/231.28/221.28	[15,25]/[15,25]/[15,30]	50/42/31	TBC
HW-B [Headwall 2]	1	231.28	[15,30]	41	TBC
HW-C [Headwall 2]	1	241.28	[15,20]	54	TBC
HW-D [Headwall 2]	1	242.28	[9,7]	60	TBC
HW-E [Headwall 2]	1	242.28	[9,7]	60	TBC
HW-F [Headwall 2]	1	241.28	[15,20]	54	TBC
HW-G [Headwall 2]	2	241.28/236.78	[15,25]/[15,25]	52/48	TBC
HW-H [Headwall 2]	3	241.28/233.28/221.28	[15,25]/[15,25]/[15,30]	52/44/31	TBC

\* HORIZONTAL ANGLE AS TAKEN FROM THE PERPENDICULAR TO THE HEADWALL.

**RESERVED FOR RFC CERTIFICATION STAMP**

WORK IN PROGRESS

<b>FILE NAME</b>	c:\pwworking\uswaldms06730\IC9727_DE_FP5_22.dgn			<b>REGION NO.</b>	10	<b>STATE</b>	WASH	<b>FED.AID PROJ.NO.</b>		<b>AECOM</b>		<b>I-405</b>	<b>BRICKYARD TO SR527</b>	<b>PLAN REF NO</b>	FP5-22
<b>TIME</b>	09:22:37			<b>JOB NUMBER</b>	22AB17		<b>CONTRACT NO.</b>	9727	<b>LOCATION NO.</b>	XL5446	<b>Washington State Department of Transportation</b>	<b>IMPROVEMENT PROJECT</b>	<b>JUANITA CREEK</b>	<b>SHEET XX OF SHEETS</b>	
<b>DATE</b>	21/2/2025			<b>CONTRACT NO.</b>	22AB17		<b>LOCATION NO.</b>	XL5446	<b>SKANSKA</b>	<b>Department of Transportation</b>	<b>SKANSKA</b>	<b>FISH PASSAGE STRUCTURE</b>	<b>EAST PORTAL WALL. TYPICAL SECTIONS</b>	<b>SHEETS</b>	
<b>PLOTTED BY</b>	EscribanoRosilloN			<b>DATE</b>	2/24/25	<b>BY</b>	MW								
<b>DESIGNED BY</b>	I RIVERO			<b>REVISION</b>	REV A - PRELIM DESIGN SUBMITTAL										
<b>ENTERED BY</b>	S SANCHEZ														
<b>CHECKED BY</b>	M WONGKAEW														
<b>PROJ. ENGR.</b>	J SLAVICEK														
<b>REGIONAL ADM.</b>	IL HODGSON														

SR FILE NO. SHEET

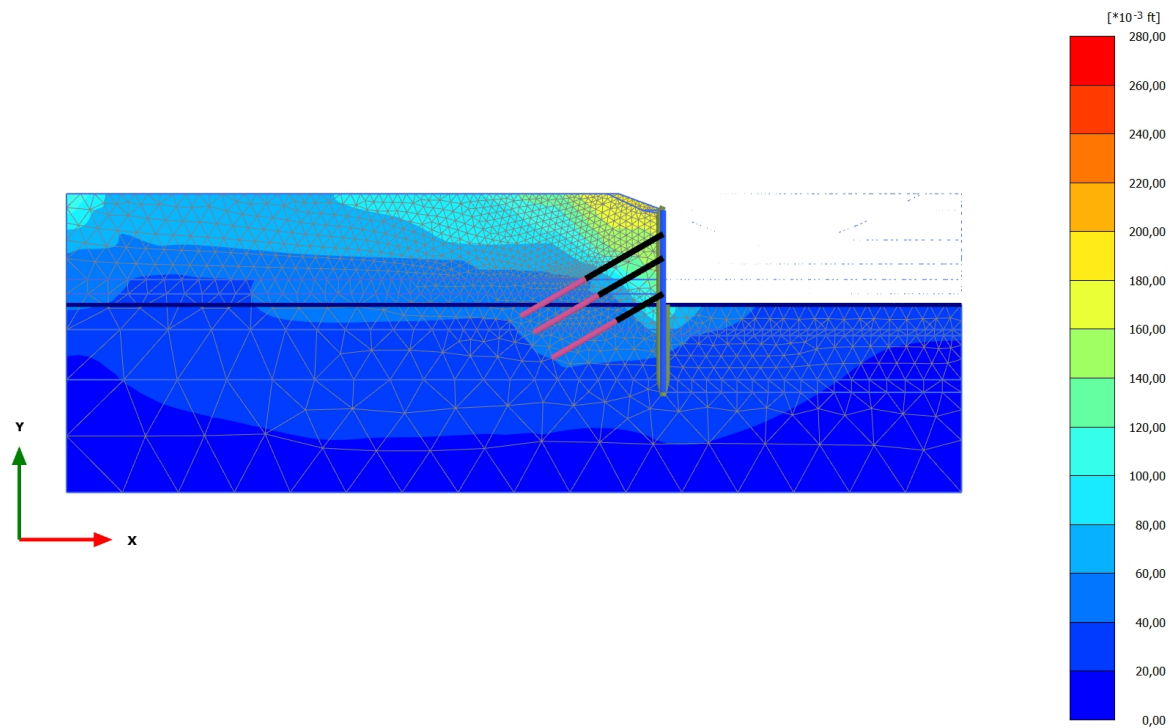
C.S. 1757 ~ PROJ. NO. 9727 ~ NORTHWEST REGION ~ I-405 MP 21.94 ~ JUANITA CREEK AT I-405 FISH PASSAGE

## **APPENDIX B: Plaxis 2D model calculations**

# PLAXIS Report

**Plaxis Model Wingwall 3\_Section 1: WW3-1  
STA. 6+06.99 to 6+38.36**

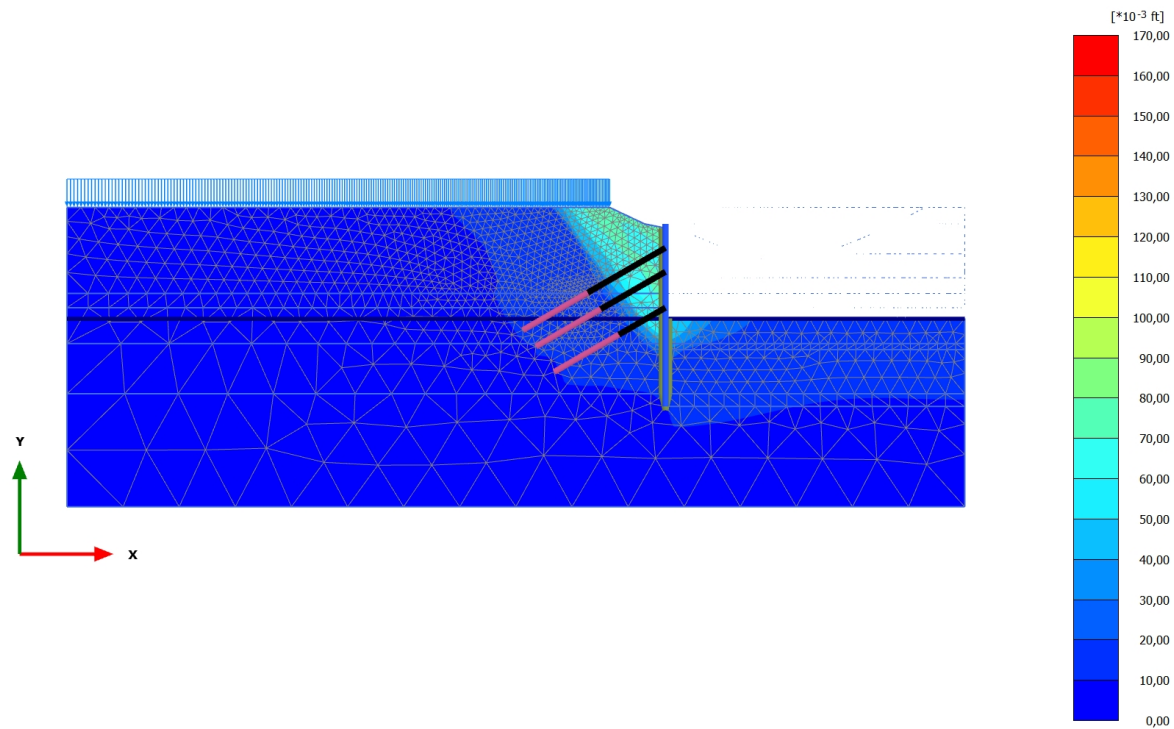
2.1.1.1.1 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Total displacements  $|u|$



**Total displacements  $|u|$  (scaled up 50,0 times)**

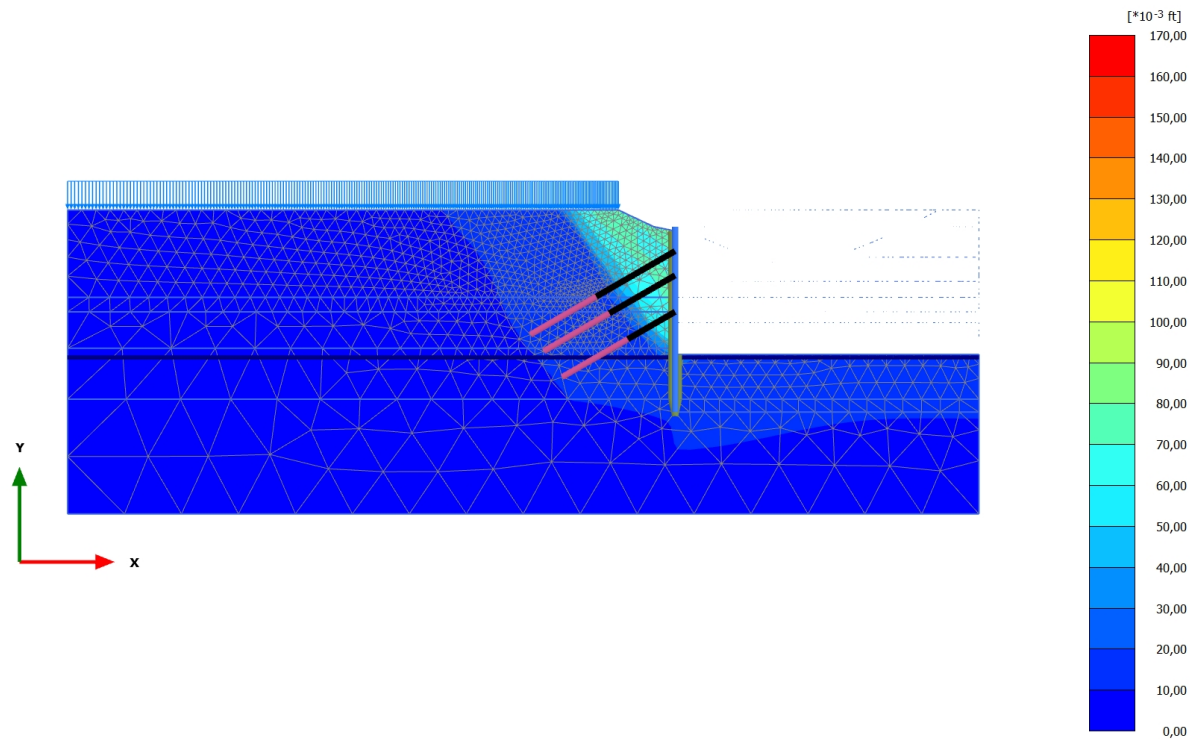
Maximum value = 0,2652 ft (Element 138 at Node 169)

### 2.1.1.1.2 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/282), Total displacements $|u|$



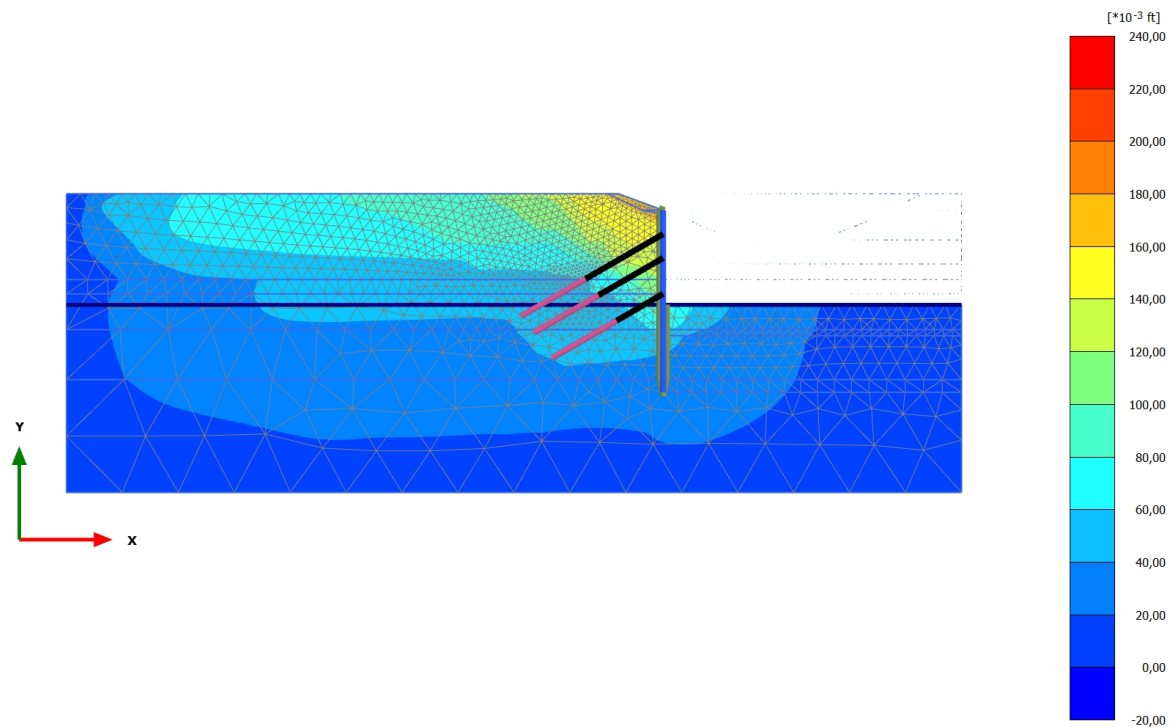
**Total displacements  $|u|$  (scaled up 50,0 times)**  
Maximum value = 0,1617 ft (Element 1401 at Node 169)

### 2.1.1.1.3 Calculation results, Exc. to bottom [Phase\_10] (10/2091), Total displacements $|u|$



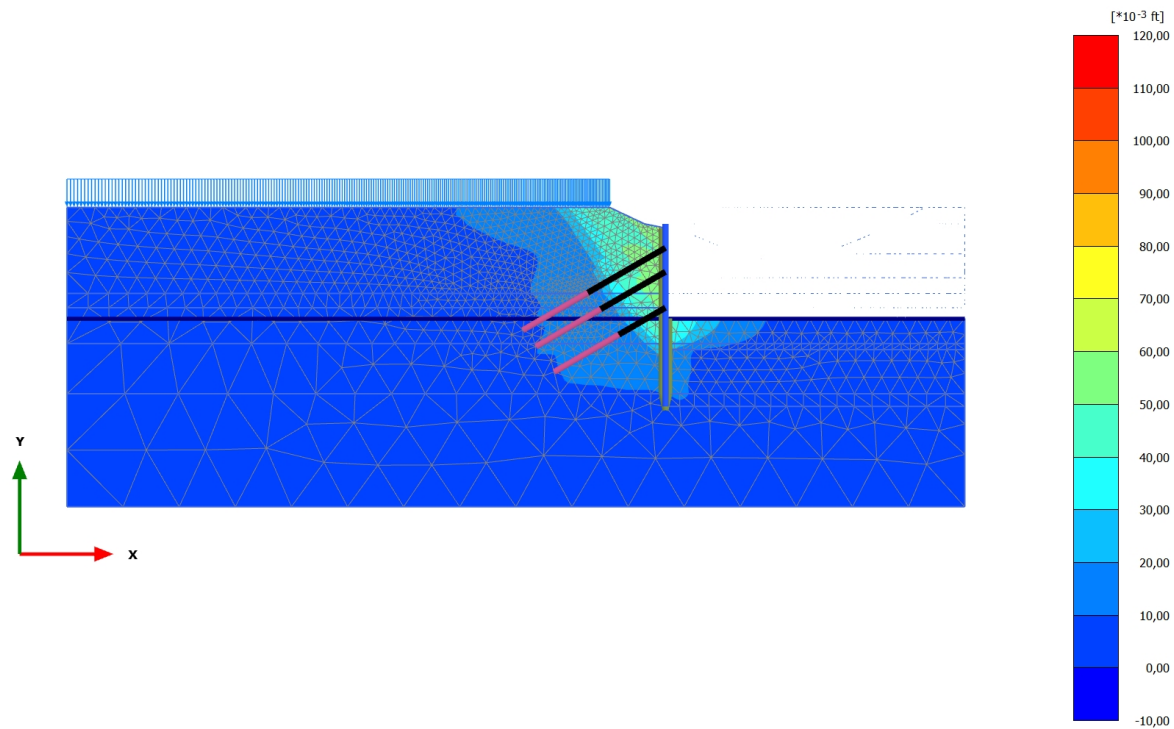
**Total displacements  $|u|$  (scaled up 50,0 times)**  
Maximum value = 0,1623 ft (Element 1401 at Node 169)

2.1.1.2.1 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2350 ft (Element 138 at Node 169)  
Minimum value = 0,000 ft (Element 536 at Node 27192)

### 2.1.1.2.2 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/282), Total displacements $u_x$

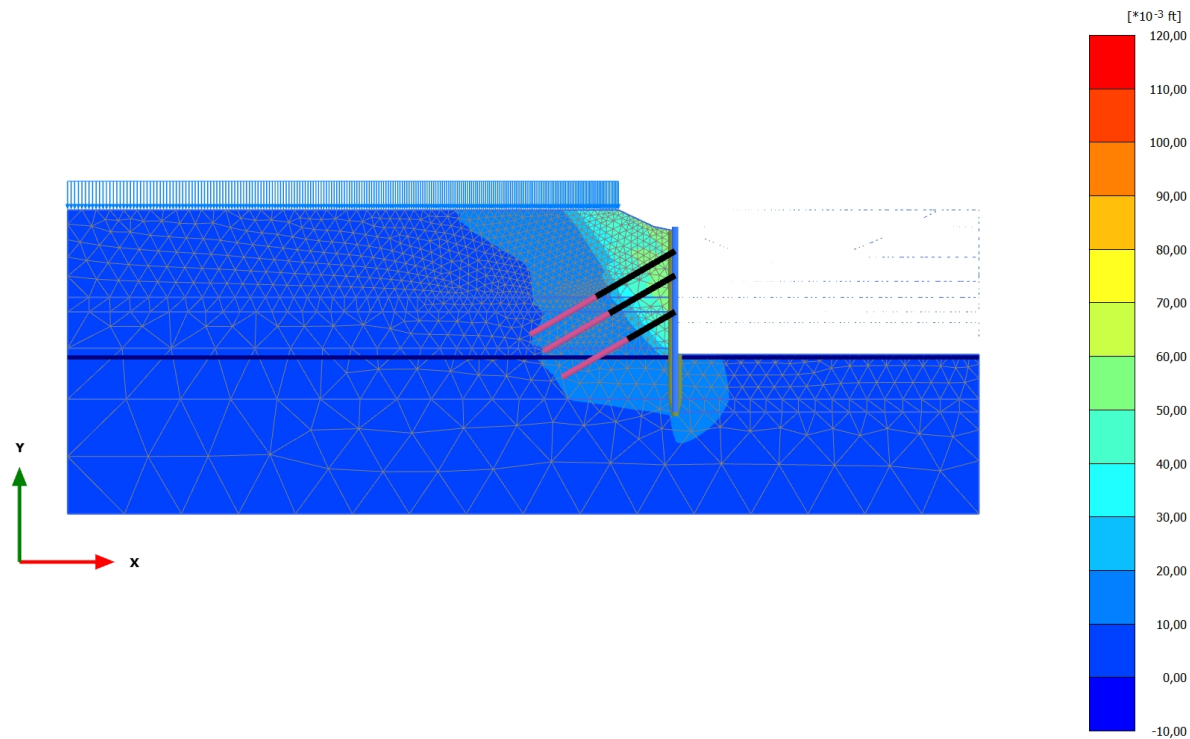


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,1180 ft (Element 1401 at Node 169)

Minimum value = 0,000 ft (Element 536 at Node 27192)

### 2.1.1.2.3 Calculation results, Exc. to bottom [Phase\_10] (10/2091), Total displacements $u_x$

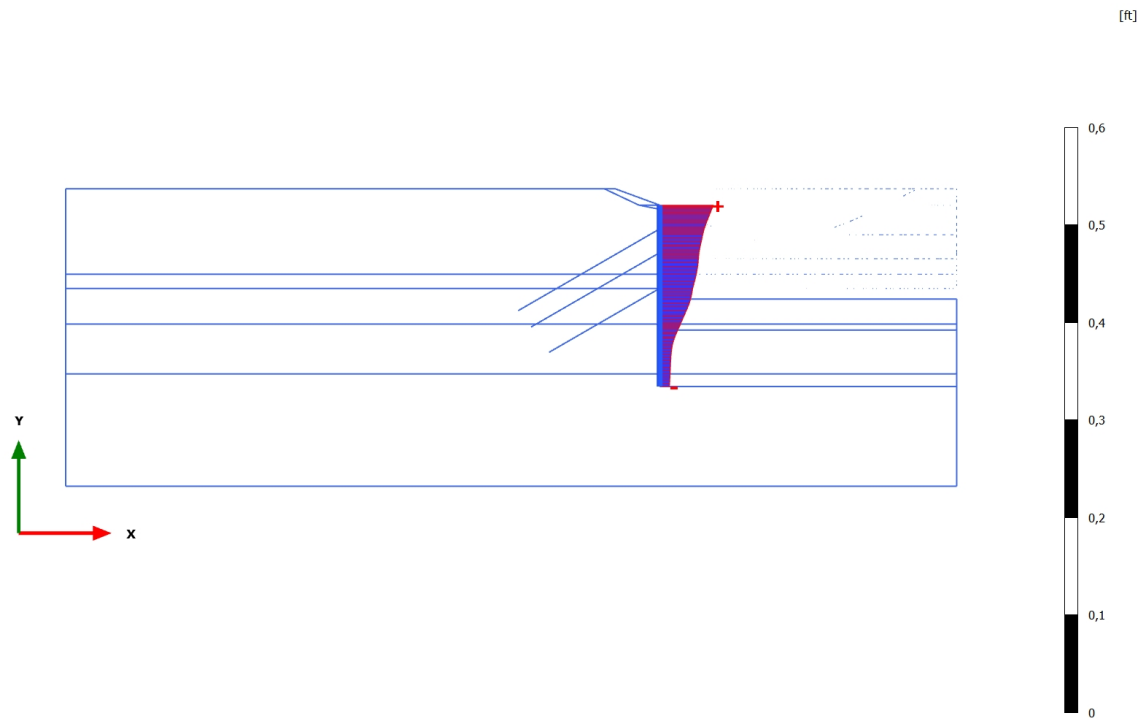


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,1178 ft (Element 1401 at Node 169)

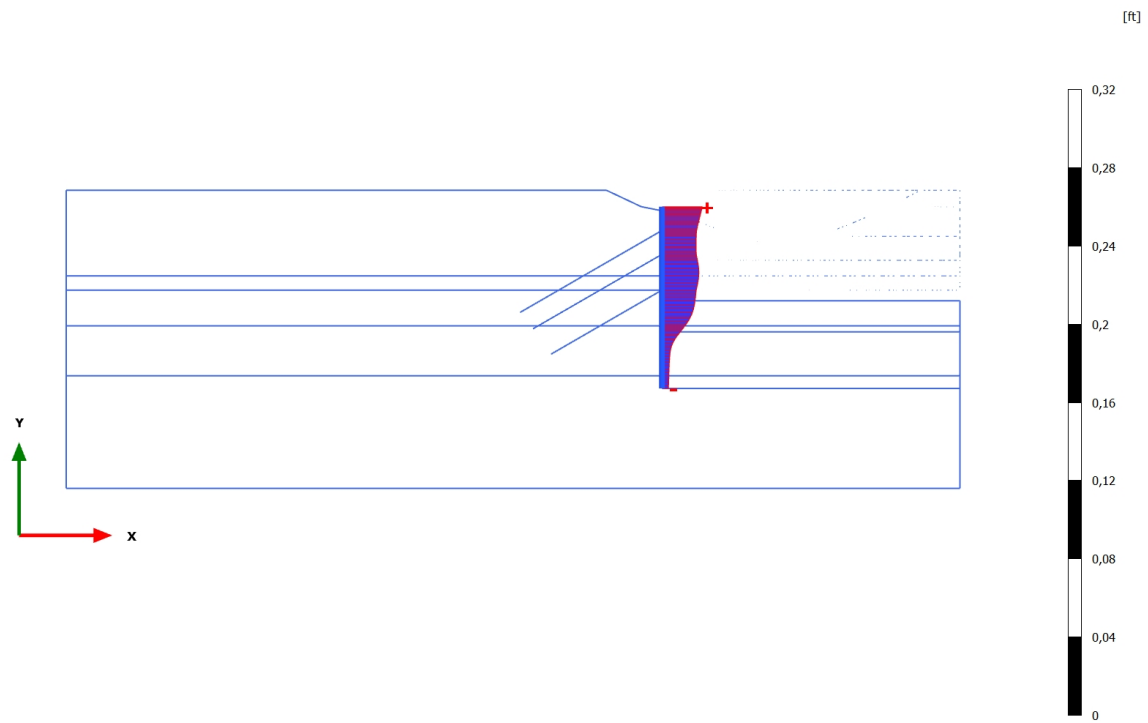
Minimum value = 0,000 ft (Element 536 at Node 27192)

3.1.1.1.1 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/199), Total displacements |u|



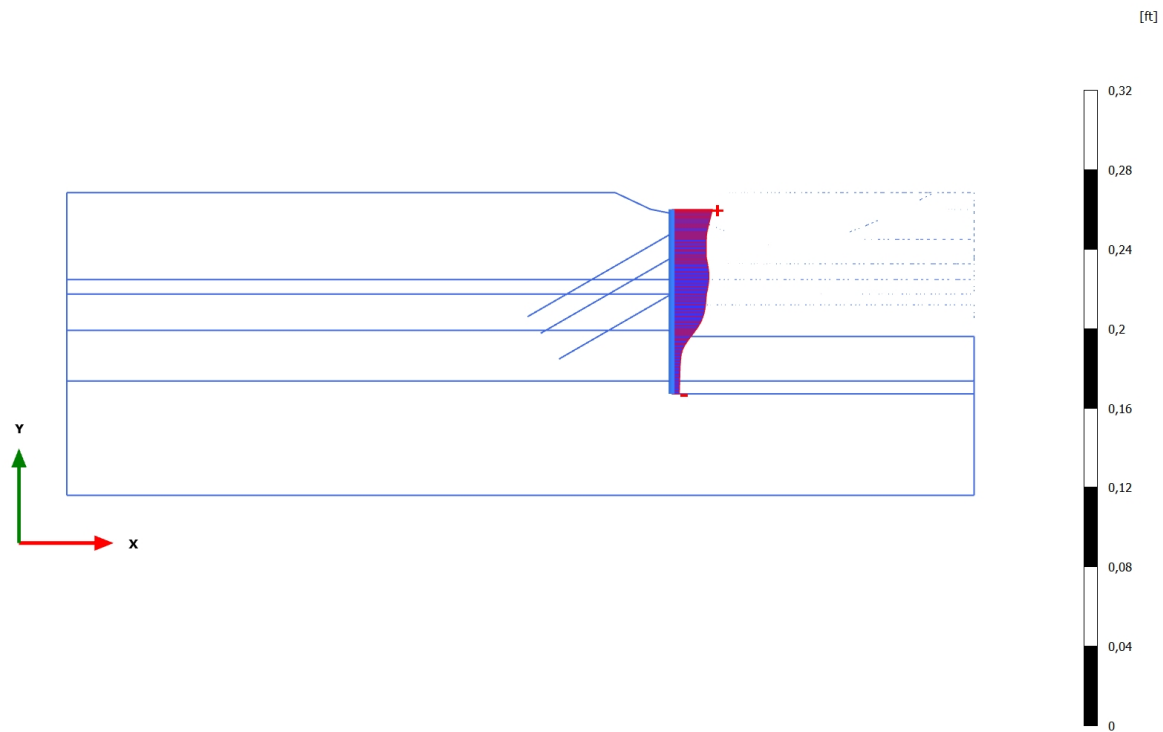
**Total displacements |u| (scaled up 100 times)**  
Maximum value = 0,1811 ft (Element 61 at Node 1937)

3.1.1.1.2 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_18] (18/282), Total displacements |u|



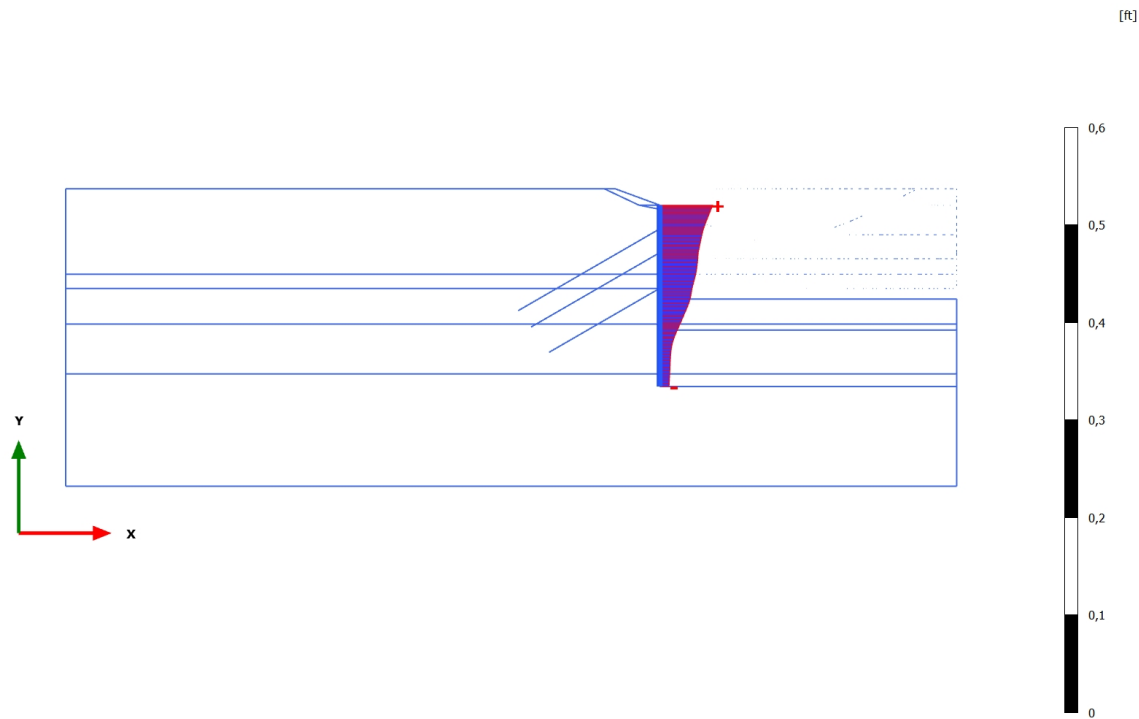
**Total displacements |u| (scaled up 200 times)**  
Maximum value = 0,06796 ft (Element 61 at Node 1937)

### 3.1.1.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/2091), Total displacements $|u|$



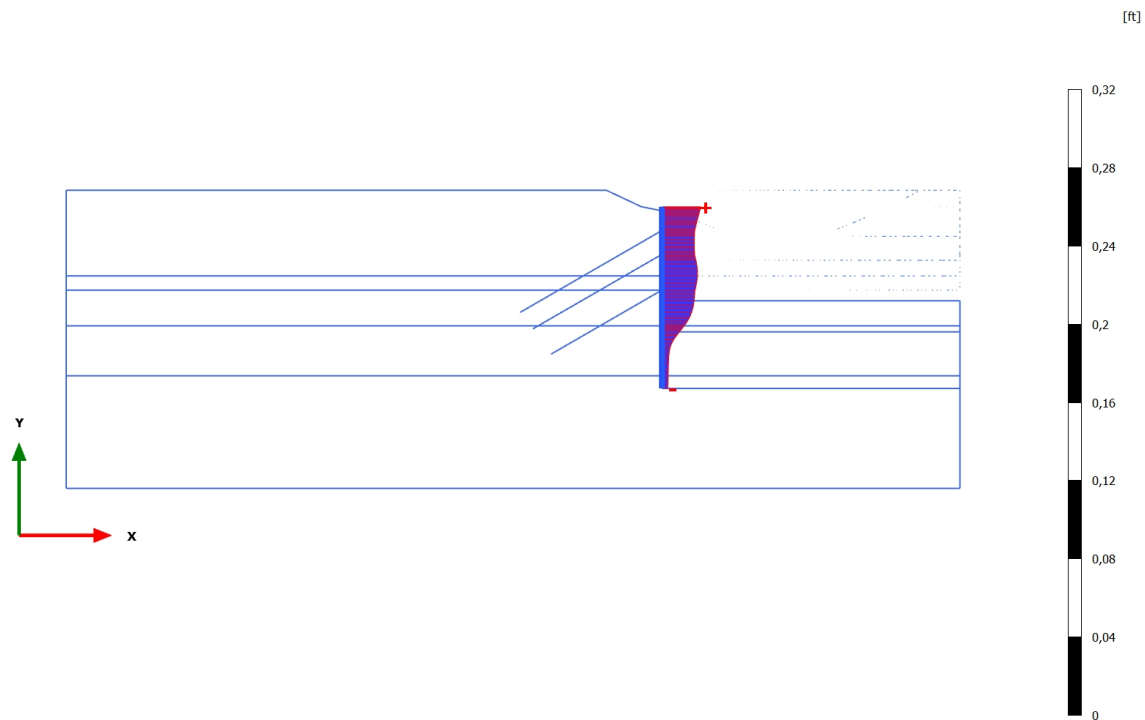
**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,06777 ft (Element 61 at Node 1937)

3.1.1.1.2.1 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/199), Total displacements  $u_x$



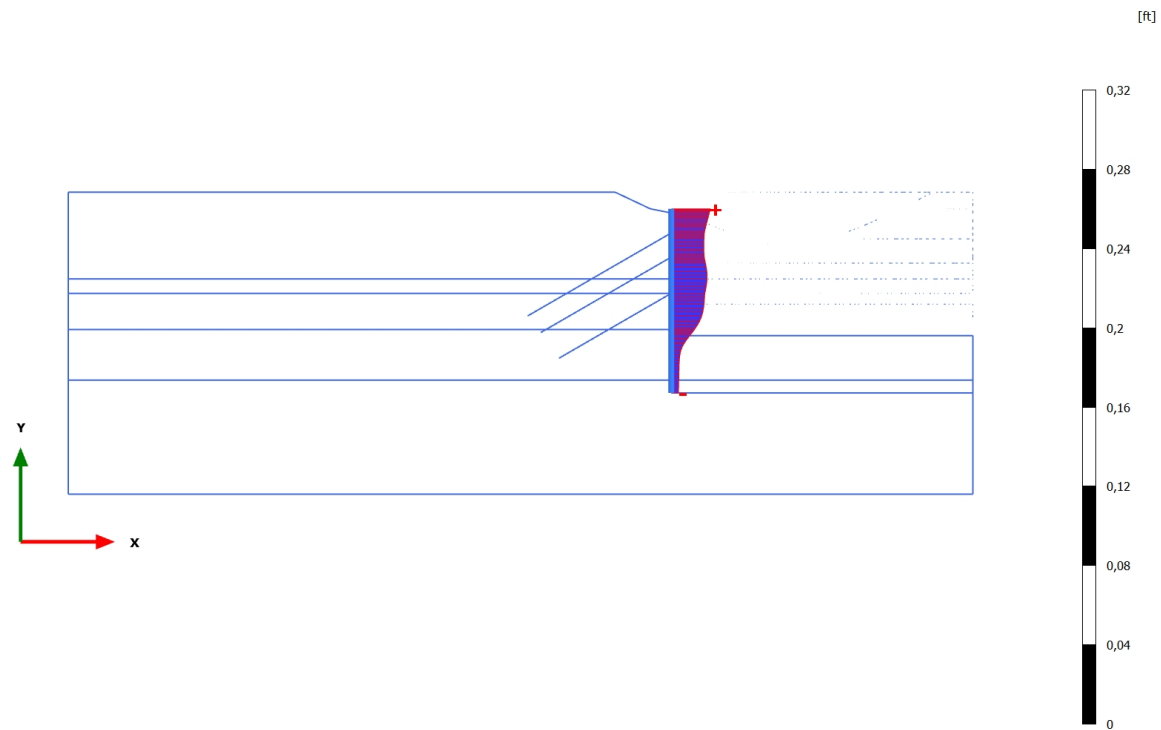
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,1790 ft (Element 61 at Node 1937)  
Minimum value = 0,03194 ft (Element 79 at Node 22161)

### 3.1.1.1.2.2 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/282), Total displacements $u_x$



**Total displacements  $u_x$  (scaled up 200 times)**  
Maximum value = 0,06529 ft (Element 61 at Node 1937)  
Minimum value =  $9,771 \cdot 10^{-3}$  ft (Element 79 at Node 22161)

### 3.1.1.1.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/2091), Total displacements $u_x$

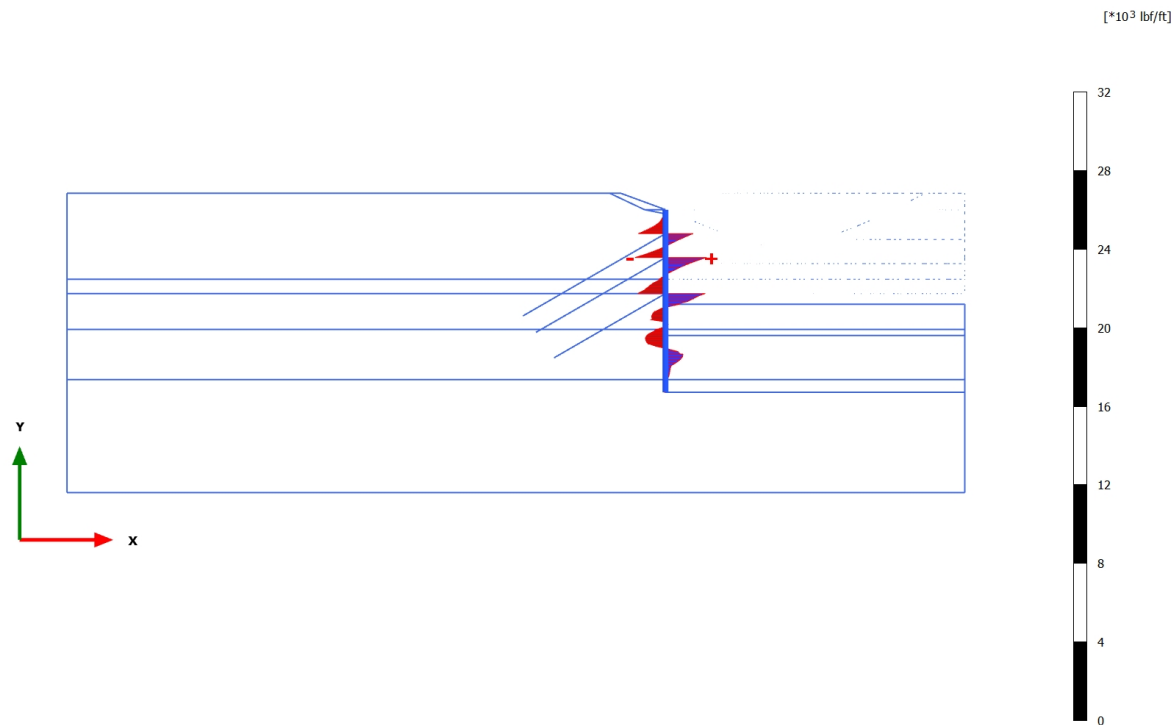


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,06491 ft (Element 61 at Node 1937)

Minimum value = 0,01183 ft (Element 79 at Node 22161)

### 3.1.2.1.1 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Shear forces Q

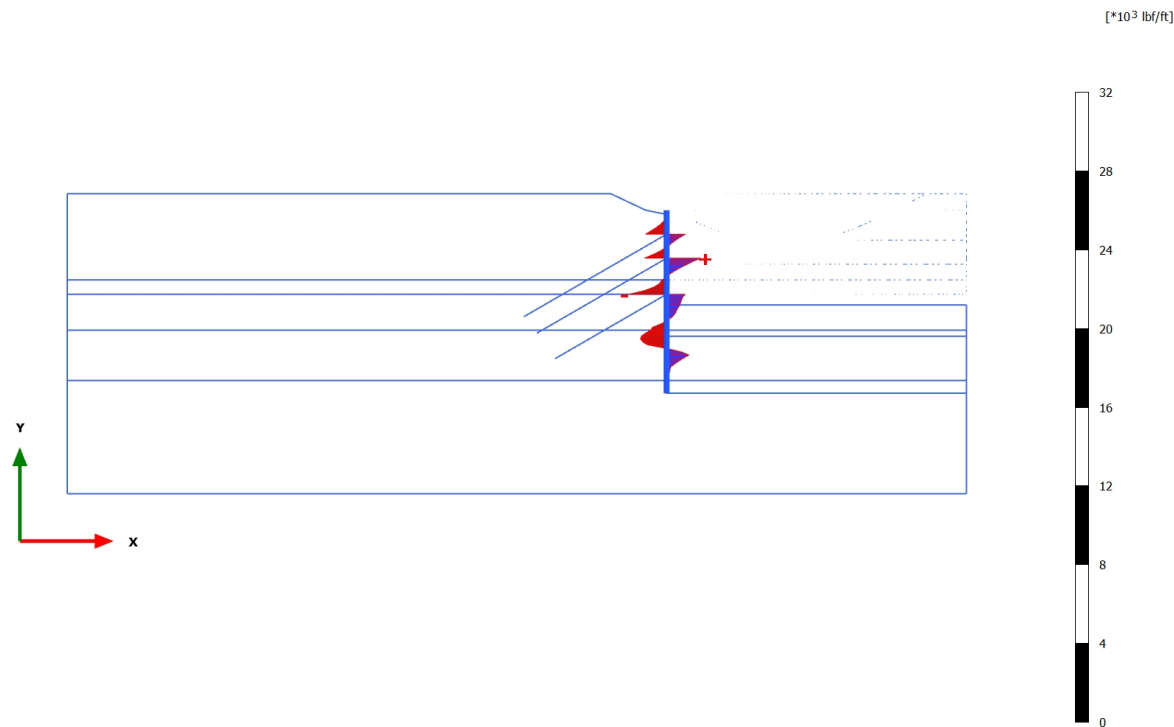


**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 6860 lbf/ft (Element 68 at Node 11320)

Minimum value = -5090 lbf/ft (Element 67 at Node 11320)

### 3.1.2.1.2 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/282), Shear forces Q

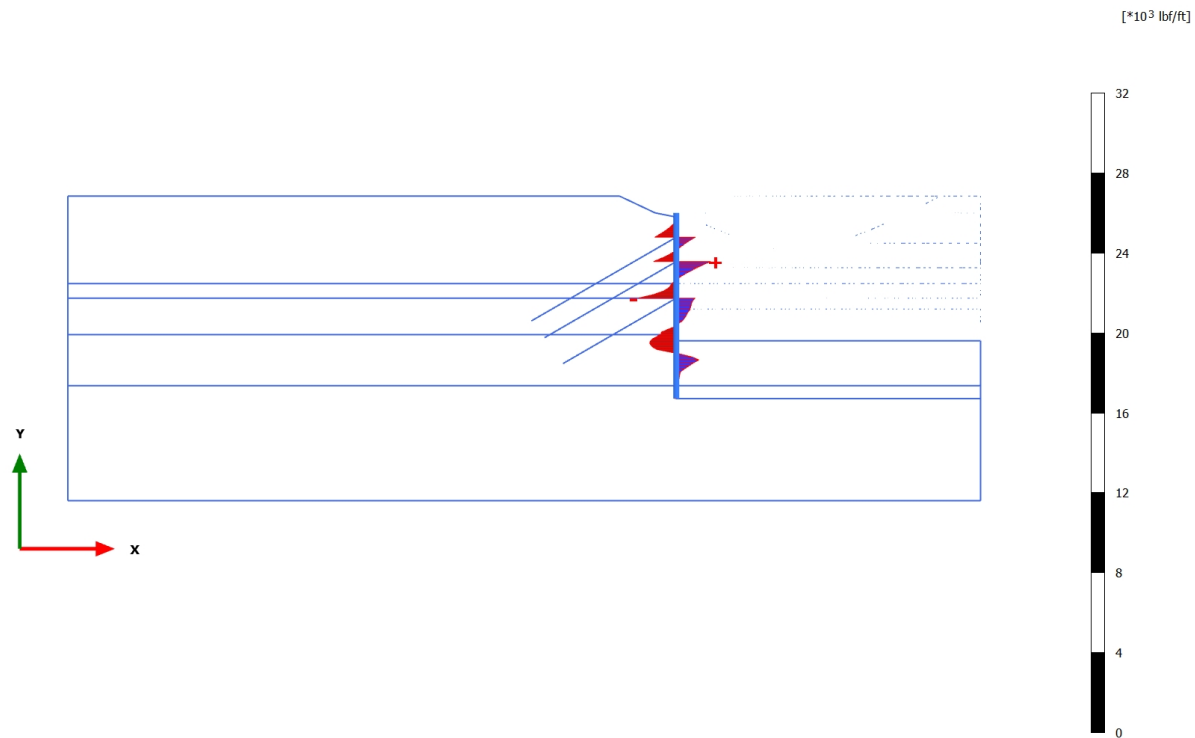


**Shear forces Q (scaled up 2,00\*10<sup>-3</sup> times)**

Maximum value = 5670 lbf/ft (Element 68 at Node 11320)

Minimum value = -6212 lbf/ft (Element 70 at Node 14402)

### 3.1.2.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/2091), Shear forces Q

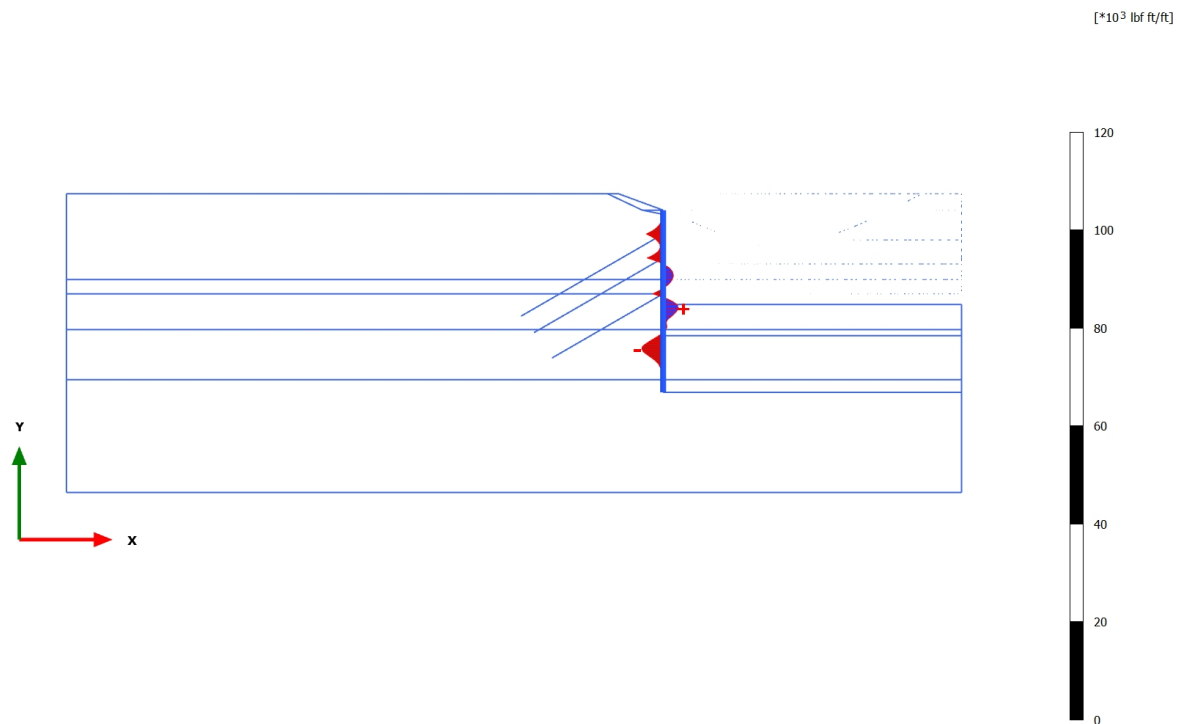


**Shear forces Q (scaled up 2,00\*10<sup>-3</sup> times)**

Maximum value = 5640 lbf/ft (Element 68 at Node 11320)

Minimum value = -6233 lbf/ft (Element 70 at Node 14402)

### 3.1.2.2.1 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Bending moments M

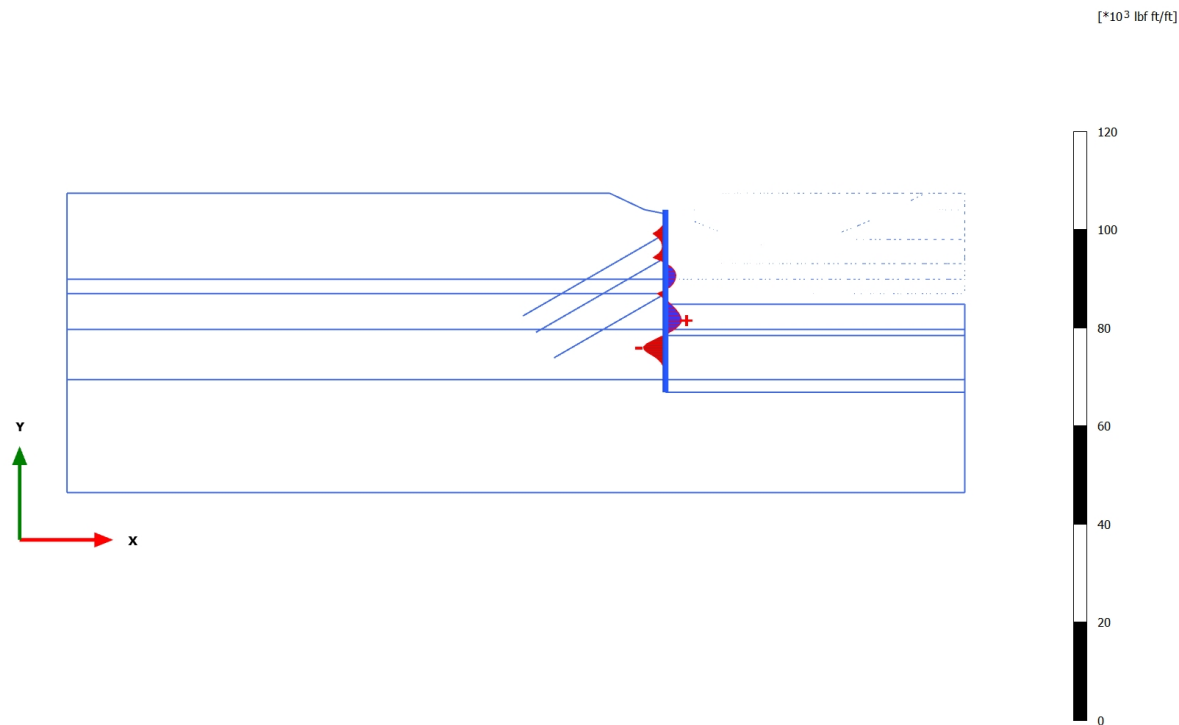


**Bending moments M (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value =  $10,29 \cdot 10^3$  lbf ft/ft (Element 72 at Node 15753)

Minimum value =  $-14,27 \cdot 10^3$  lbf ft/ft (Element 76 at Node 19142)

### 3.1.2.2.2 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/282), Bending moments M

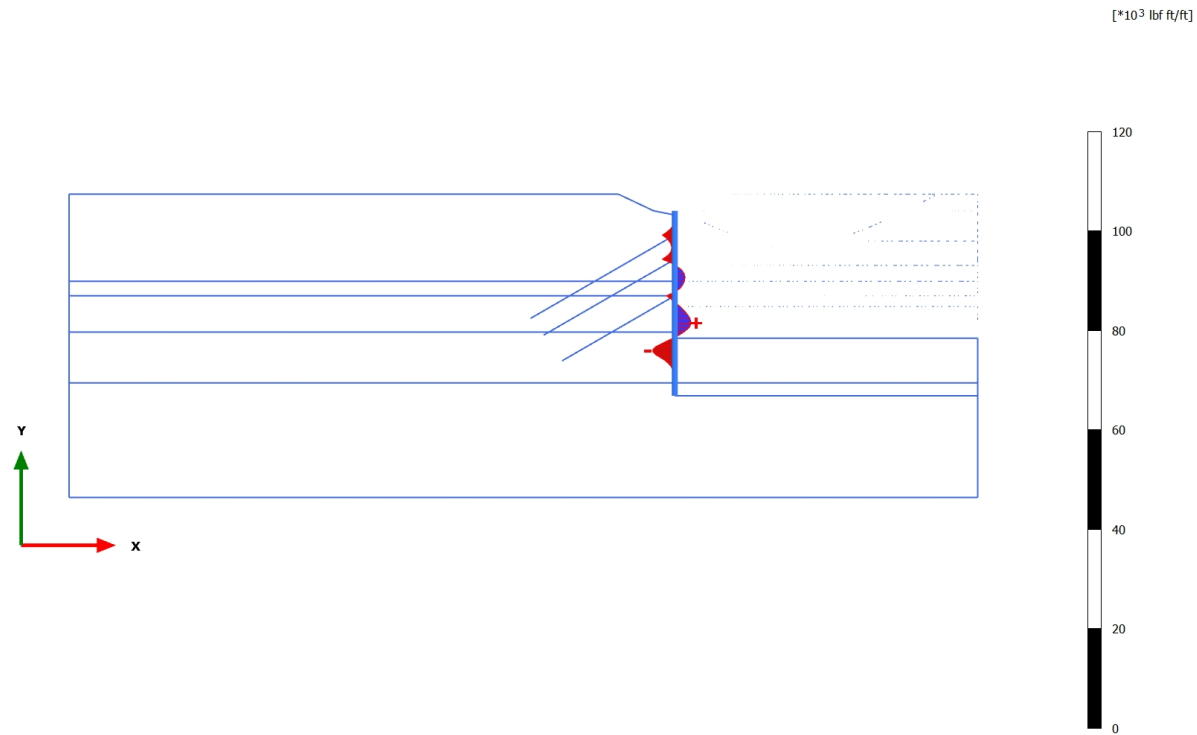


#### Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)

Maximum value = 10,72\*10<sup>3</sup> lbf ft/ft (Element 72 at Node 16894)

Minimum value = -14,59\*10<sup>3</sup> lbf ft/ft (Element 76 at Node 19143)

### 3.1.2.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/2091), Bending moments M

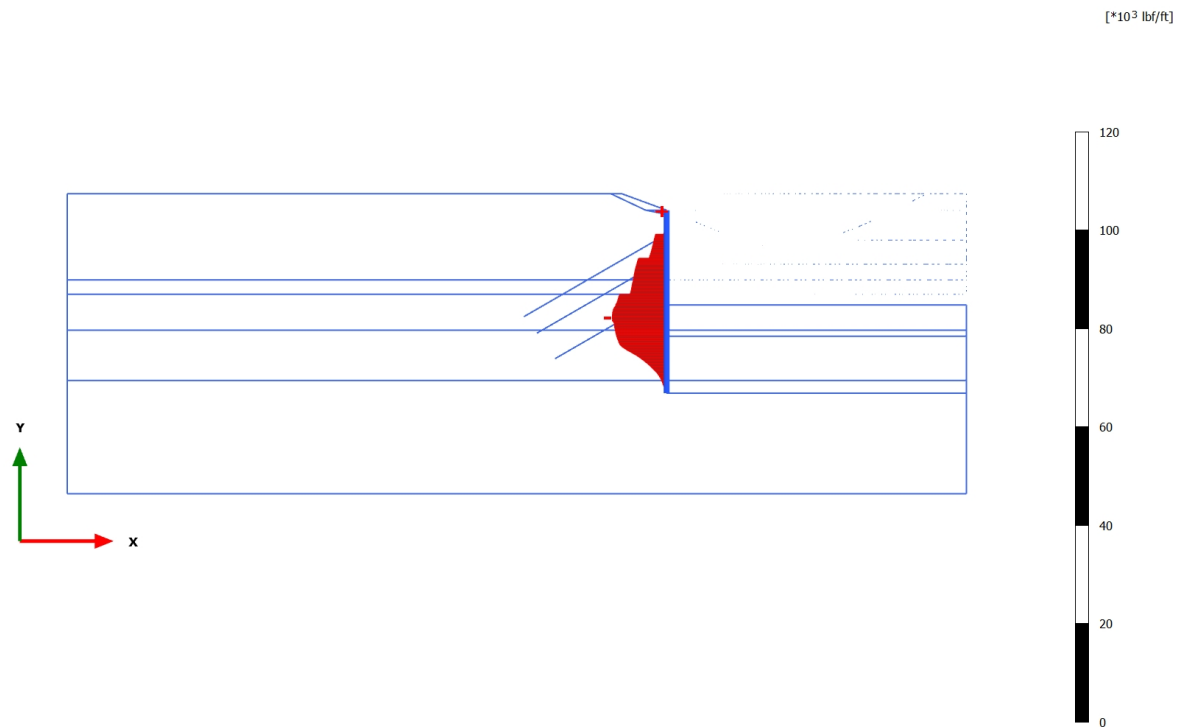


**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 10,77\*10<sup>3</sup> lbf ft/ft (Element 72 at Node 16894)

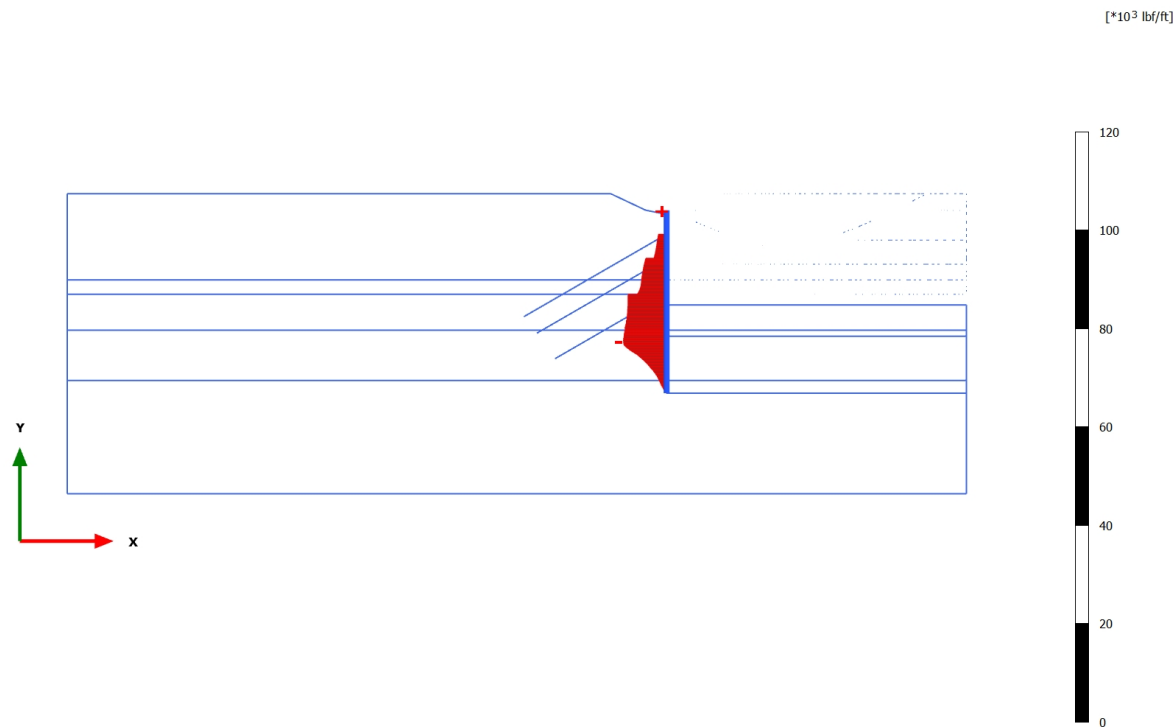
Minimum value = -14,53\*10<sup>3</sup> lbf ft/ft (Element 76 at Node 19143)

### 3.1.2.3.1 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Axial forces N



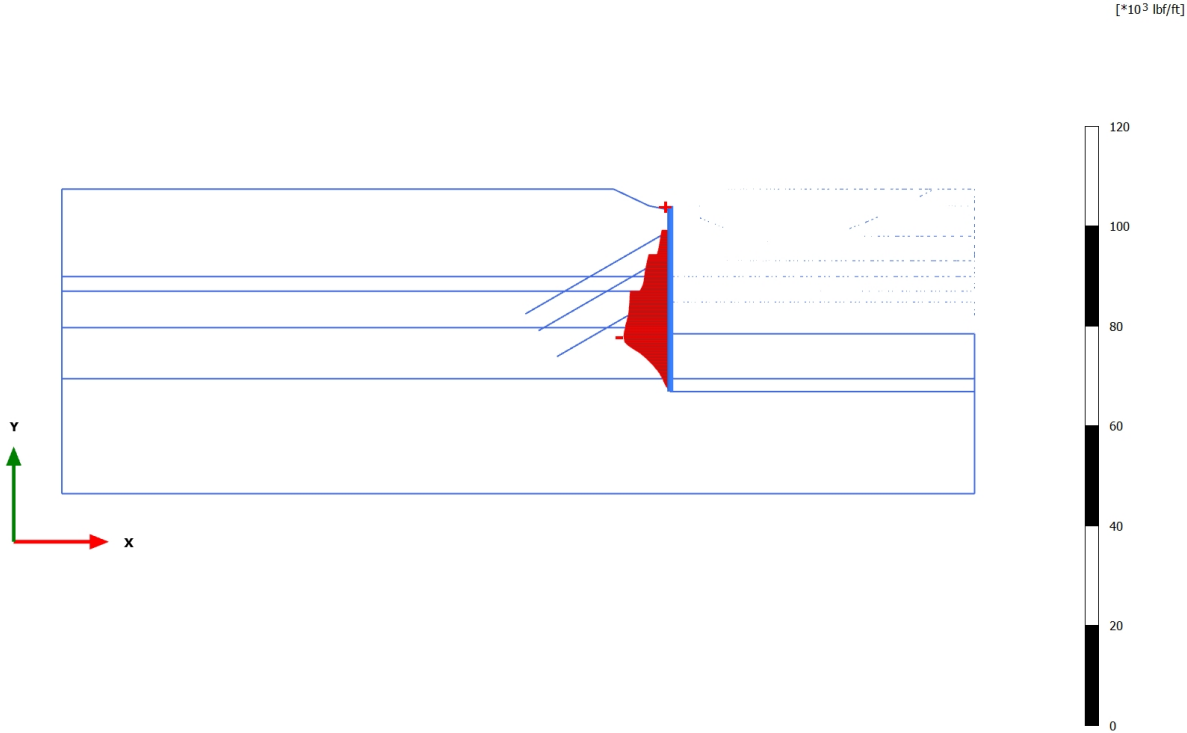
**Axial forces N (scaled up  $0,500*10^{-3}$  times)**  
Maximum value = -2,523 lbf/ft (Element 61 at Node 1937)  
Minimum value =  $-36,27*10^3$  lbf/ft (Element 72 at Node 15751)

### 3.1.2.3.2 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/282), Axial forces N



**Axial forces N (scaled up  $0,500 \cdot 10^{-3}$  times)**  
Maximum value =  $-0,4253 \cdot 10^{-3}$  lbf/ft (Element 61 at Node 1937)  
Minimum value =  $-28,81 \cdot 10^3$  lbf/ft (Element 75 at Node 18400)

3.1.2.3.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/2091), Axial forces N



**Axial forces N (scaled up  $0,500*10^{-3}$  times)**  
Maximum value =  $-0,4253*10^{-3}$  lbf/ft (Element 61 at Node 1937)  
Minimum value =  $-30,44*10^3$  lbf/ft (Element 75 at Node 18401)

3.2.1.1.1 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/199), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	8458	1	100,000	86,500	84,526	0,000	84,526
Element 1-1 (Node-to-node anchor)	27524	2	74,019	71,500	84,526	0,000	84,526
NodeToNodeAnchor\_1\_1	11320	1	100,000	78,500	110,321	0,000	110,321
Element 2-2 (Node-to-node anchor)	27577	2	78,349	66,000	110,321	0,000	110,321
NodeToNodeAnchor\_2\_1	14402	1	100,000	66,500	107,982	0,000	107,982
Element 3-3 (Node-to-node anchor)	27646	2	84,412	57,500	107,982	0,000	107,982

### 3.2.1.1.2 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/282), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	8458	1	100,000	86,500	61,447	0,000	61,447
Element 1-1 (Node-to-node anchor)	27524	2	74,019	71,500	61,447	0,000	61,447
NodeToNodeAnchor\_1\_1	11320	1	100,000	78,500	86,630	0,000	86,630
Element 2-2 (Node-to-node anchor)	27577	2	78,349	66,000	86,630	0,000	86,630
NodeToNodeAnchor\_2\_1	14402	1	100,000	66,500	91,983	0,000	91,983
Element 3-3 (Node-to-node anchor)	27646	2	84,412	57,500	91,983	0,000	91,983

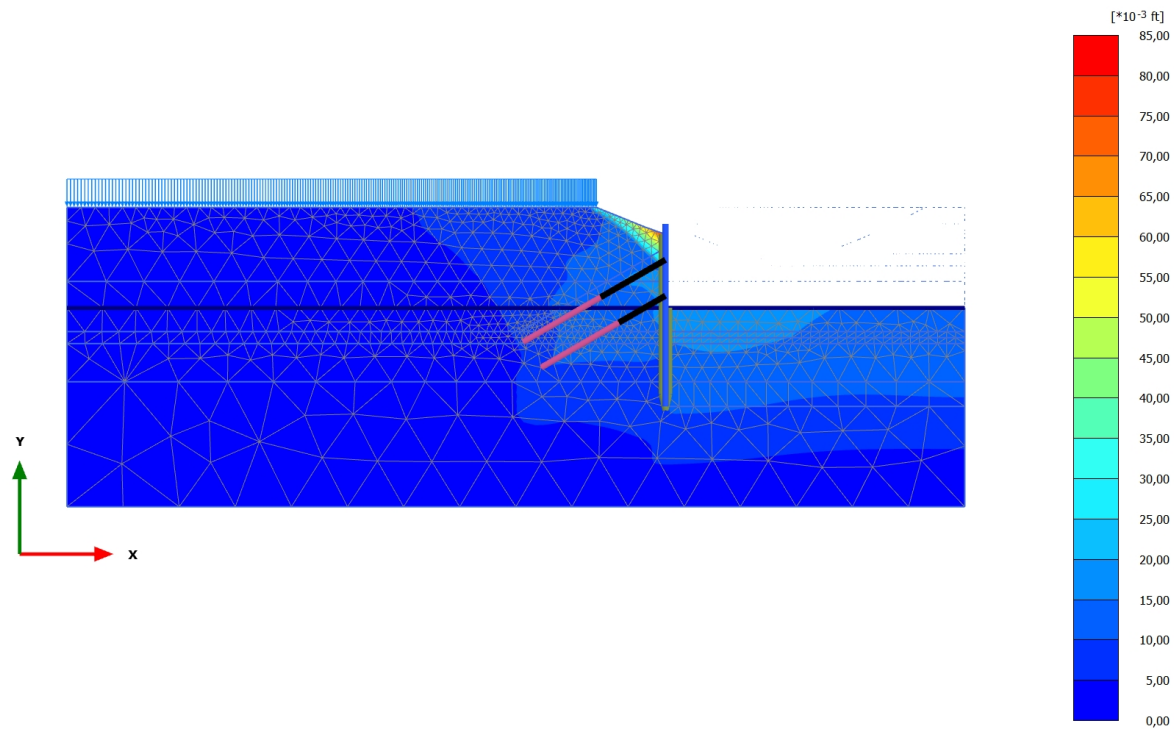
3.2.1.1.3 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/2091), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	8458	1	100,000	86,500	61,355	0,000	61,355
Element 1-1 (Node-to-node anchor)	27524	2	74,019	71,500	61,355	0,000	61,355
NodeToNodeAnchor\_1\_1	11320	1	100,000	78,500	86,426	0,000	86,426
Element 2-2 (Node-to-node anchor)	27577	2	78,349	66,000	86,426	0,000	86,426
NodeToNodeAnchor\_2\_1	14402	1	100,000	66,500	91,936	0,000	91,936
Element 3-3 (Node-to-node anchor)	27646	2	84,412	57,500	91,936	0,000	91,936

# PLAXIS Report

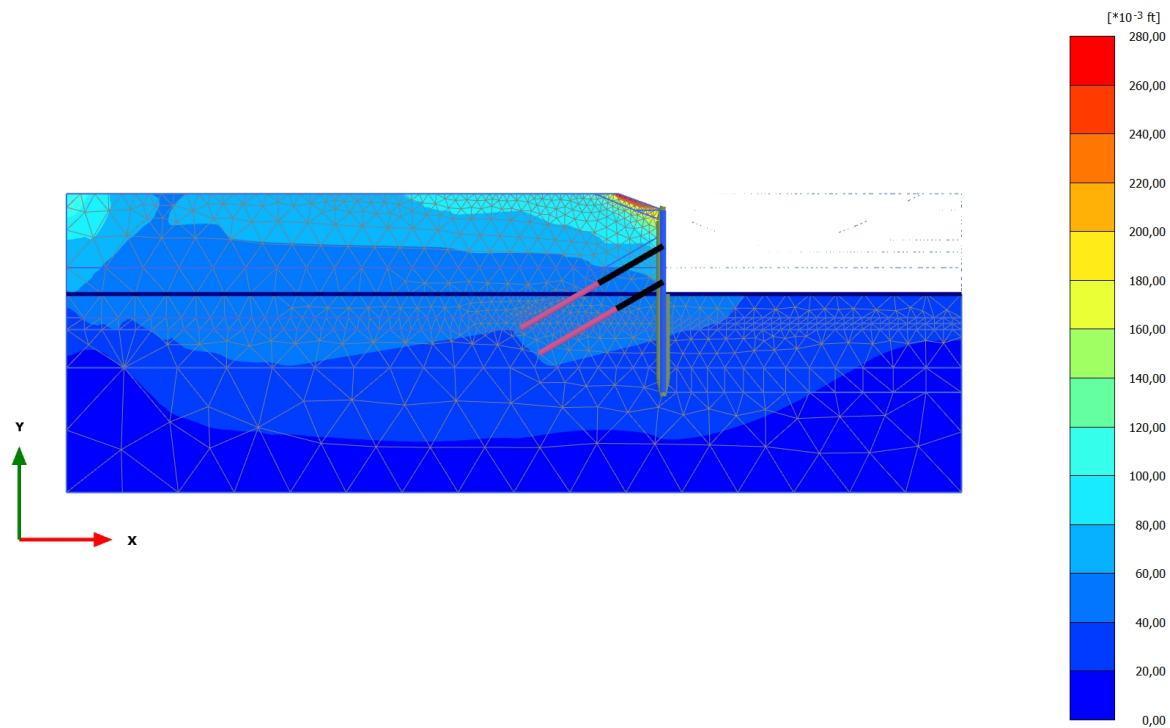
**Plaxis Model Wingwall 3\_Section 2: WW3-2  
STA. 6+38.36 to 6+62.36**

2.1.1.1.1 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/361), Total displacements  $|u|$



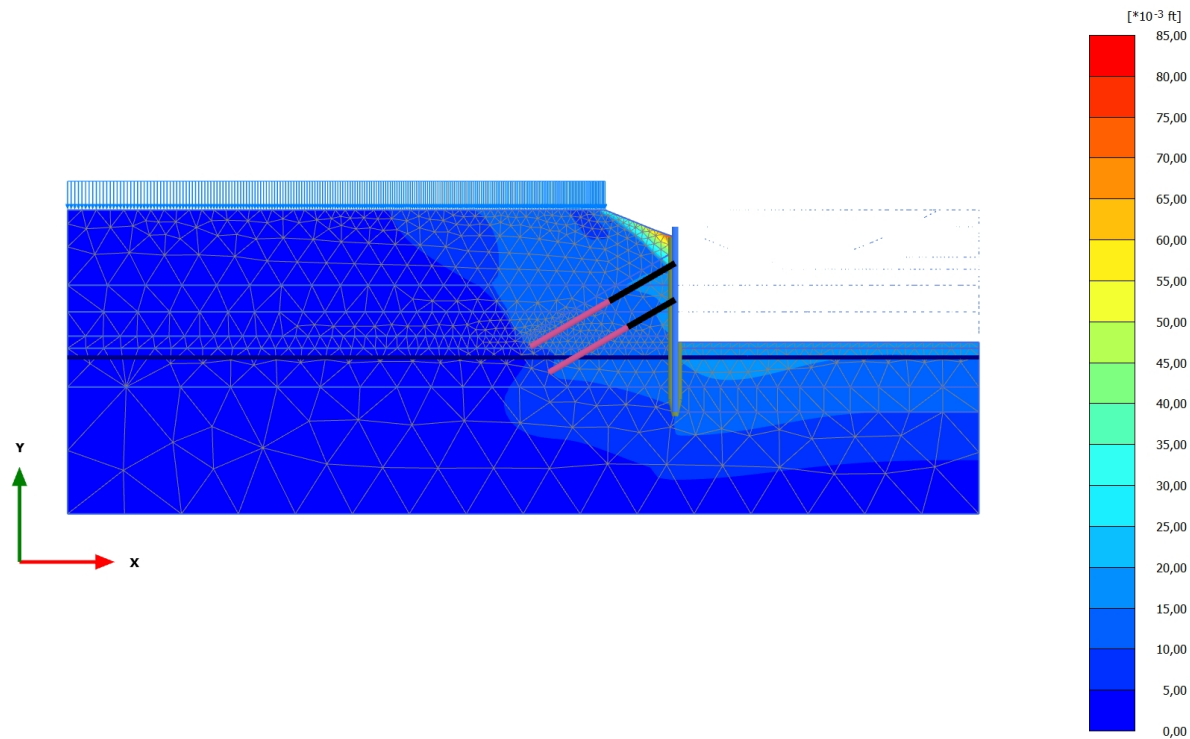
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,08109 ft (Element 860 at Node 6456)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/579), Total displacements  $|u|$



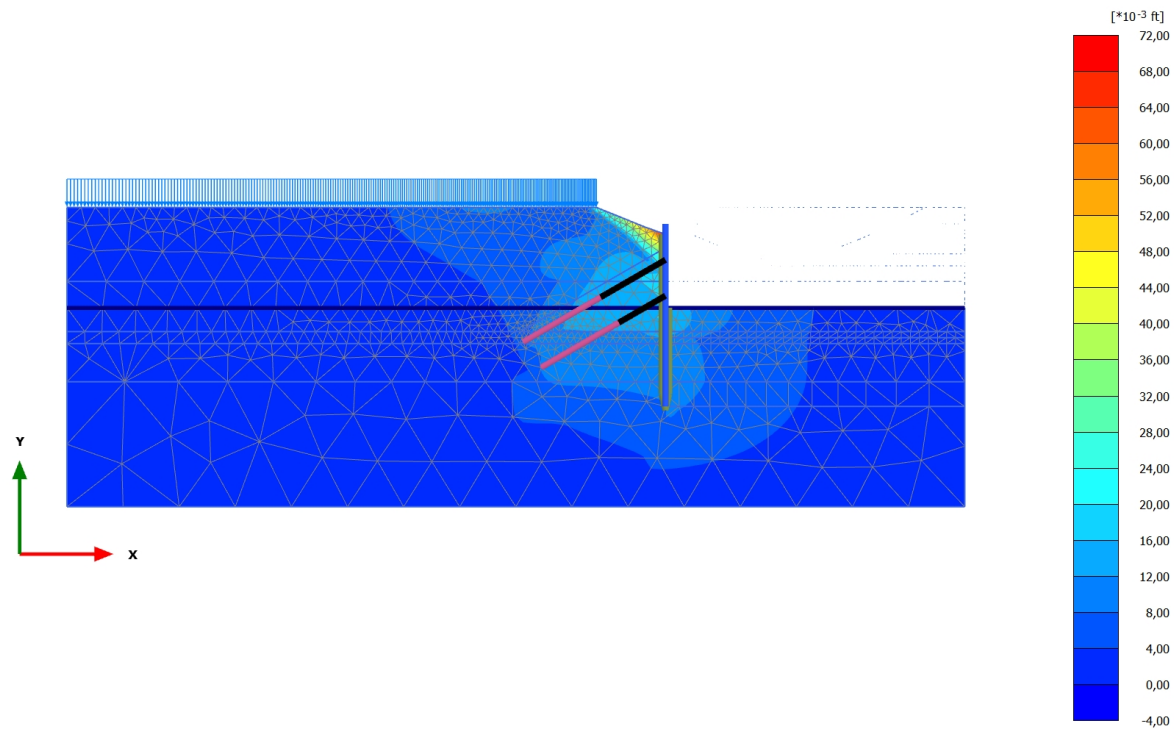
**Total displacements  $|u|$  (scaled up 50,0 times)**  
Maximum value = 0,2781 ft (Element 146 at Node 6415)

### 2.1.1.1.3 Calculation results, Exc. to bottom [Phase\_10] (10/1046), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,08159 ft (Element 860 at Node 6456)

### 2.1.1.2.1 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/361), Total displacements $u_x$

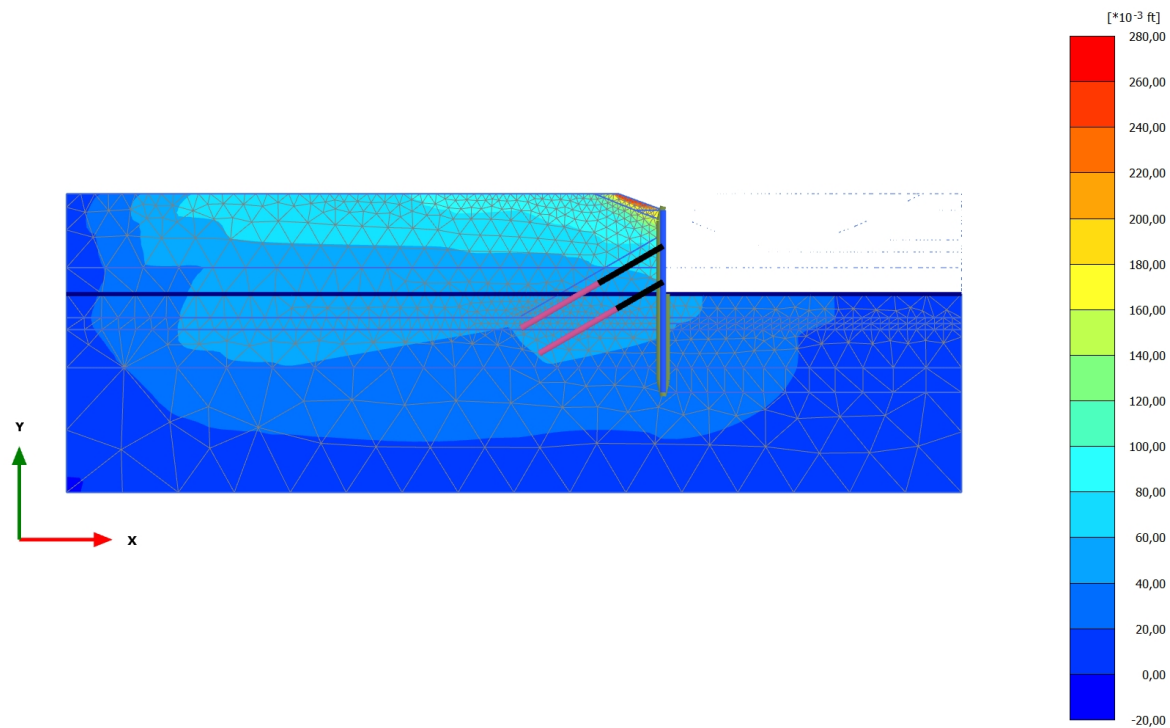


#### Total displacements $u_x$ (scaled up 100 times)

Maximum value = 0,06825 ft (Element 860 at Node 6456)

Minimum value = 0,000 ft (Element 565 at Node 18851)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/579), Total displacements  $u_x$

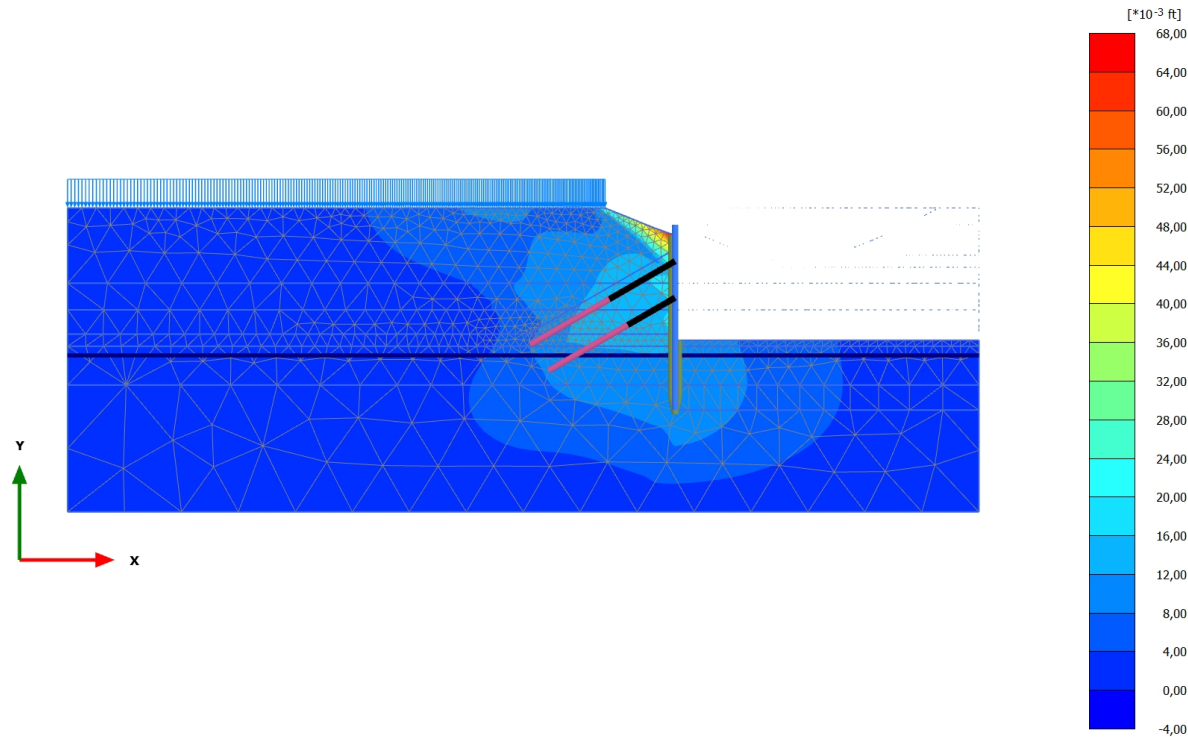


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,2656 ft (Element 146 at Node 6415)

Minimum value = -0,03449\* $10^{-3}$  ft (Element 2255 at Node 17621)

### 2.1.1.2.3 Calculation results, Exc. to bottom [Phase\_10] (10/1046), Total displacements $u_x$

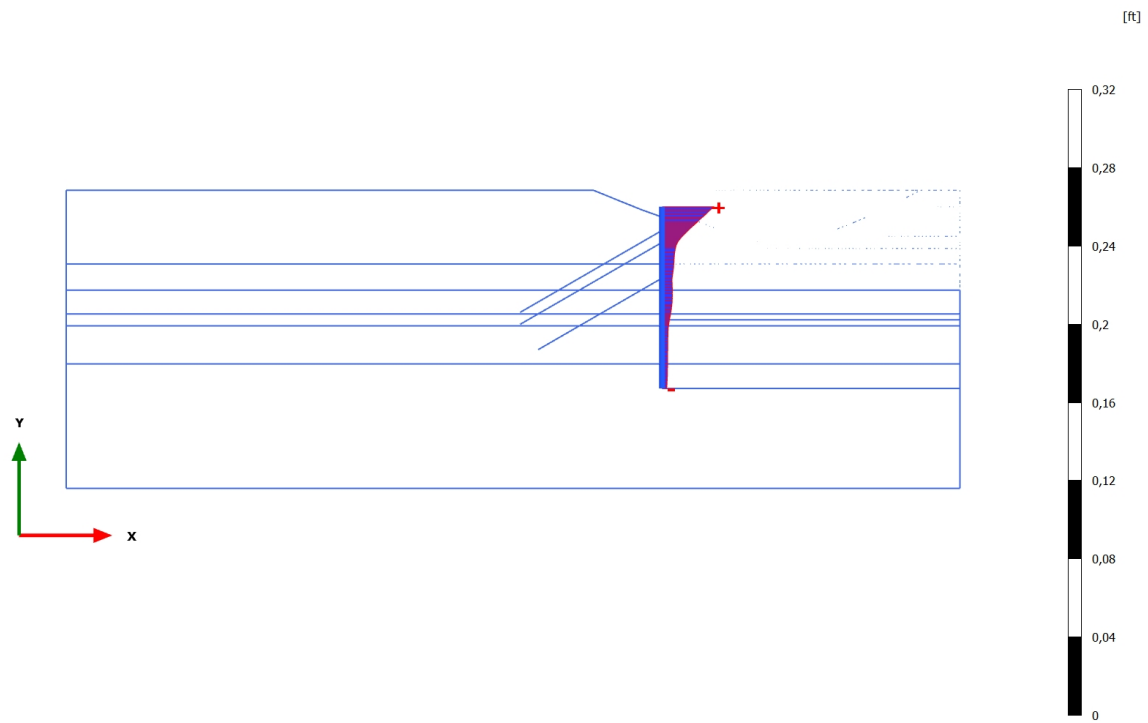


**Total displacements  $u_x$  (scaled up 100 times)**

Maximum value = 0,06792 ft (Element 860 at Node 6456)

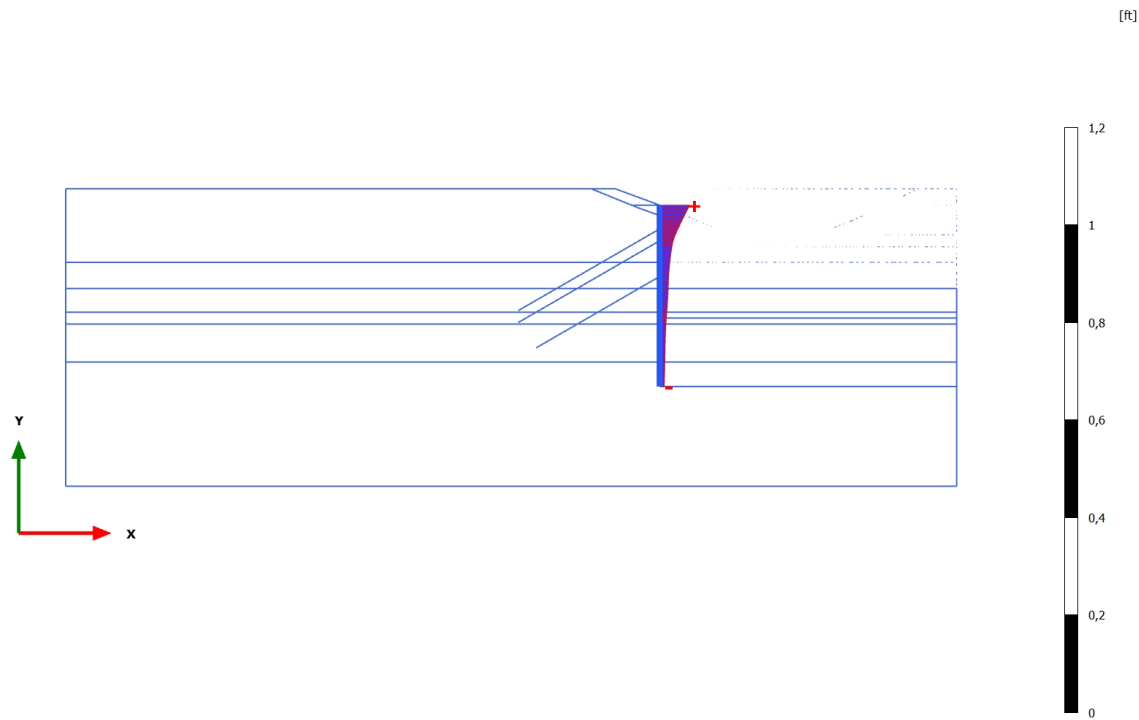
Minimum value = 0,000 ft (Element 565 at Node 18851)

3.1.1.1.1 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_18] (18/361), Total displacements |u|



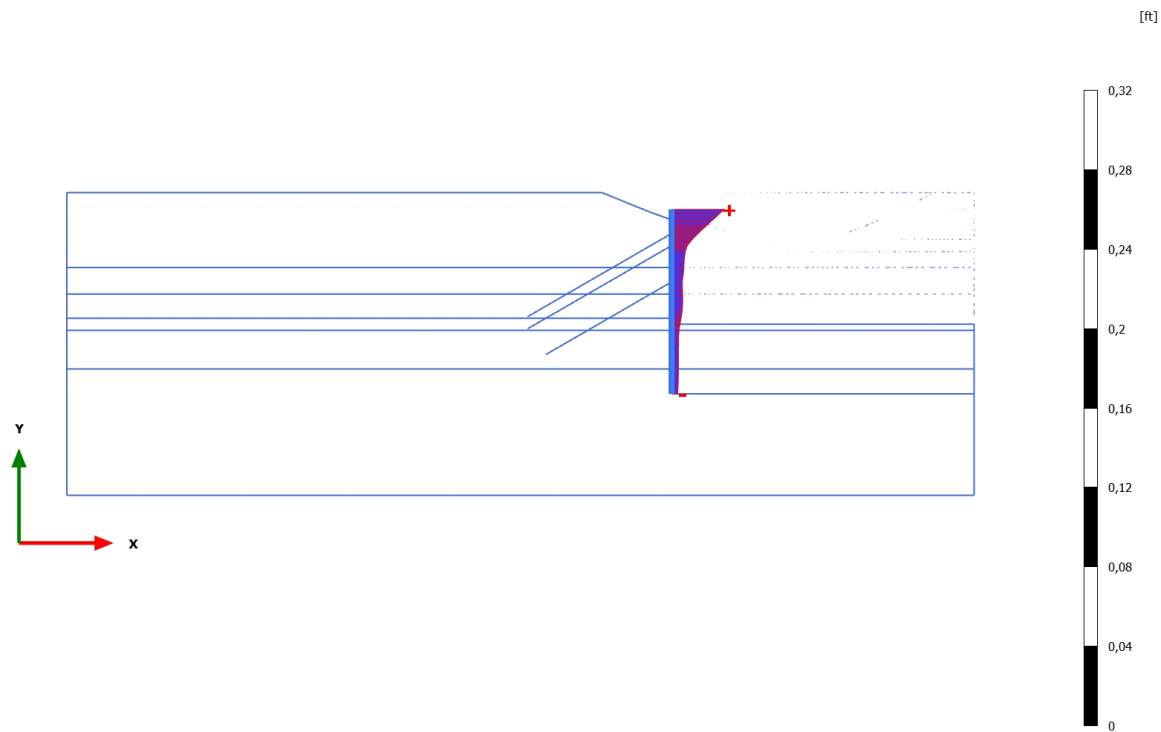
**Total displacements |u| (scaled up 200 times)**  
Maximum value = 0,08739 ft (Element 64 at Node 5333)

3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/579), Total displacements |u|



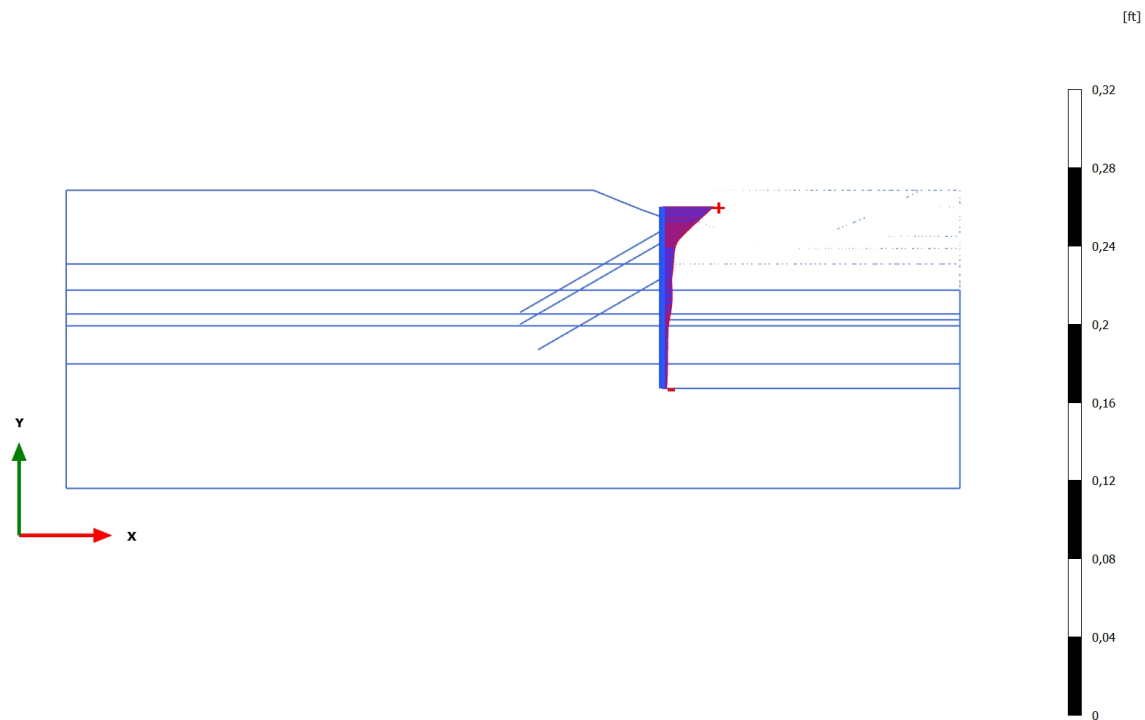
**Total displacements |u| (scaled up 50,0 times)**  
Maximum value = 0,2019 ft (Element 64 at Node 5333)

### 3.1.1.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/1046), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,08710 ft (Element 64 at Node 5333)

### 3.1.1.1.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/361), Total displacements $u_x$

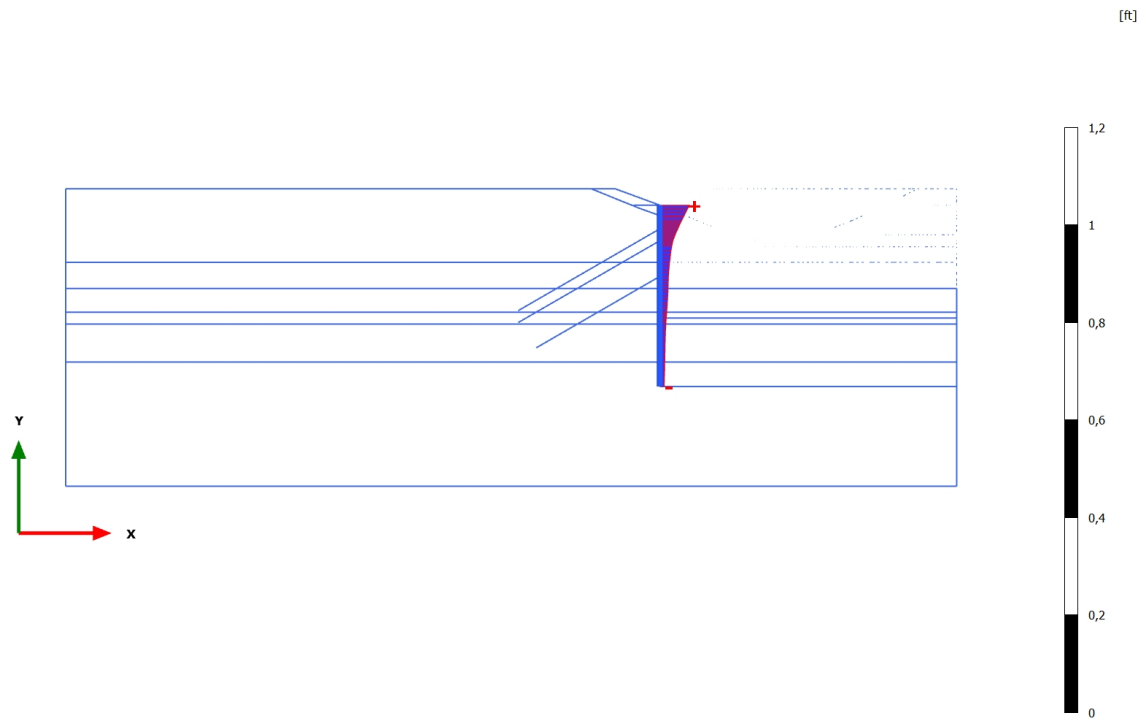


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,08720 ft (Element 64 at Node 5333)

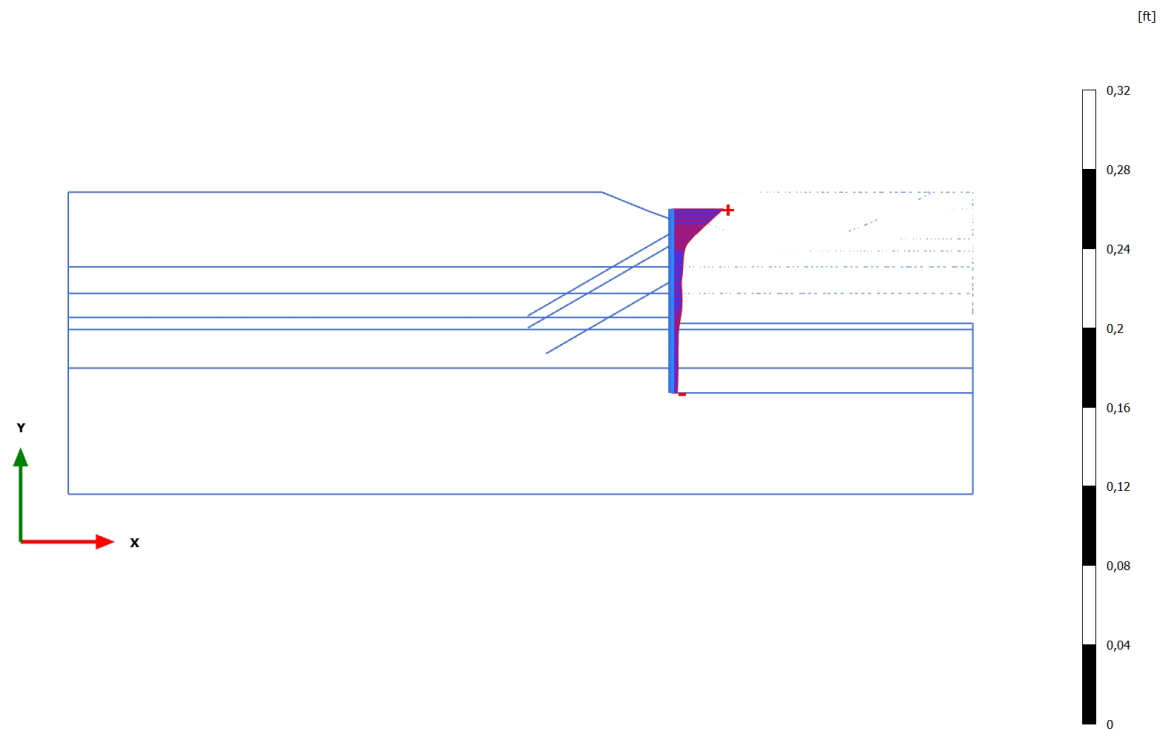
Minimum value =  $7,888 \cdot 10^{-3}$  ft (Element 81 at Node 12659)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/579), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2015 ft (Element 64 at Node 5333)  
Minimum value = 0,03012 ft (Element 81 at Node 12659)

### 3.1.1.1.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/1046), Total displacements $u_x$

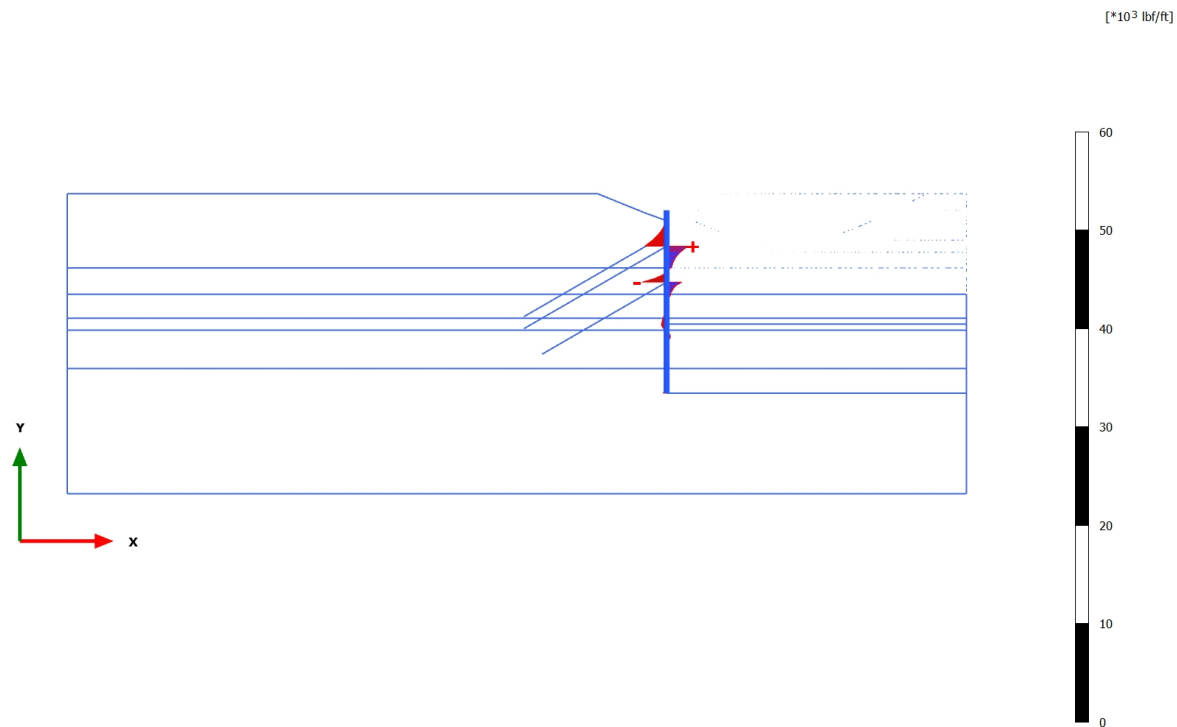


#### Total displacements $u_x$ (scaled up 200 times)

Maximum value = 0,08682 ft (Element 64 at Node 5333)

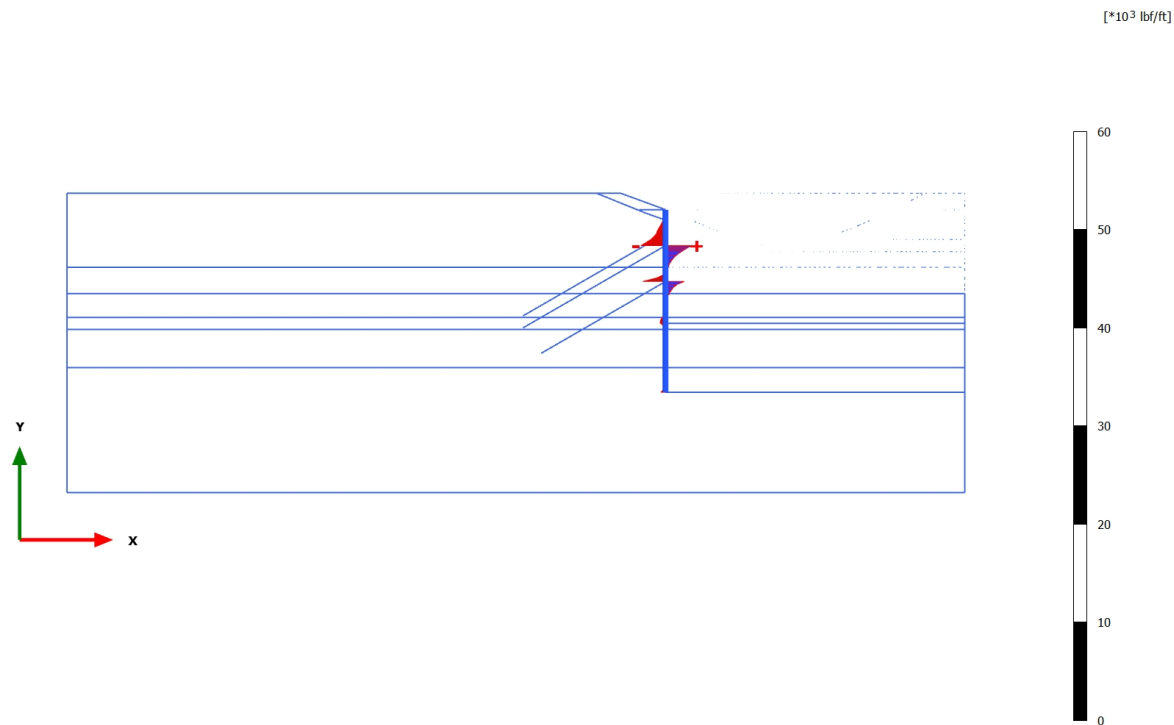
Minimum value = 9,859\*10<sup>-3</sup> ft (Element 81 at Node 12659)

### 3.1.2.1.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/361), Shear forces Q



**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**  
Maximum value = 7212 lbf/ft (Element 69 at Node 6266)  
Minimum value = -8253 lbf/ft (Element 71 at Node 7414)

### 3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/579), Shear forces Q

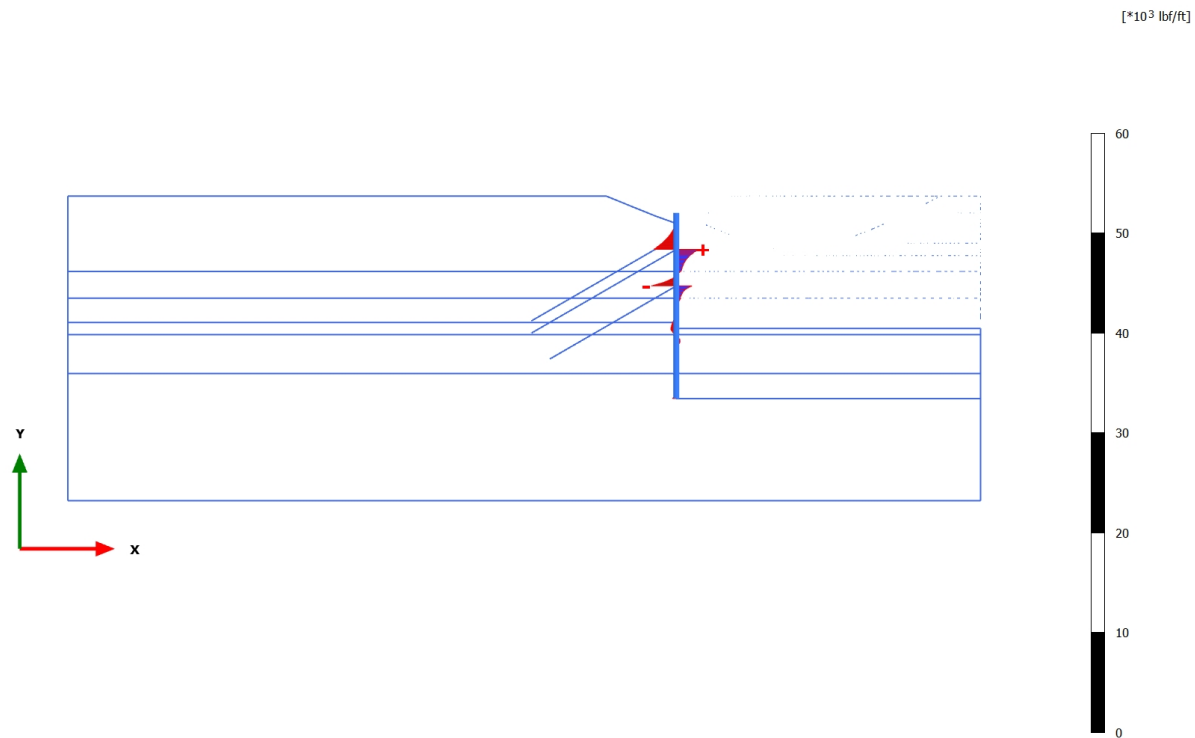


**Shear forces Q (scaled up  $1,00 \cdot 10^{-3}$  times)**

Maximum value = 8817 lbf/ft (Element 69 at Node 6266)

Minimum value = -8208 lbf/ft (Element 68 at Node 6266)

### 3.1.2.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/1046), Shear forces Q

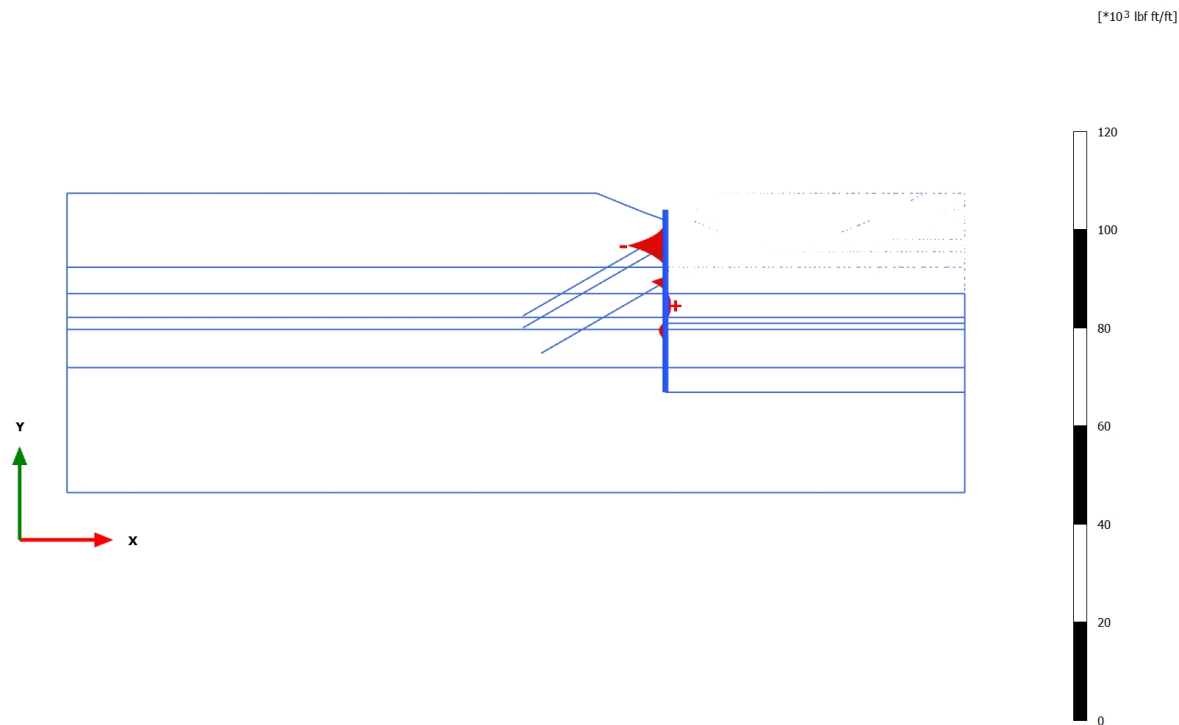


**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**

Maximum value = 7203 lbf/ft (Element 69 at Node 6266)

Minimum value = -8245 lbf/ft (Element 71 at Node 7414)

### 3.1.2.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/361), Bending moments M

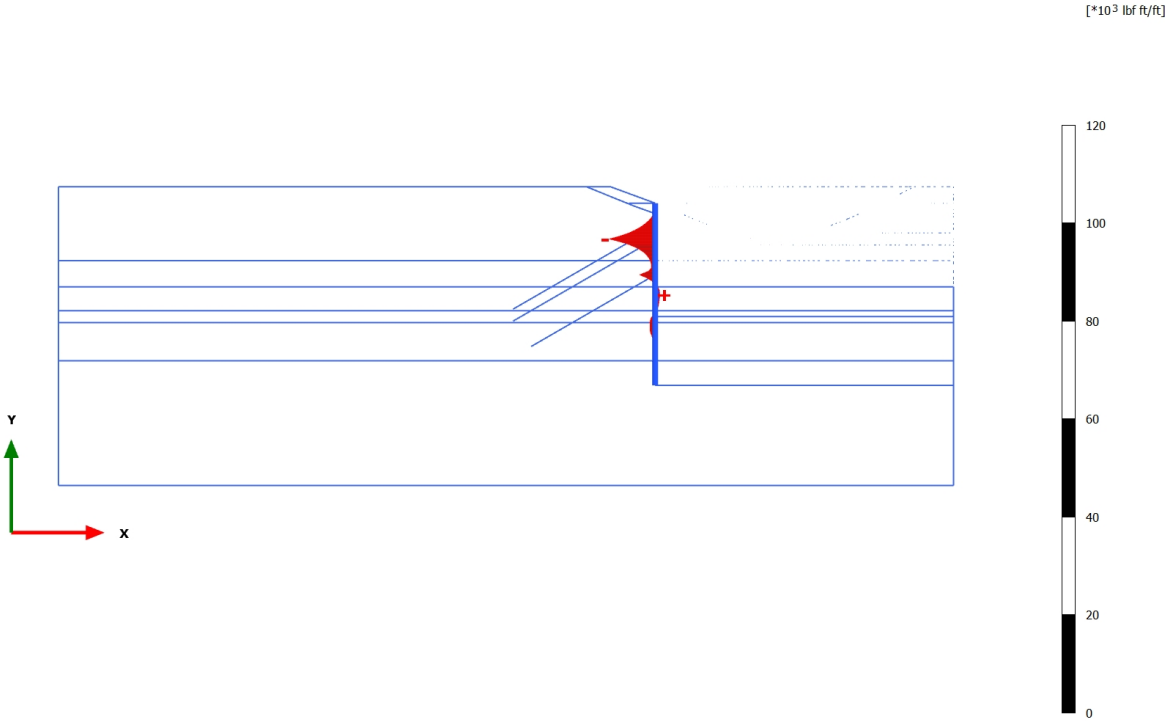


#### Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)

Maximum value = 3490 lbf ft/ft (Element 73 at Node 7917)

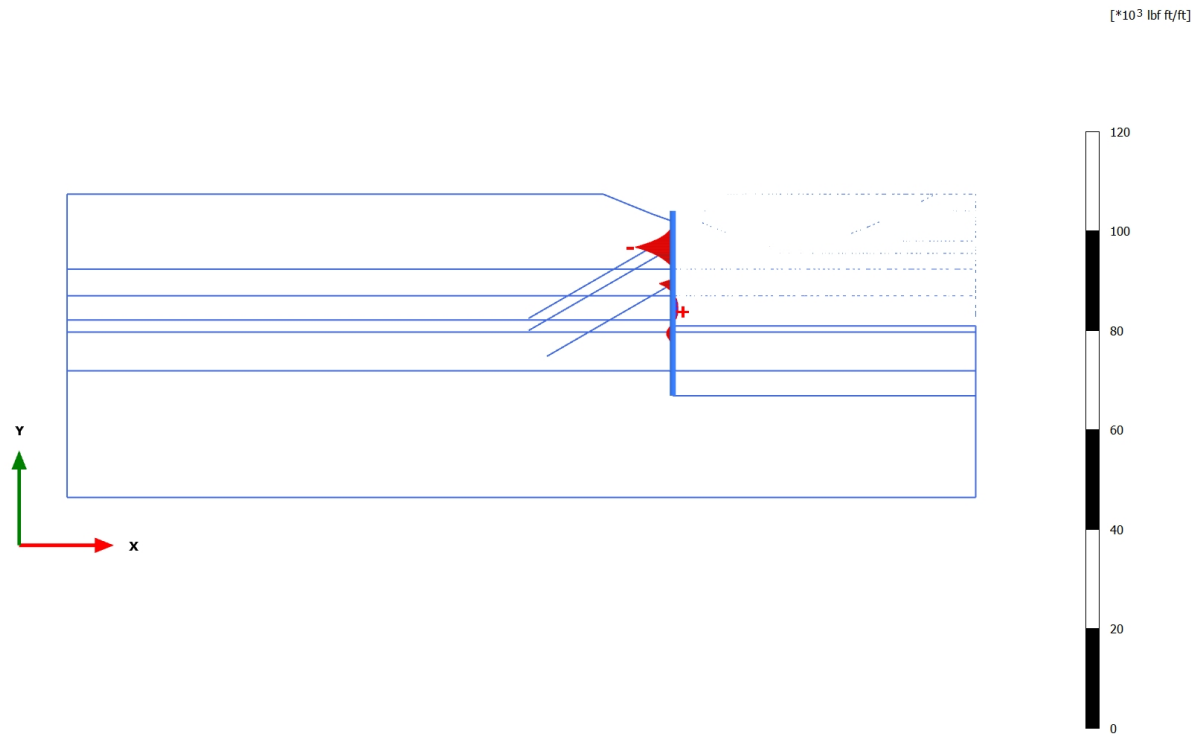
Minimum value = -24,90\*10<sup>3</sup> lbf ft/ft (Element 68 at Node 6266)

3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/579), Bending moments M



**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 3033 lbf ft/ft (Element 73 at Node 7918)  
Minimum value = -30,58\*10<sup>3</sup> lbf ft/ft (Element 68 at Node 6266)

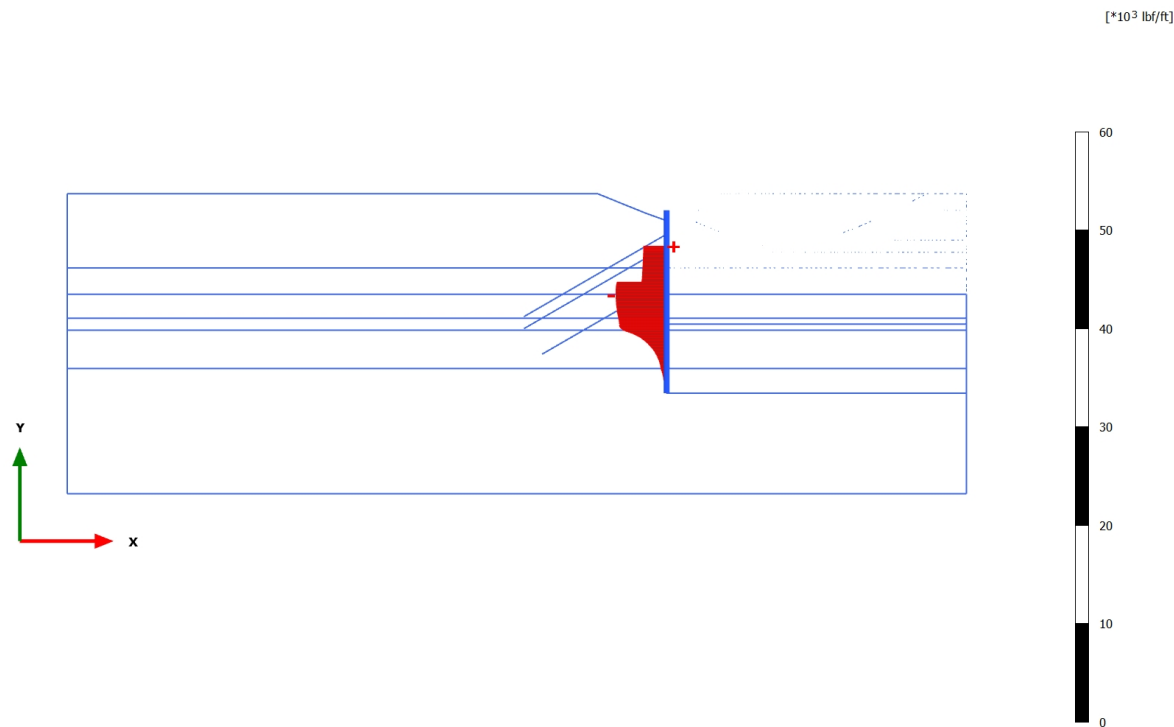
### 3.1.2.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/1046), Bending moments M



**Bending moments M (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value = 3455 lbf ft/ft (Element 74 at Node 8516)  
Minimum value =  $-24,90 \cdot 10^3$  lbf ft/ft (Element 68 at Node 6266)

### 3.1.2.3.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/361), Axial forces N

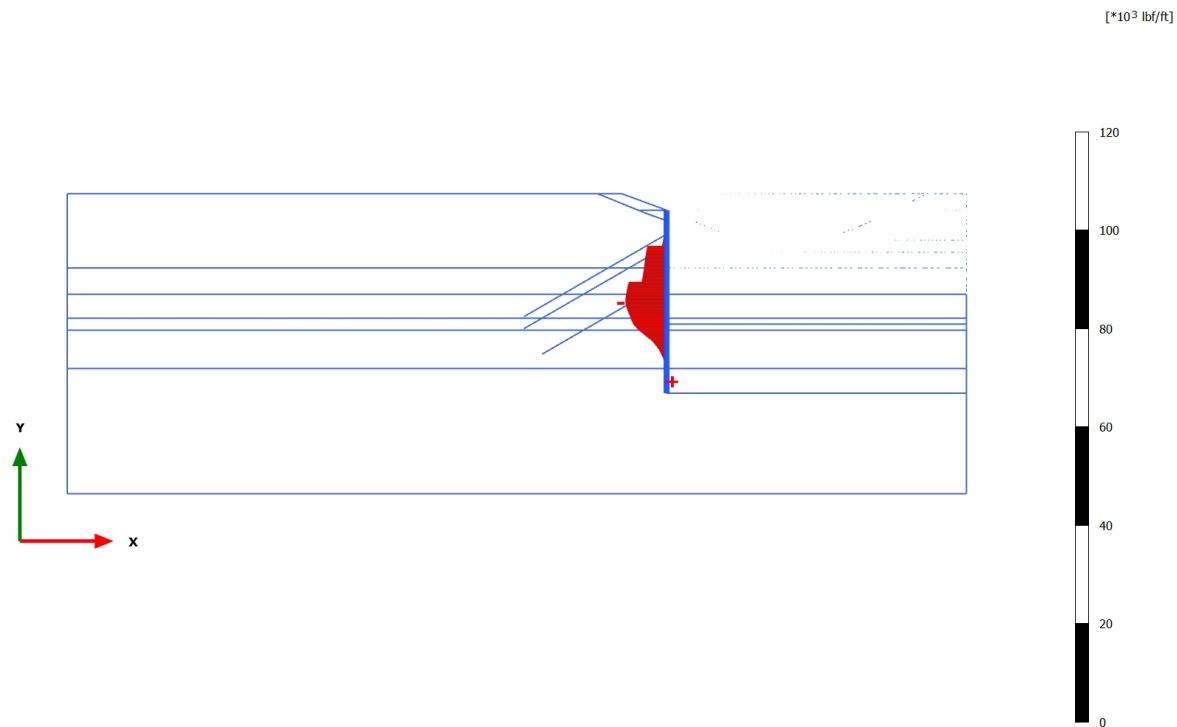


#### Axial forces N (scaled up 1,00\*10<sup>-3</sup> times)

Maximum value = 698,1 lbf/ft (Element 68 at Node 6266)

Minimum value = -16,90\*10<sup>3</sup> lbf/ft (Element 72 at Node 7916)

### 3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/579), Axial forces N

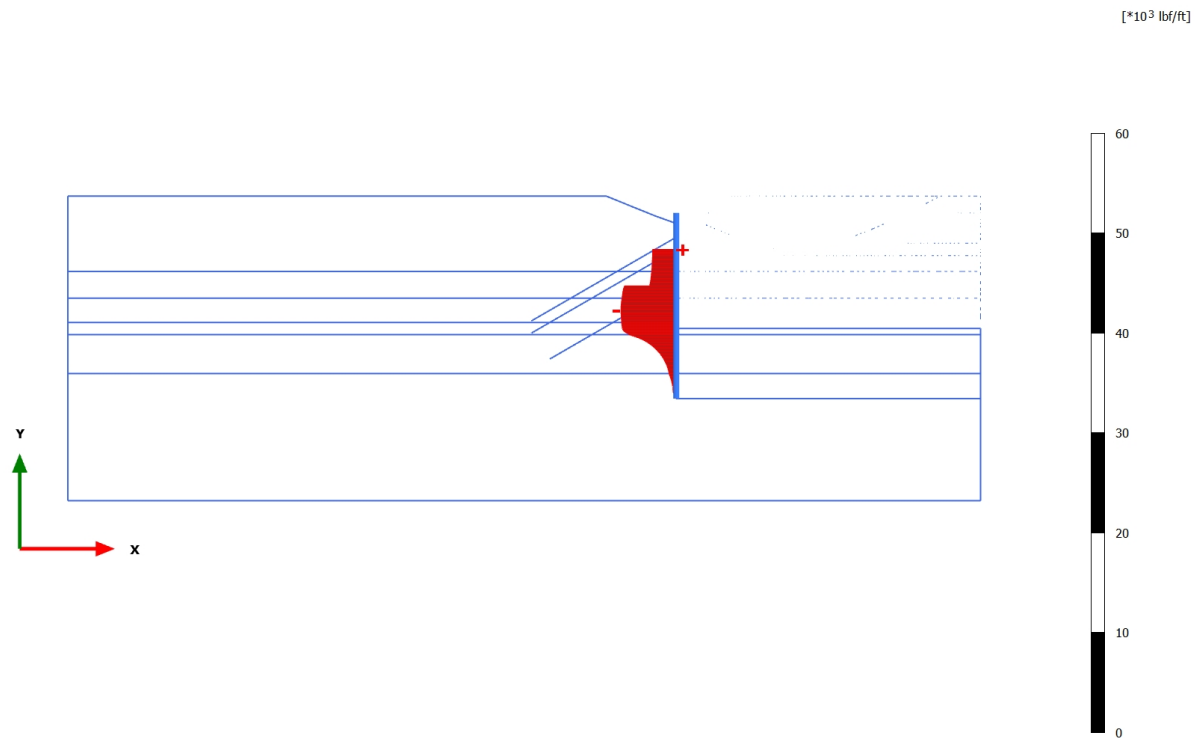


**Axial forces N (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value = 588,9 lbf/ft (Element 81 at Node 12658)

Minimum value =  $-27,34 \cdot 10^3$  lbf/ft (Element 73 at Node 7918)

### 3.1.2.3.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/1046), Axial forces N



**Axial forces N (scaled up  $1,00 \times 10^{-3}$  times)**

Maximum value = 614,8 lbf/ft (Element 68 at Node 6266)

Minimum value = -18,19  $\times 10^3$  lbf/ft (Element 73 at Node 7917)

3.2.1.1.1 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/361), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	6266	1	100,000	82,500	100,805	0,000	101,844
Element 2-2 (Node-to-node anchor)	19505	2	78,349	70,000	100,805	0,000	101,844
NodeToNodeAnchor\_2\_1	7414	1	100,000	70,500	99,473	0,000	100,043
Element 3-3 (Node-to-node anchor)	19562	2	84,412	61,500	99,473	0,000	100,043

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/579), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	6266	1	100,000	82,500	118,074	0,000	118,074
Element 2-2 (Node-to-node anchor)	19505	2	78,349	70,000	118,074	0,000	118,074
NodeToNodeAnchor\_2\_1	7414	1	100,000	70,500	102,353	0,000	102,353
Element 3-3 (Node-to-node anchor)	19562	2	84,412	61,500	102,353	0,000	102,353

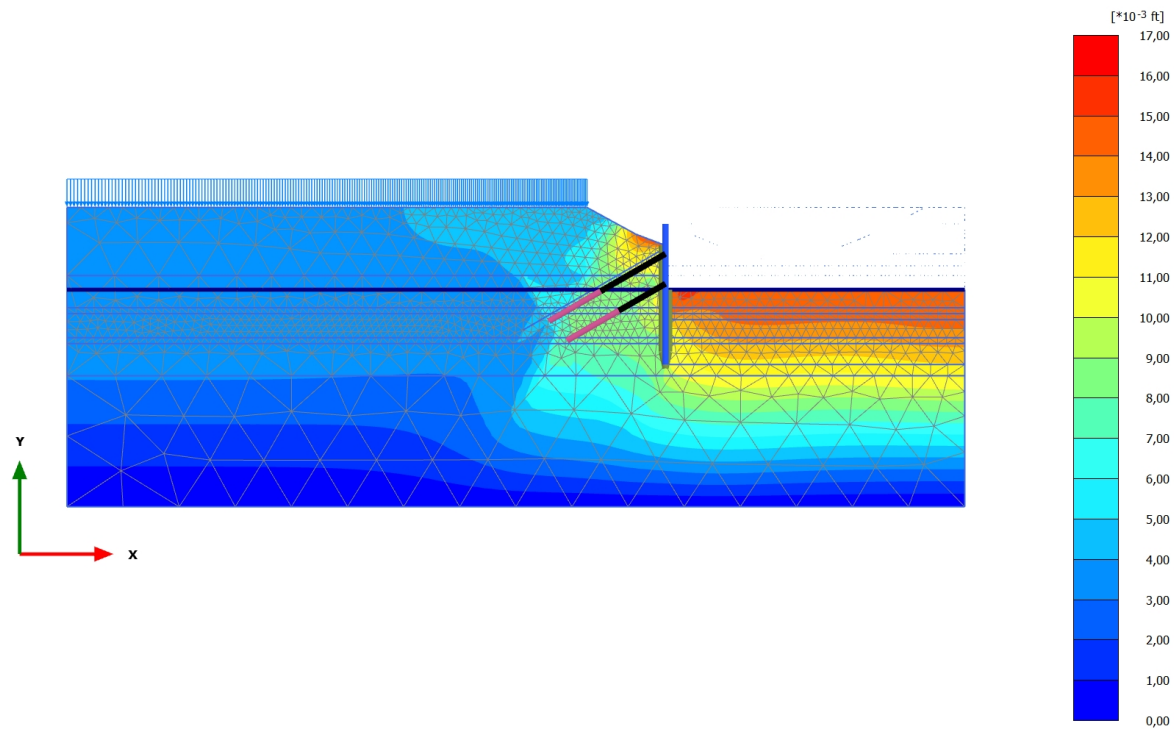
3.2.1.1.3 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/1046), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	6266	1	100,000	82,500	100,884	0,000	101,844
Element 2-2 (Node-to-node anchor)	19505	2	78,349	70,000	100,884	0,000	101,844
NodeToNodeAnchor\_2\_1	7414	1	100,000	70,500	99,795	0,000	100,043
Element 3-3 (Node-to-node anchor)	19562	2	84,412	61,500	99,795	0,000	100,043

# PLAXIS Report

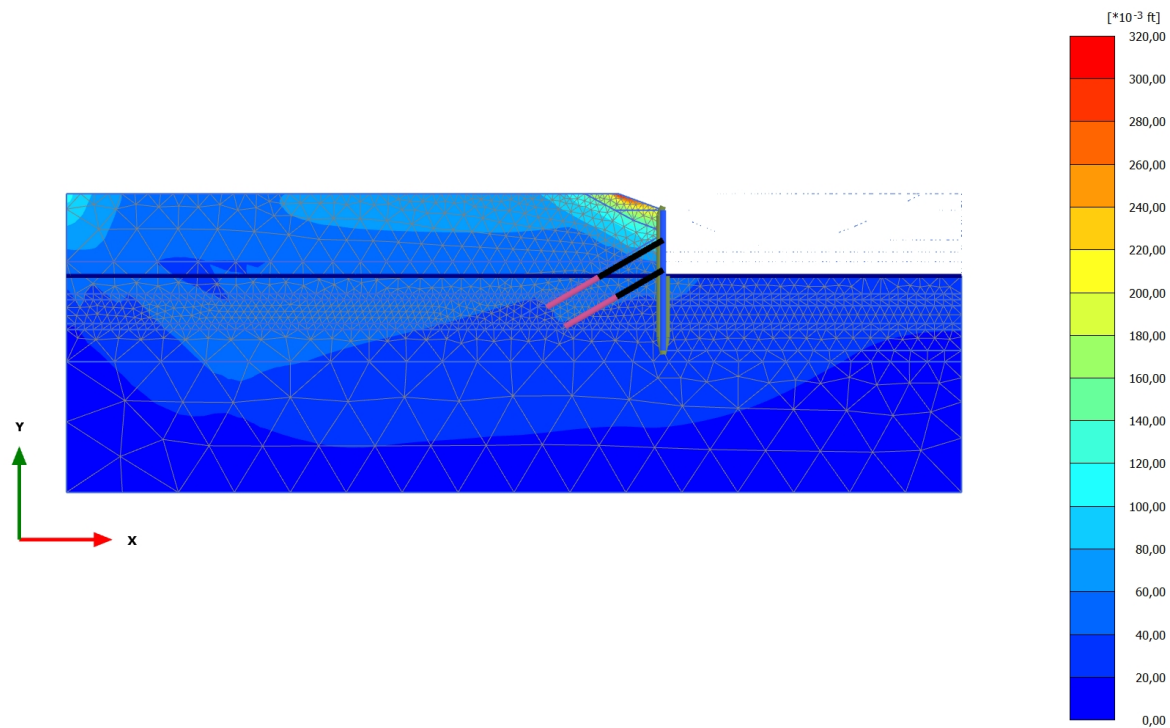
**Plaxis Model Wingwall 3\_Section 2: WW3-2  
STA. 6+62.36 to 6+05.69**

2.1.1.1.1 Calculation results, Long-term (corroded, final surface level) [Phase\_17] (17/102), Total displacements  $|u|$



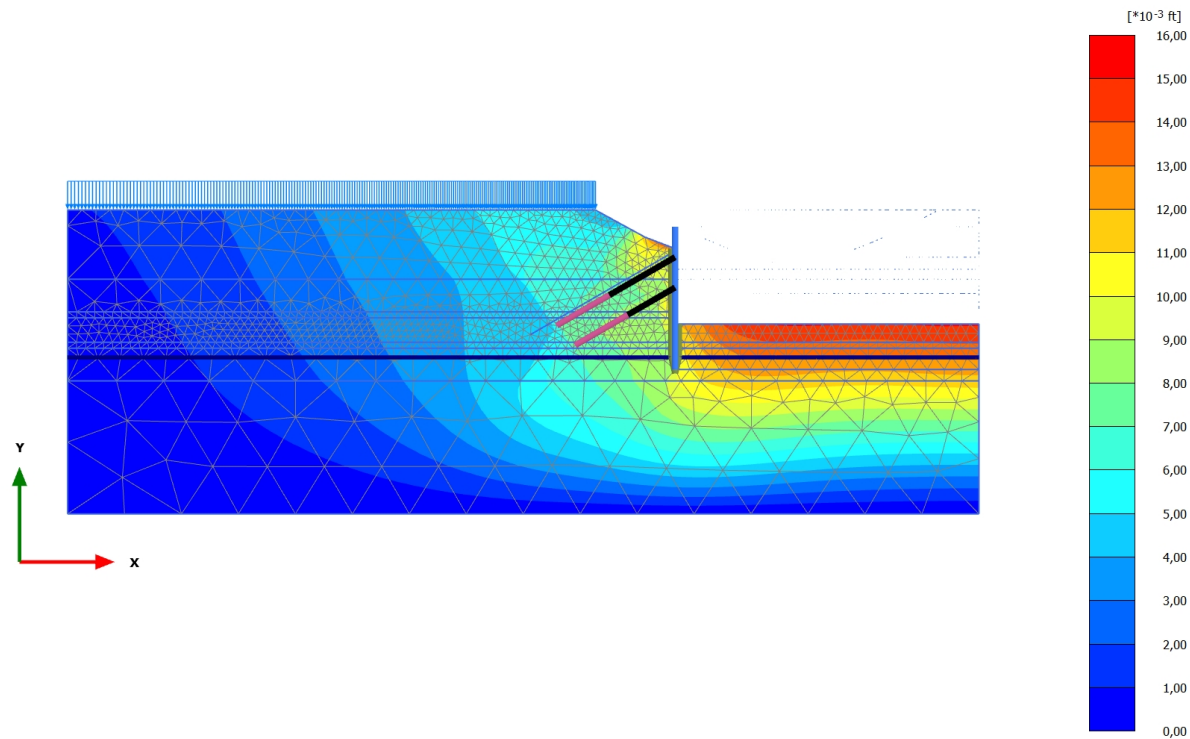
**Total displacements  $|u|$  (scaled up 500 times)**  
Maximum value = 0,01603 ft (Element 930 at Node 6654)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/468), Total displacements  $|u|$



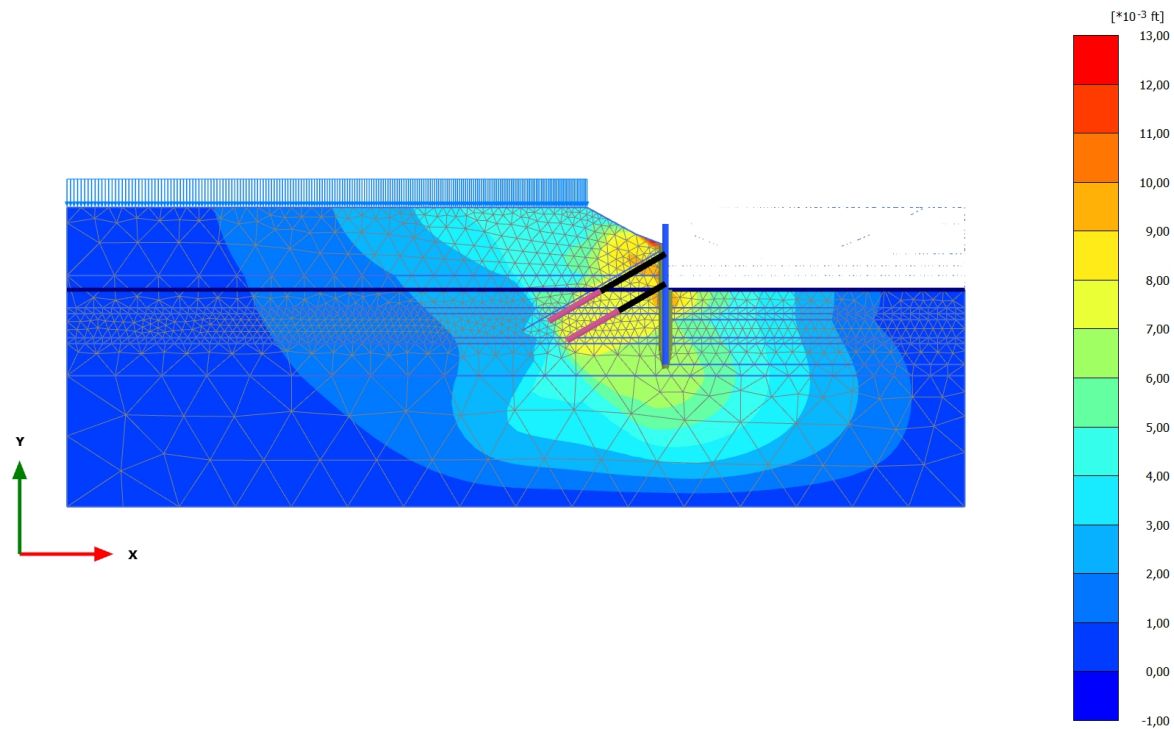
**Total displacements  $|u|$  (scaled up 20,0 times)**  
Maximum value = 0,3069 ft (Element 152 at Node 9166)

### 2.1.1.1.3 Calculation results, Exc. to bottom [Phase\_10] (10/563), Total displacements $|u|$



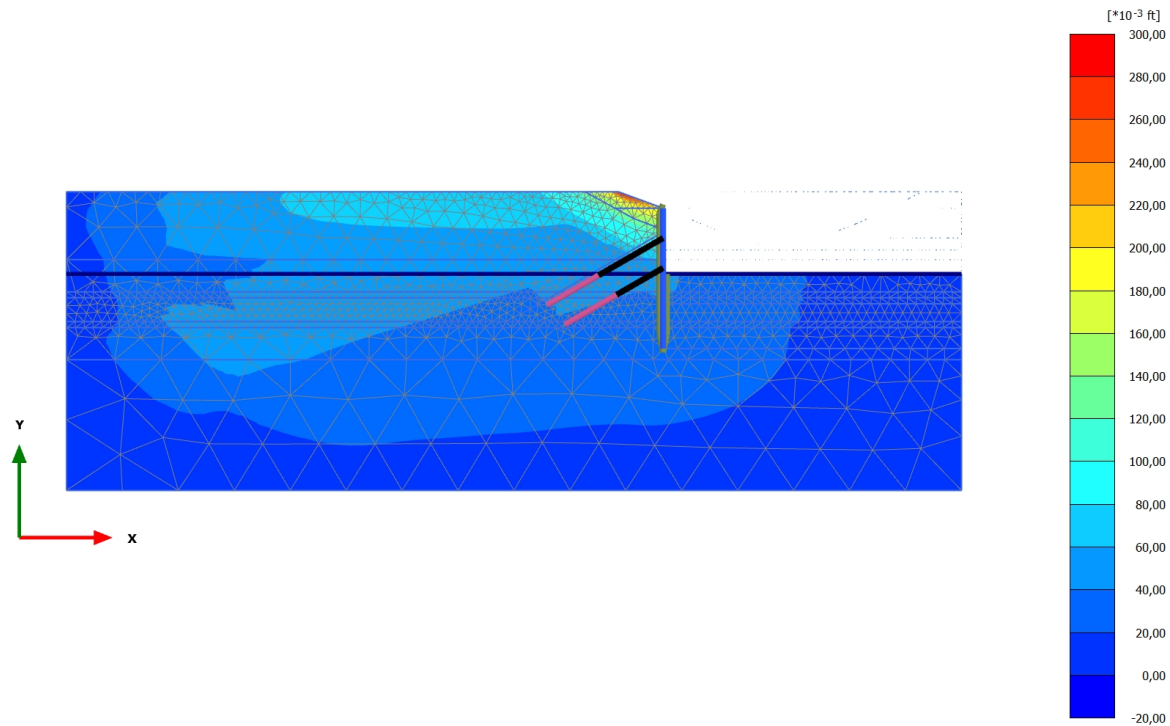
**Total displacements  $|u|$  (scaled up 500 times)**  
Maximum value = 0,01514 ft (Element 2501 at Node 8588)

2.1.1.2.1 Calculation results, Long-term (corroded, final surface level) [Phase\_17]  
(17/102), Total displacements  $u_x$



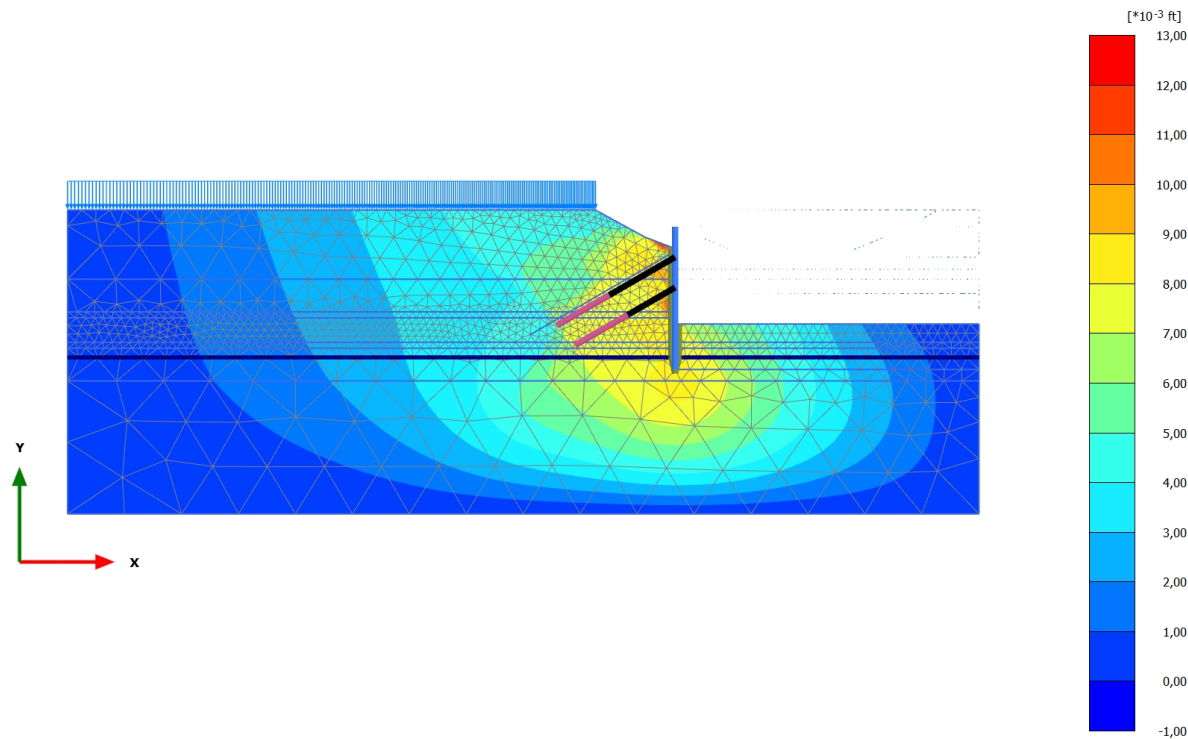
**Total displacements  $u_x$  (scaled up 500 times)**  
Maximum value = 0,01249 ft (Element 791 at Node 8371)  
Minimum value = 0,000 ft (Element 547 at Node 26133)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/468), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2813 ft (Element 159 at Node 8297)  
Minimum value = 0,000 ft (Element 547 at Node 26133)

### 2.1.1.2.3 Calculation results, Exc. to bottom [Phase\_10] (10/563), Total displacements $u_x$

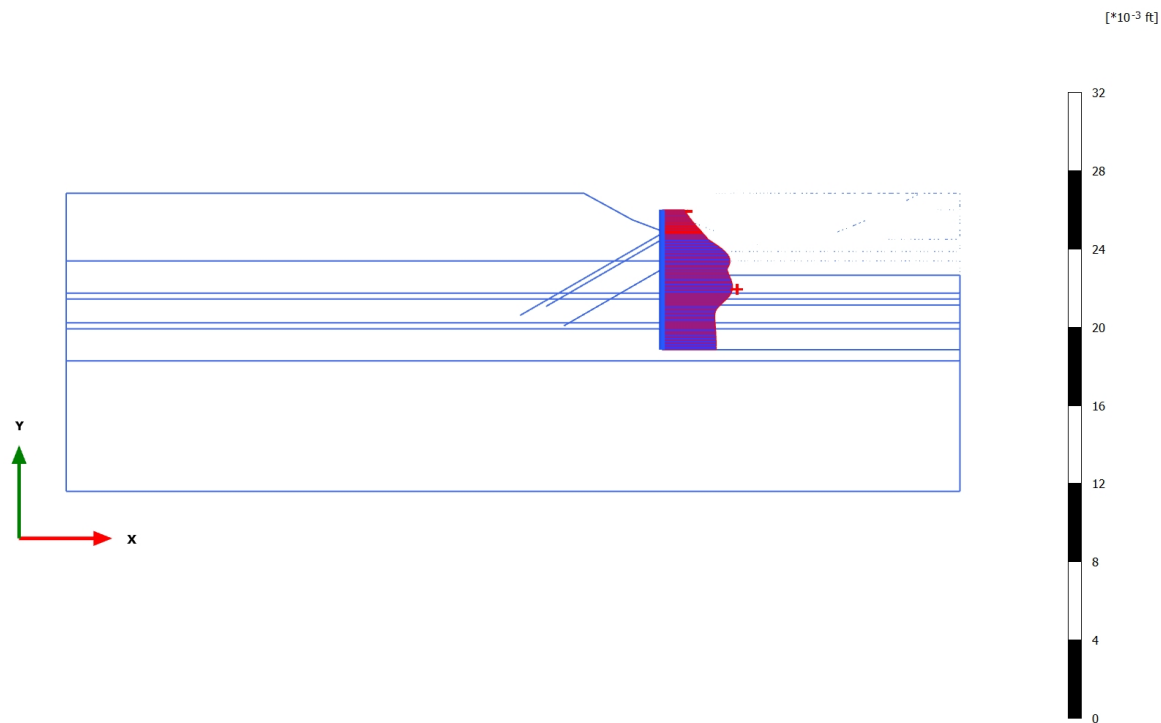


#### Total displacements $u_x$ (scaled up 500 times)

Maximum value = 0,01202 ft (Element 791 at Node 8371)

Minimum value = 0,000 ft (Element 547 at Node 26133)

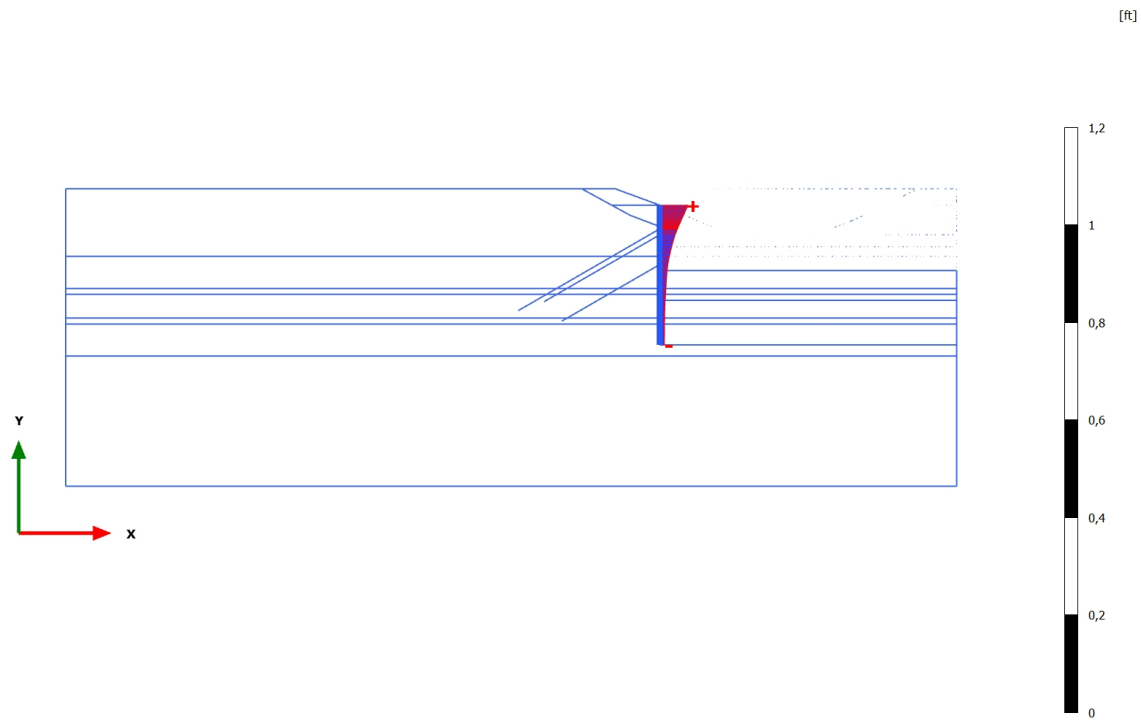
3.1.1.1.1 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_17] (17/102), Total displacements |u|



**Total displacements |u| (scaled up 2,00\*10<sup>3</sup> times)**

Maximum value = 0,01186 ft (Element 73 at Node 9586)

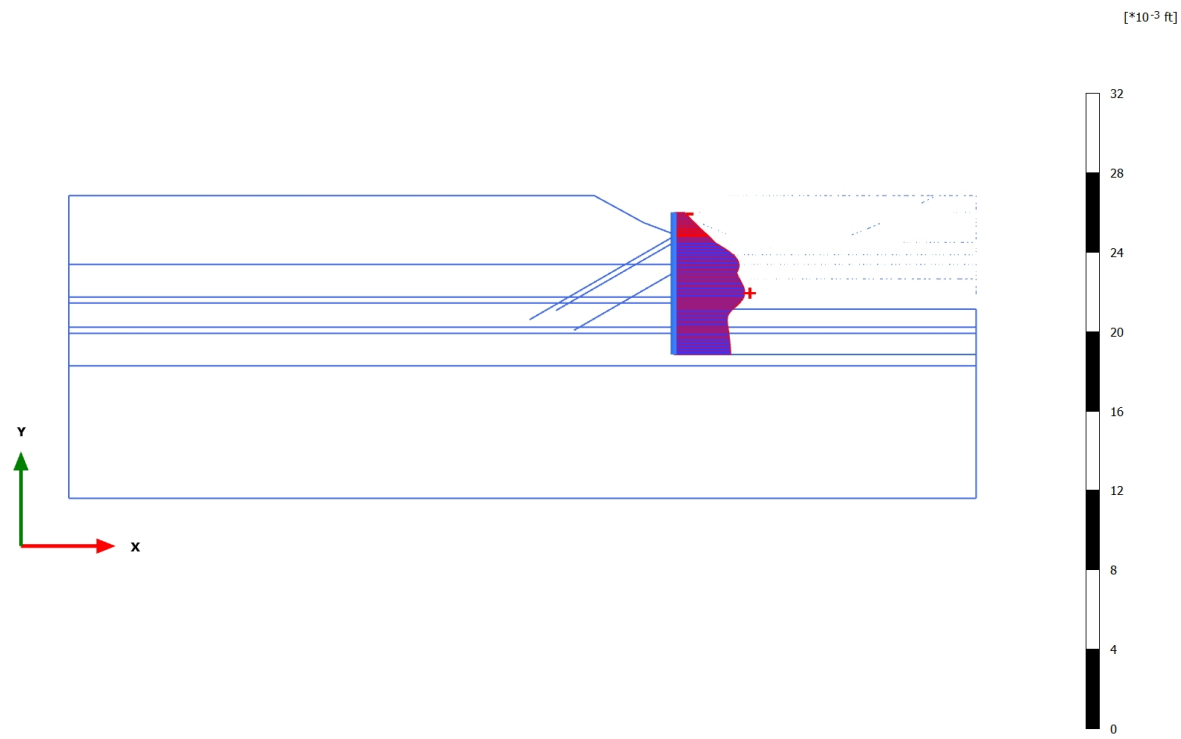
3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/468), Total displacements |u|



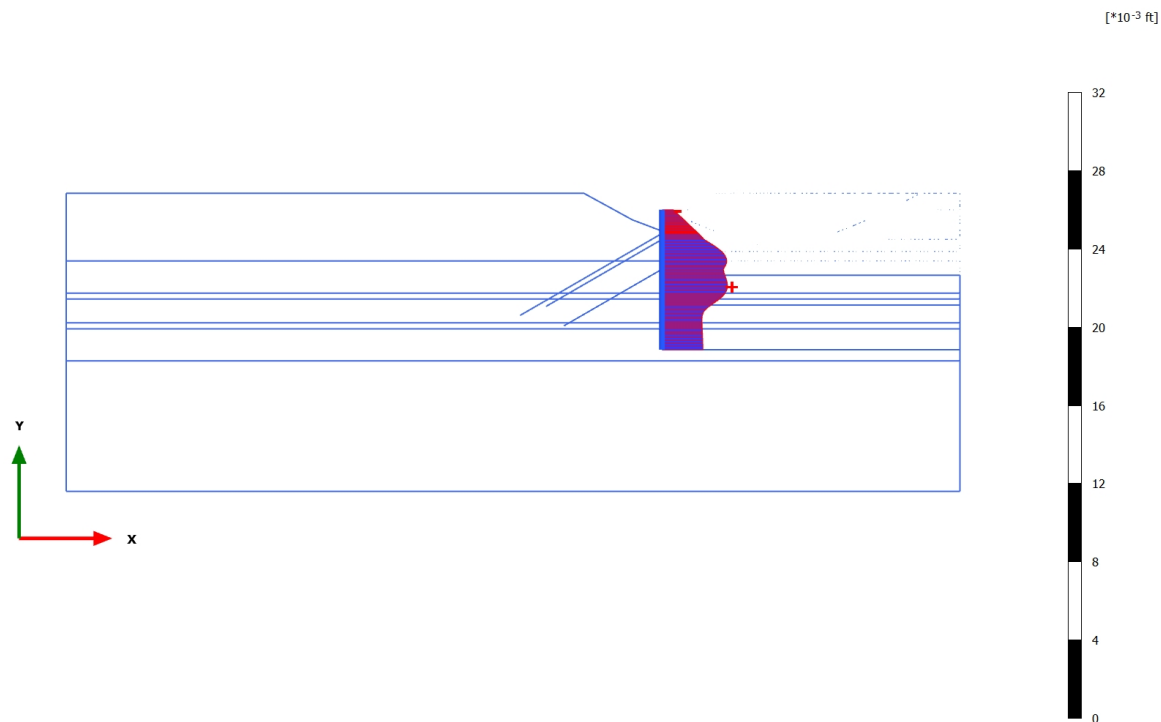
**Total displacements |u| (scaled up 50,0 times)**

Maximum value = 0,1923 ft (Element 61 at Node 5787)

### 3.1.1.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/563), Total displacements |u|

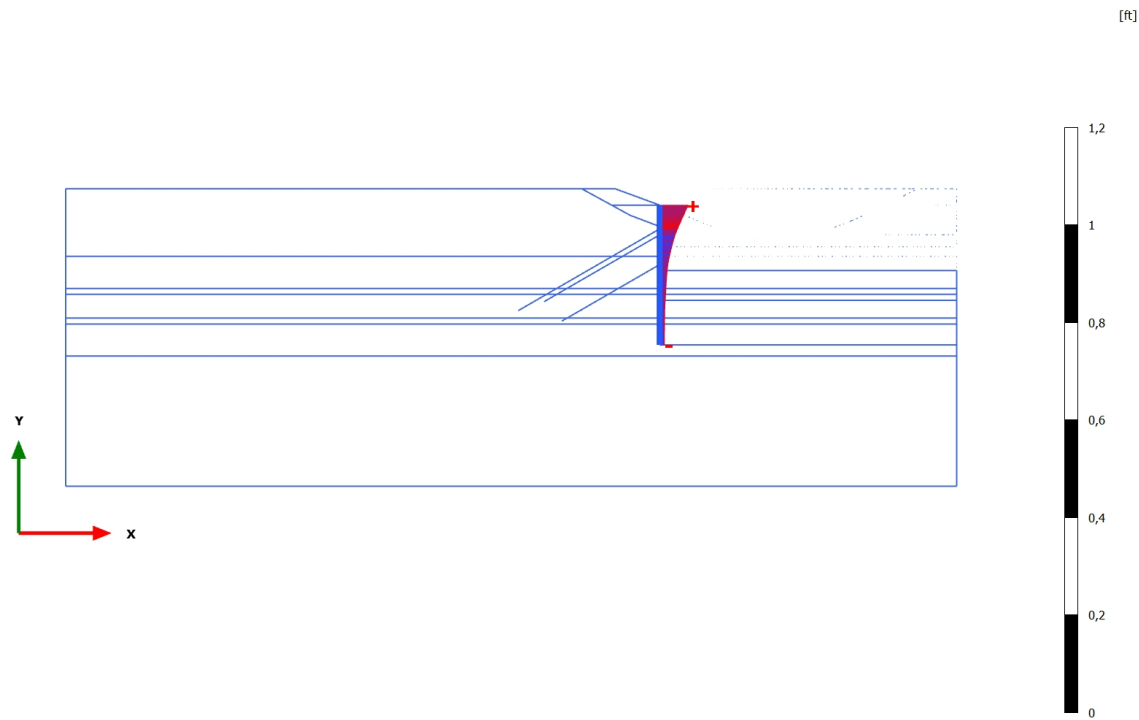


### 3.1.1.1.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_17] (17/102), Total displacements $u_x$



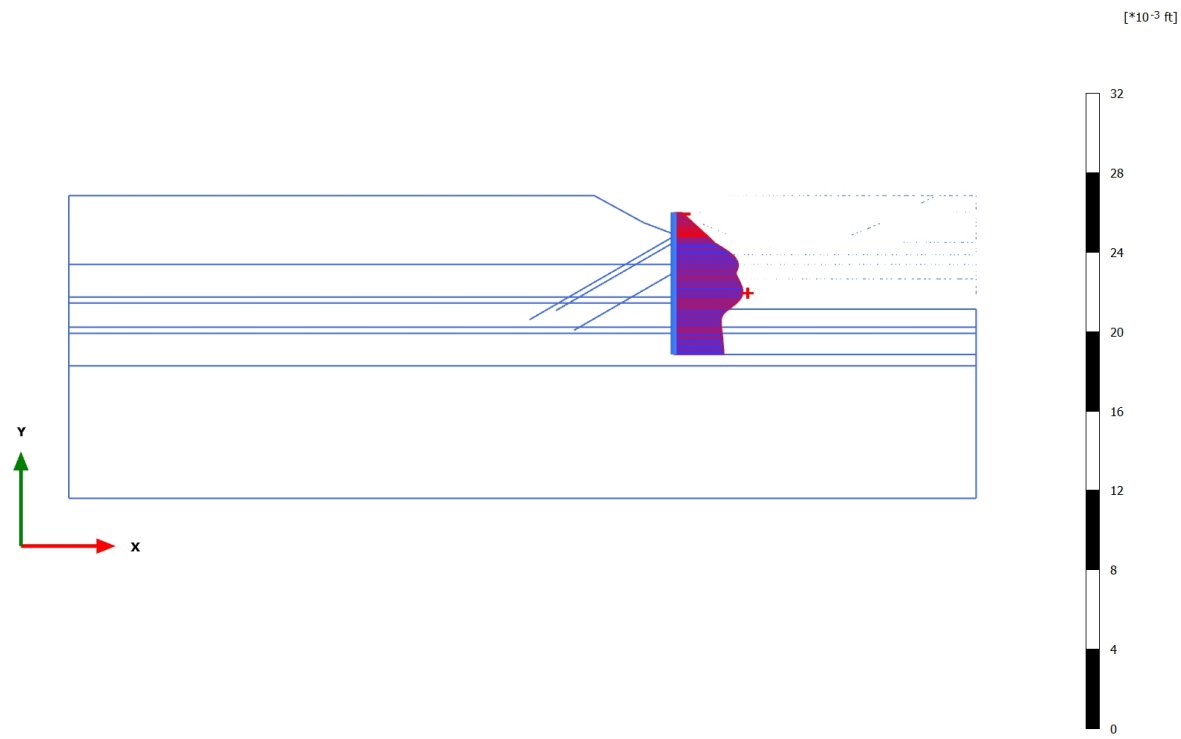
**Total displacements  $u_x$  (scaled up  $2,00 \cdot 10^3$  times)**  
Maximum value = 0,01101 ft (Element 73 at Node 9587)  
Minimum value =  $1,920 \cdot 10^{-3}$  ft (Element 61 at Node 5787)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/468), Total displacements  $u_x$



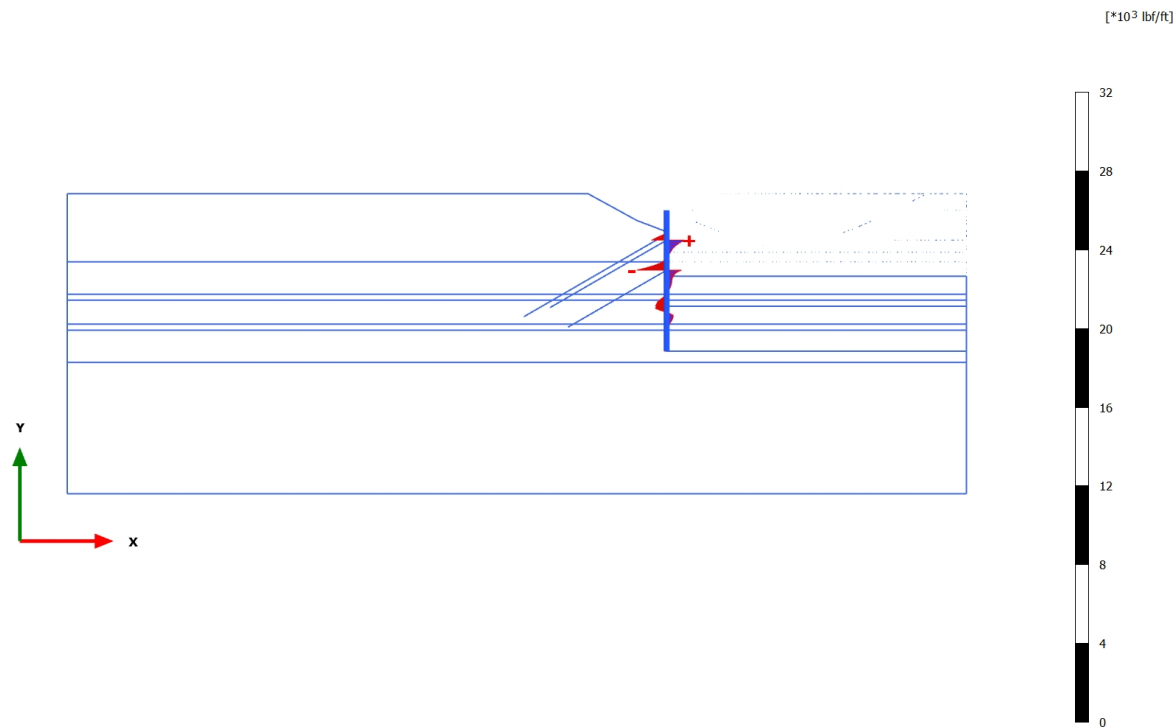
**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,1923 ft (Element 61 at Node 5787)  
Minimum value = 0,03156 ft (Element 80 at Node 13871)

### 3.1.1.1.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/563), Total displacements $u_x$



**Total displacements  $u_x$  (scaled up  $2,00 \cdot 10^3$  times)**  
Maximum value = 0,01149 ft (Element 73 at Node 9586)  
Minimum value =  $1,395 \cdot 10^{-3}$  ft (Element 61 at Node 5787)

### 3.1.2.1.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_17] (17/102), Shear forces Q

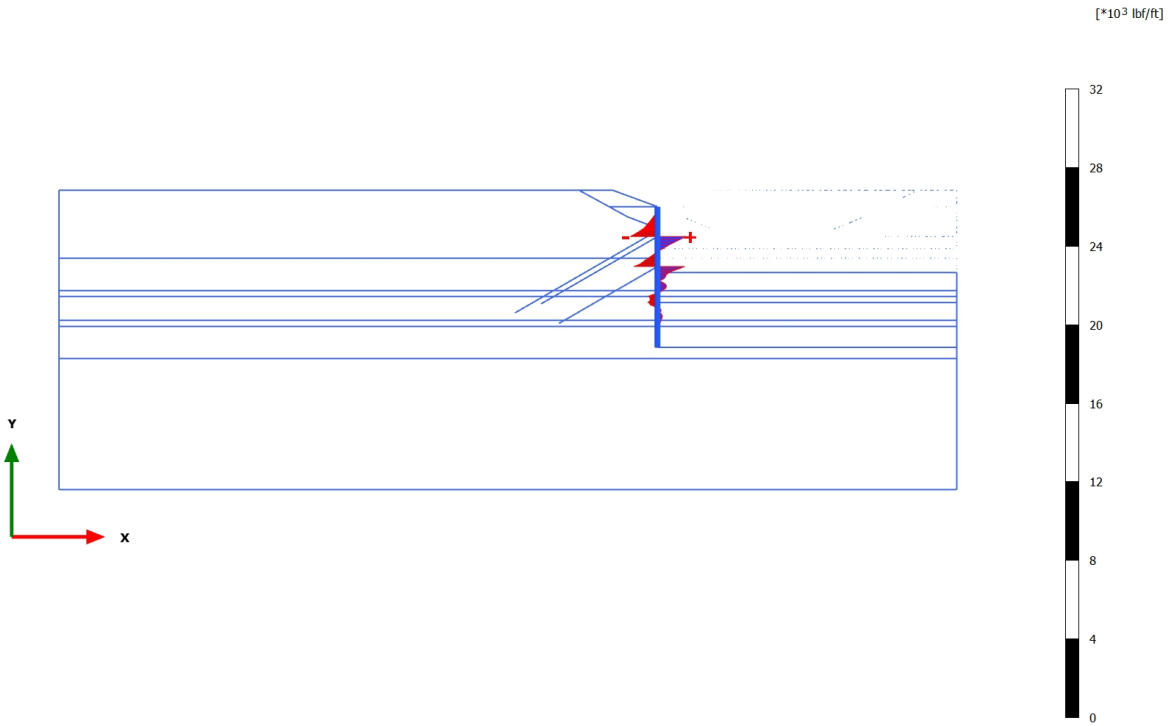


**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 2949 lbf/ft (Element 68 at Node 5988)

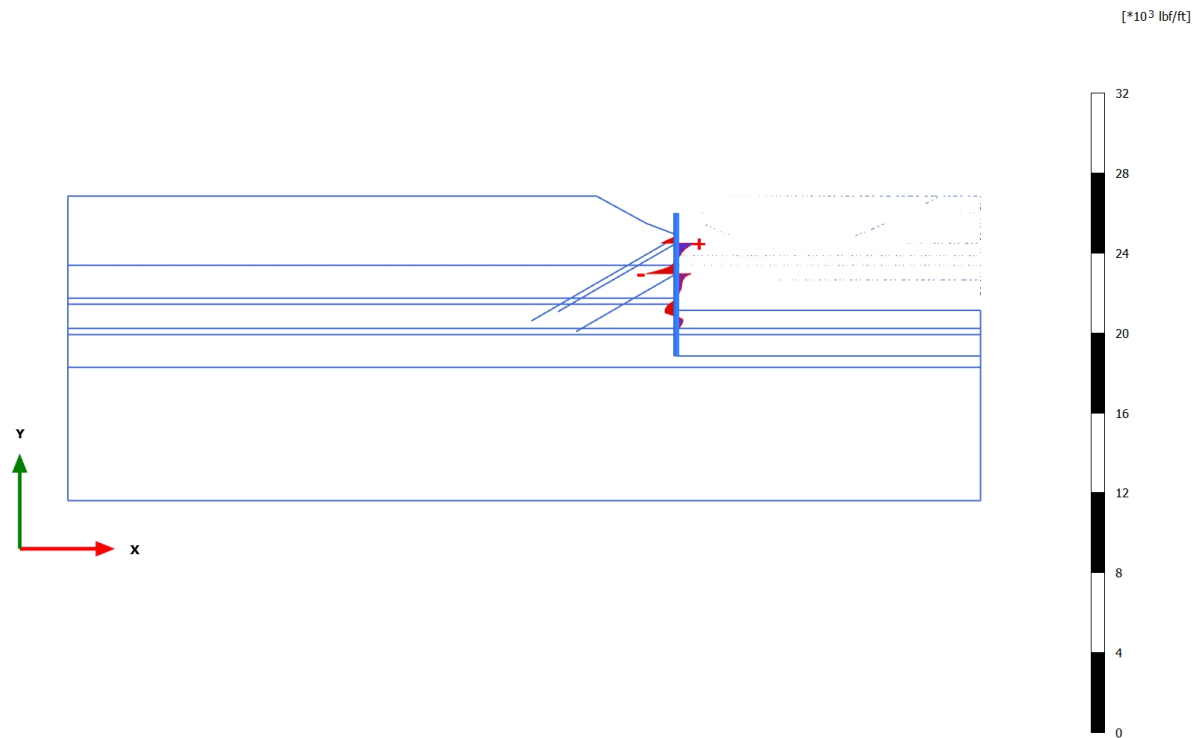
Minimum value = -4997 lbf/ft (Element 70 at Node 8238)

3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/468), Shear forces Q



**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**  
Maximum value = 4763 lbf/ft (Element 68 at Node 5988)  
Minimum value = -4535 lbf/ft (Element 67 at Node 5988)

### 3.1.2.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/563), Shear forces Q

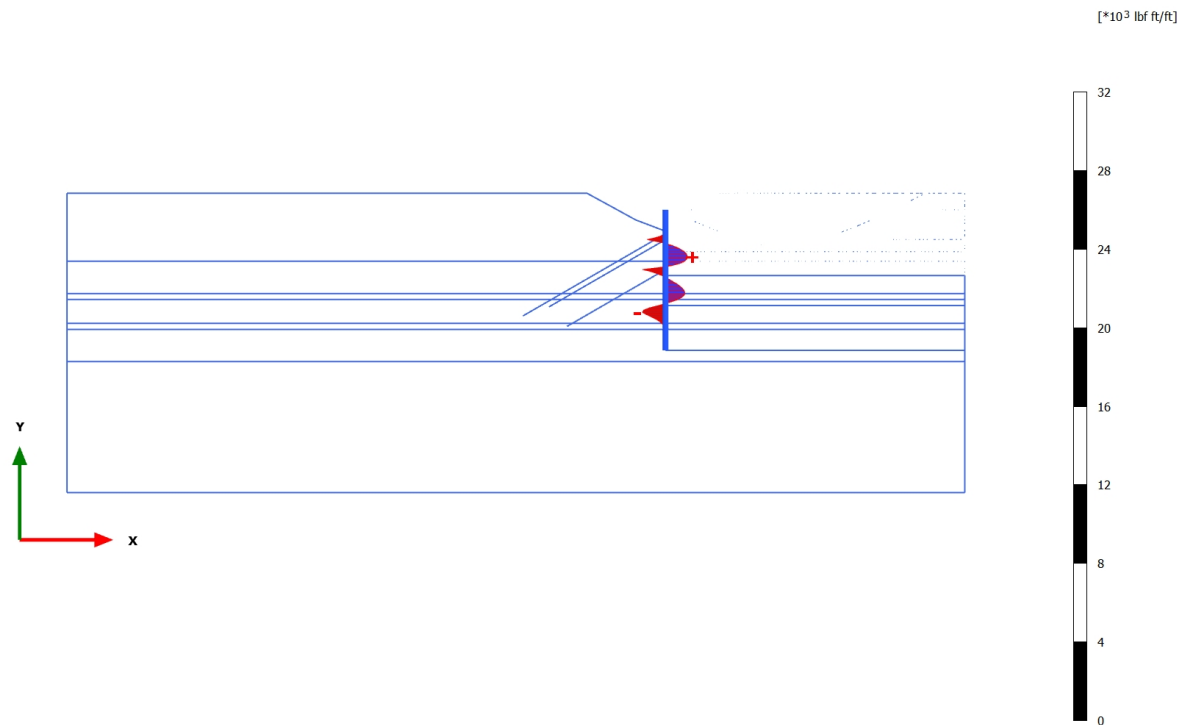


**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 2939 lbf/ft (Element 68 at Node 5988)

Minimum value = -5004 lbf/ft (Element 70 at Node 8238)

### 3.1.2.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_17] (17/102), Bending moments M

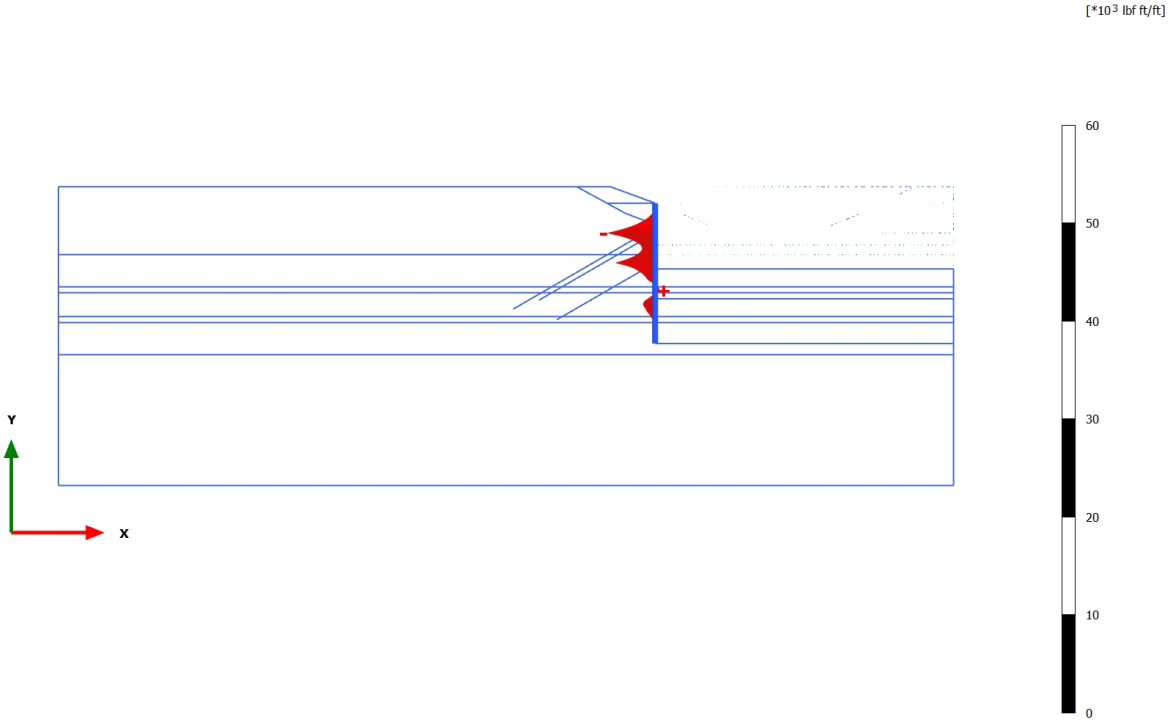


#### Bending moments M (scaled up $2,00 \cdot 10^{-3}$ times)

Maximum value = 3693 lbf ft/ft (Element 69 at Node 6566)

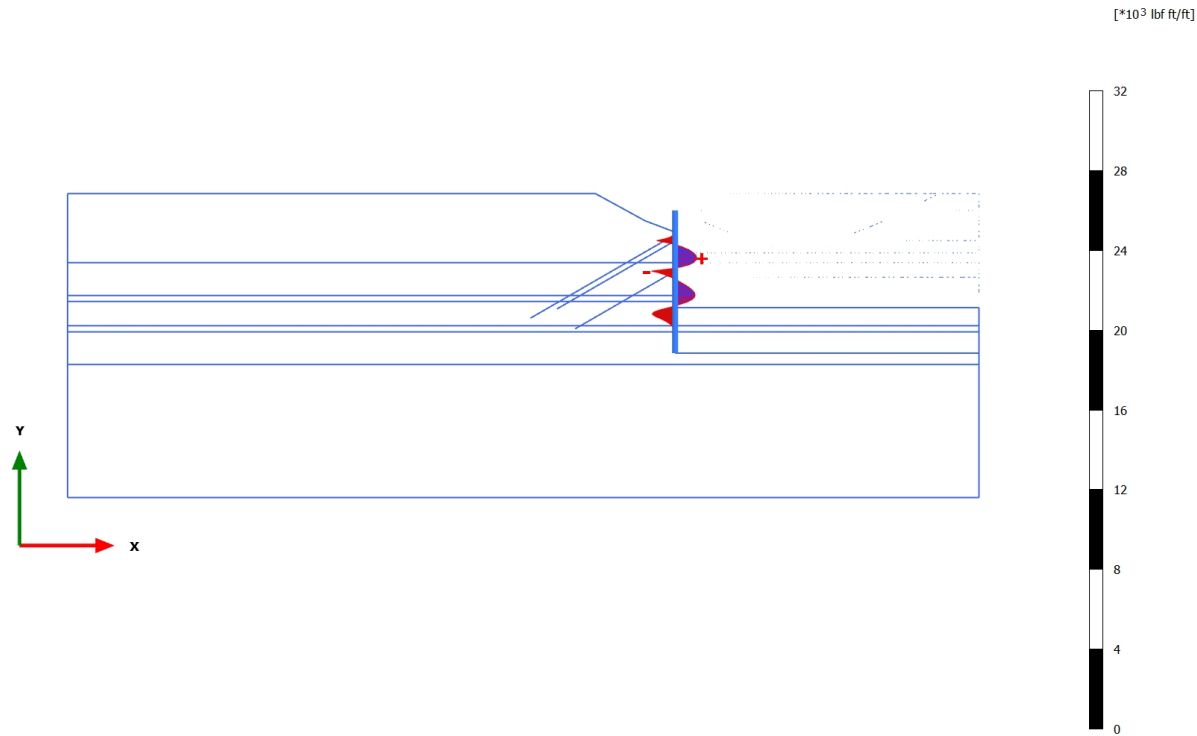
Minimum value = -3875 lbf ft/ft (Element 76 at Node 10899)

3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/468), Bending moments M



**Bending moments M (scaled up  $1,00 \cdot 10^{-3}$  times)**  
Maximum value = 1304 lbf ft/ft (Element 74 at Node 10498)  
Minimum value =  $-15,69 \cdot 10^3$  lbf ft/ft (Element 68 at Node 5988)

### 3.1.2.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/563), Bending moments M

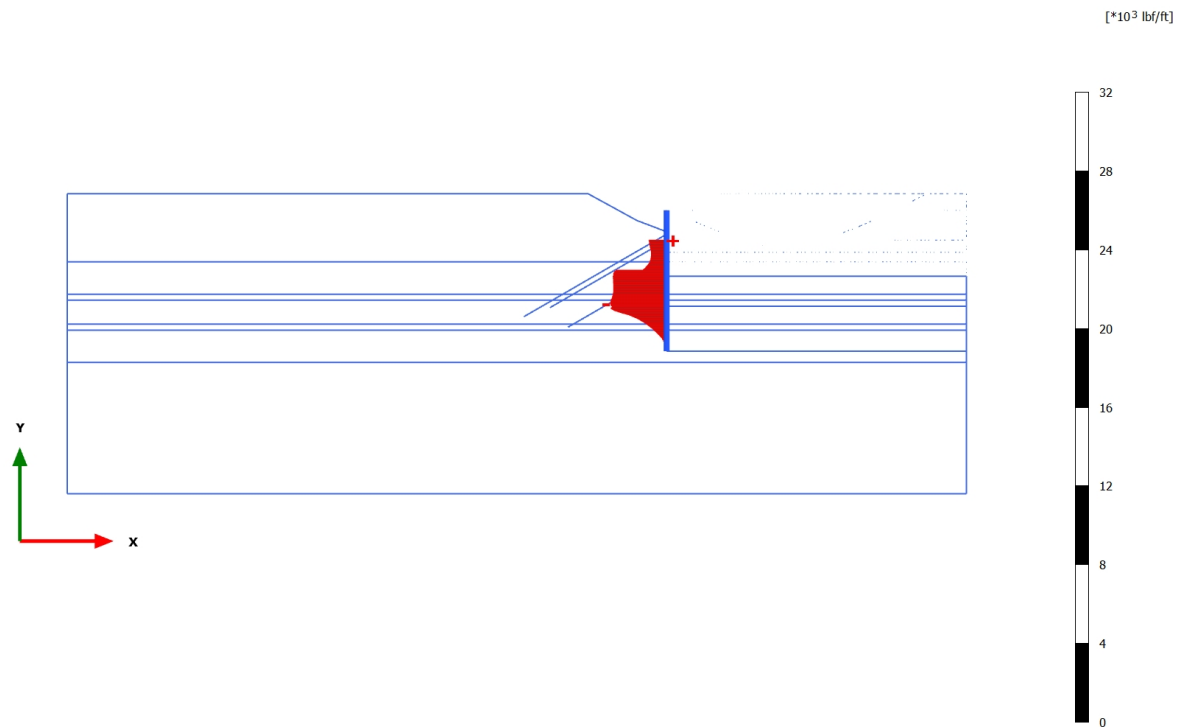


**Bending moments M (scaled up  $2,00*10^{-3}$  times)**

Maximum value = 3567 lbf ft/ft (Element 69 at Node 6566)

Minimum value = -3905 lbf ft/ft (Element 70 at Node 8238)

### 3.1.2.3.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_17] (17/102), Axial forces N

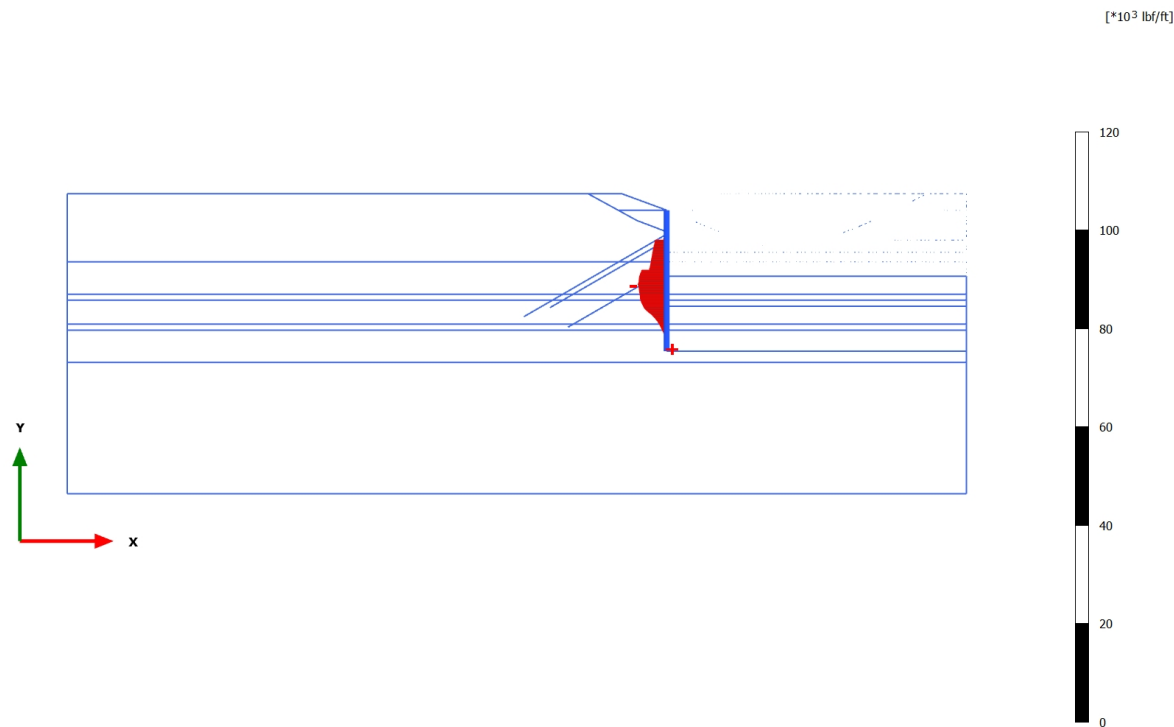


#### Axial forces N (scaled up $2,00*10^{-3}$ times)

Maximum value = 233,4 lbf/ft (Element 67 at Node 5988)

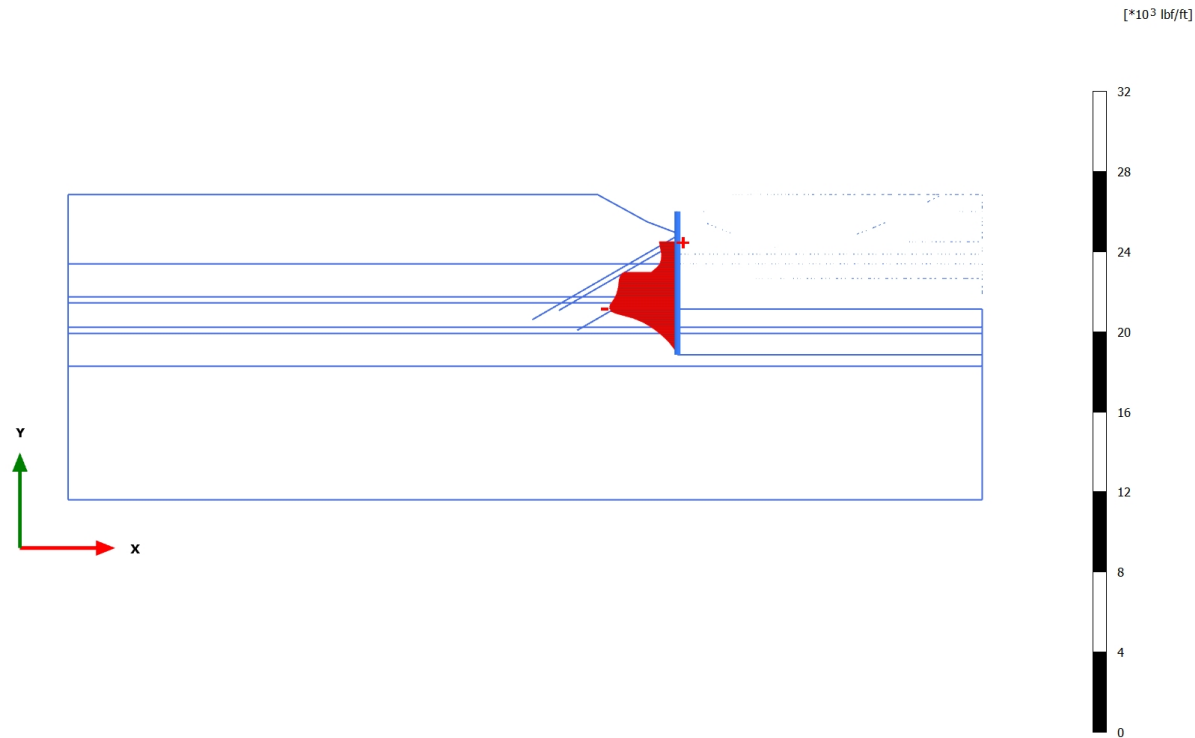
Minimum value = -9364 lbf/ft (Element 75 at Node 10818)

3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/468), Axial forces N



**Axial forces N (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 422,5 lbf/ft (Element 80 at Node 13872)  
Minimum value = -19,01\*10<sup>3</sup> lbf/ft (Element 72 at Node 9584)

### 3.1.2.3.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/563), Axial forces N



**Axial forces N (scaled up 2,00\*10<sup>-3</sup> times)**  
Maximum value = 210,0 lbf/ft (Element 67 at Node 5988)  
Minimum value = -11,12\*10<sup>3</sup> lbf/ft (Element 75 at Node 10819)

3.2.1.1.1 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_17] (17/102), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	5988	1	100,000	84,500	50,720	0,000	50,904
Element 2-2 (Node-to-node anchor)	26260	2	78,349	72,000	50,720	0,000	50,904
NodeToNodeAnchor\_2\_1	8238	1	100,000	74,500	70,671	0,000	70,783
Element 3-3 (Node-to-node anchor)	26338	2	84,412	65,500	70,671	0,000	70,783

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/468), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	5988	1	100,000	84,500	85,730	0,000	85,730
Element 2-2 (Node-to-node anchor)	26260	2	78,349	72,000	85,730	0,000	85,730
NodeToNodeAnchor\_2\_1	8238	1	100,000	74,500	78,217	0,000	78,217
Element 3-3 (Node-to-node anchor)	26338	2	84,412	65,500	78,217	0,000	78,217

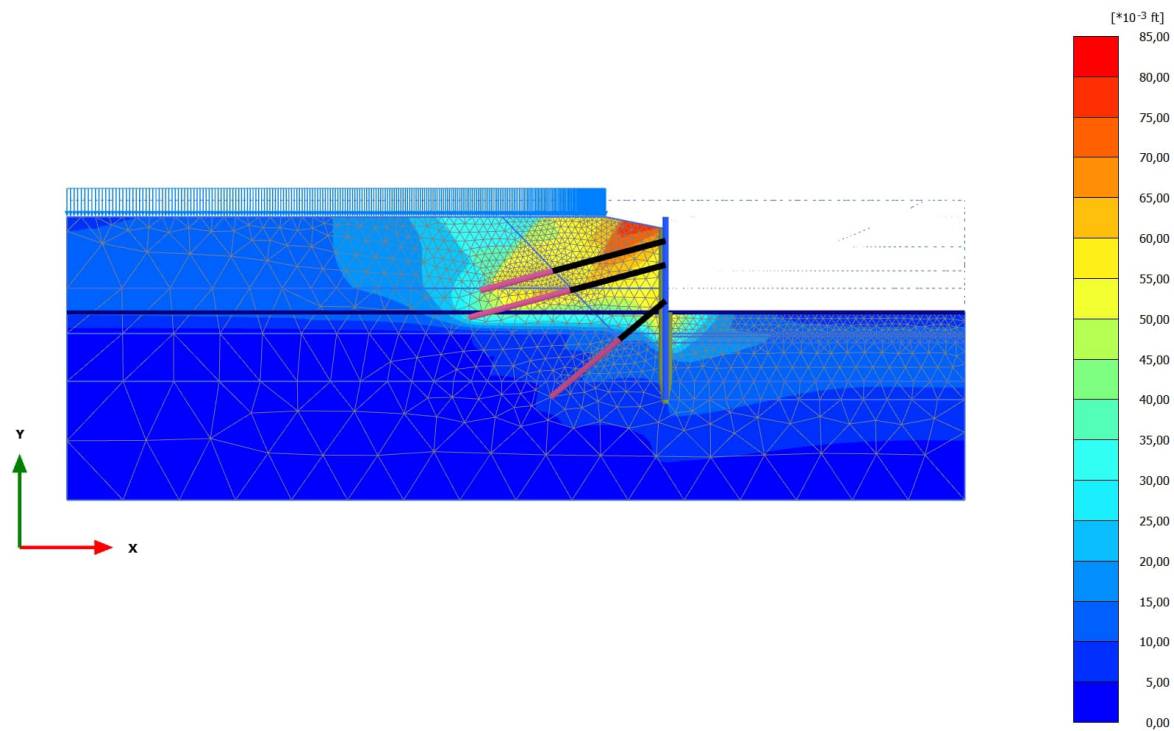
### 3.2.1.1.3 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10] (10/563), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_1\_1	5988	1	100,000	84,500	50,642	0,000	50,904
Element 2-2 (Node-to-node anchor)	26260	2	78,349	72,000	50,642	0,000	50,904
NodeToNodeAnchor\_2\_1	8238	1	100,000	74,500	70,783	0,000	70,783
Element 3-3 (Node-to-node anchor)	26338	2	84,412	65,500	70,783	0,000	70,783

# PLAXIS Report

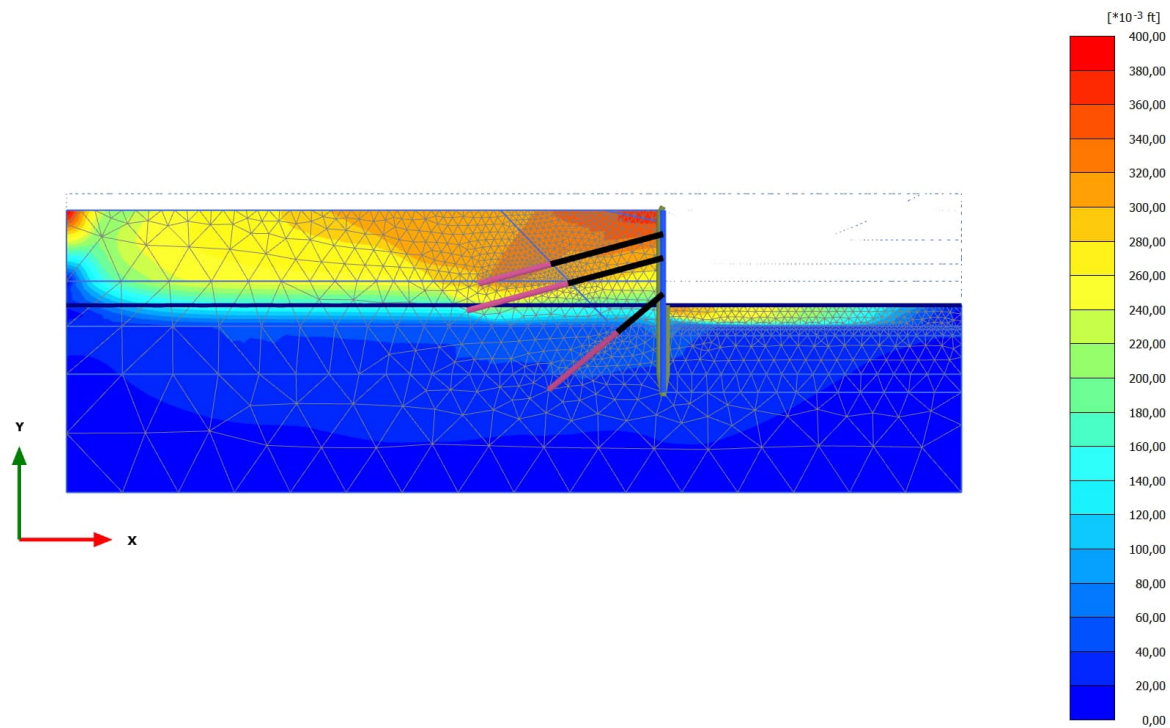
**Plaxis Model Wingwall 4\_Section 1: WW4-1  
STA. 6+06.99 to 6+15.49**

### 2.1.1.1.1 Calculation results, Long-term (corroded, final surface level) [Phase\_16] (16/176), Total displacements $|u|$



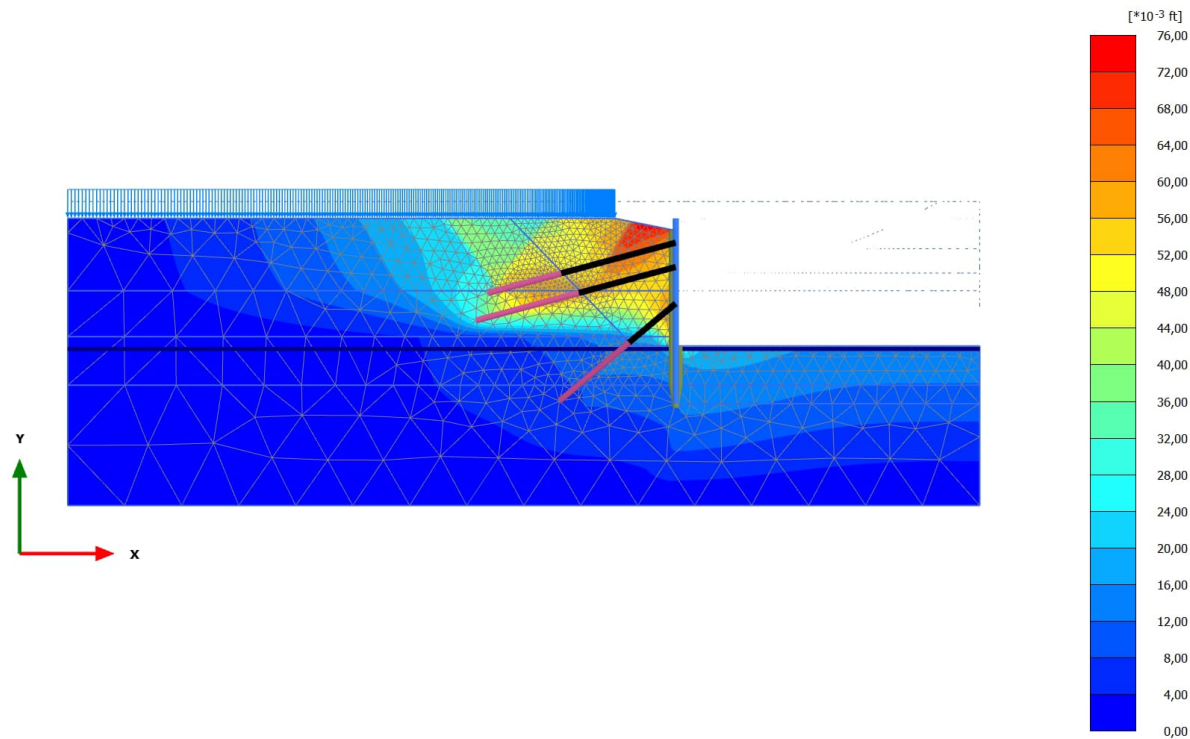
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,08024 ft (Element 764 at Node 4055)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/193), Total displacements  $|u|$



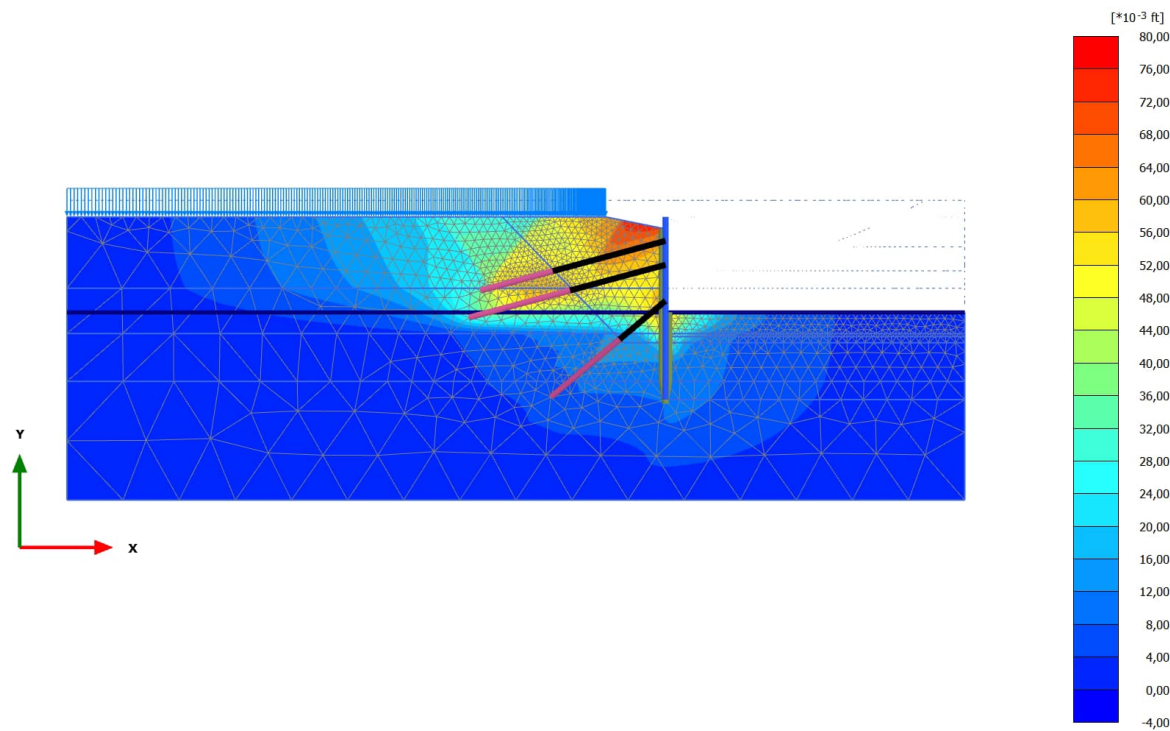
**Total displacements  $|u|$  (scaled up 20,0 times)**  
Maximum value = 0,3943 ft (Element 1176 at Node 11716)

### 2.1.1.1.3 Calculation results, Exc. to bottom [Phase\_10] (10/959), Total displacements $|u|$



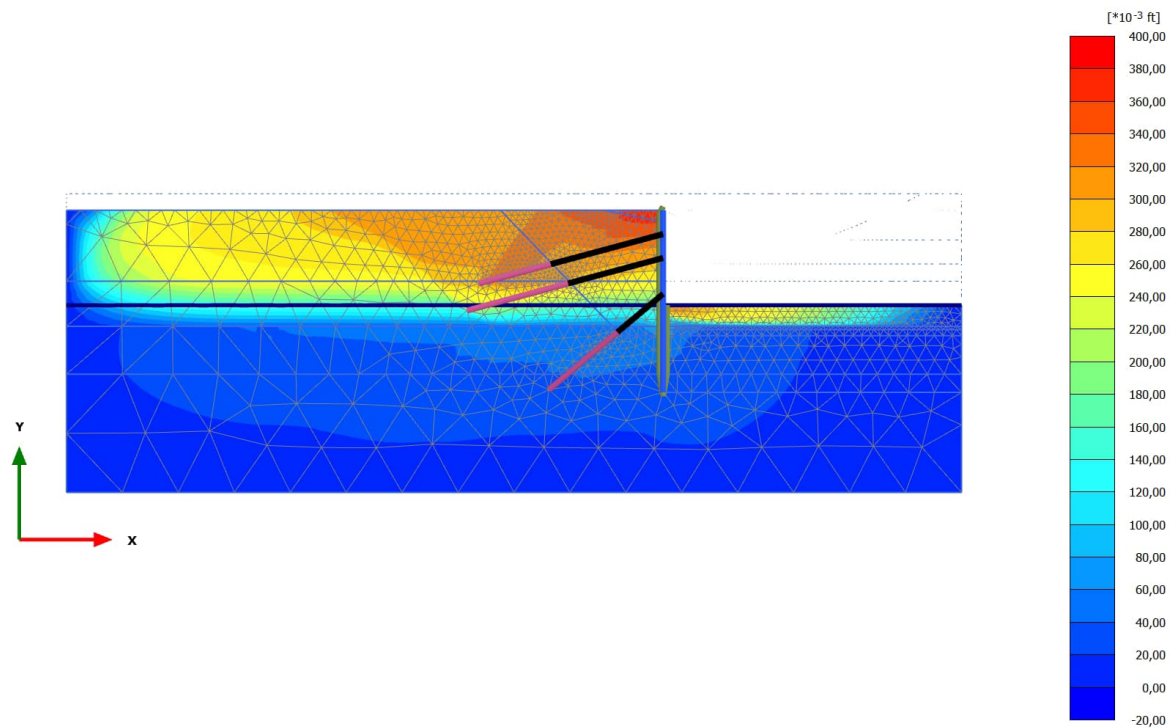
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,07441 ft (Element 764 at Node 4055)

### 2.1.1.2.1 Calculation results, Long-term (corroded, final surface level) [Phase\_16] (16/176), Total displacements $u_x$



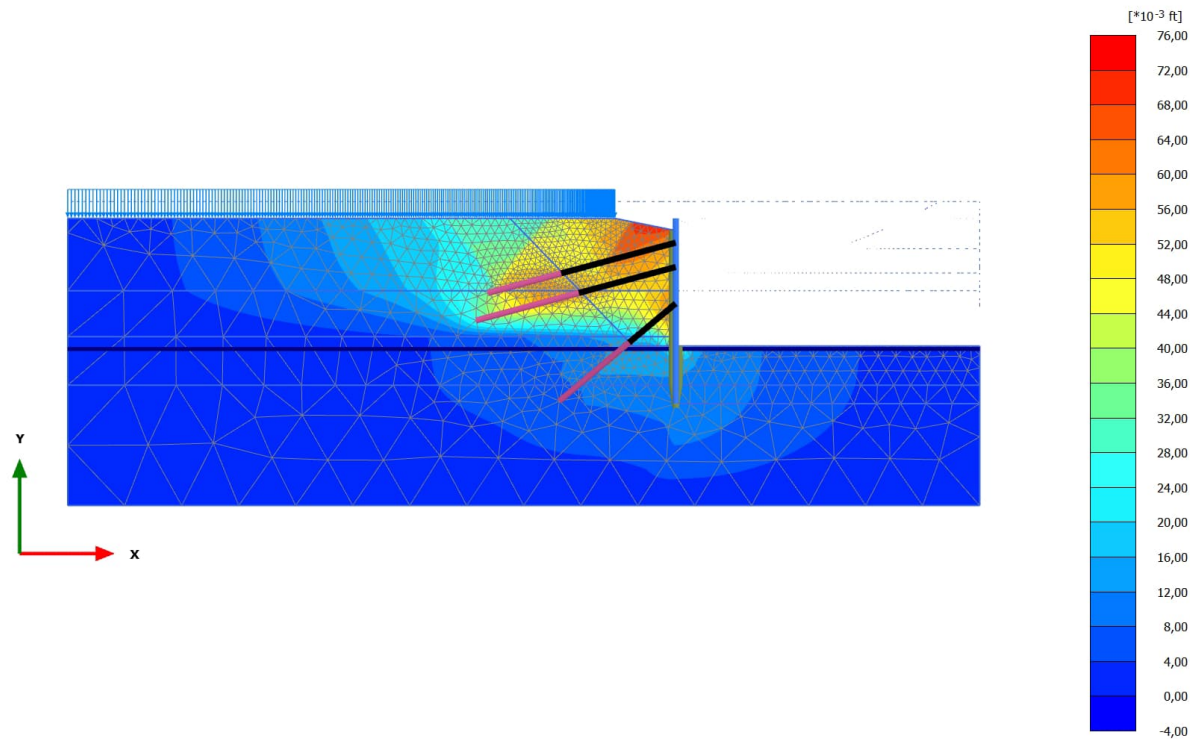
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,07679 ft (Element 726 at Node 4293)  
Minimum value = 0,000 ft (Element 1152 at Node 13310)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/193), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 20,0 times)**  
Maximum value = 0,3813 ft (Element 259 at Node 4420)  
Minimum value = 0,000 ft (Element 1152 at Node 13310)

### 2.1.1.2.3 Calculation results, Exc. to bottom [Phase\_10] (10/959), Total displacements $u_x$

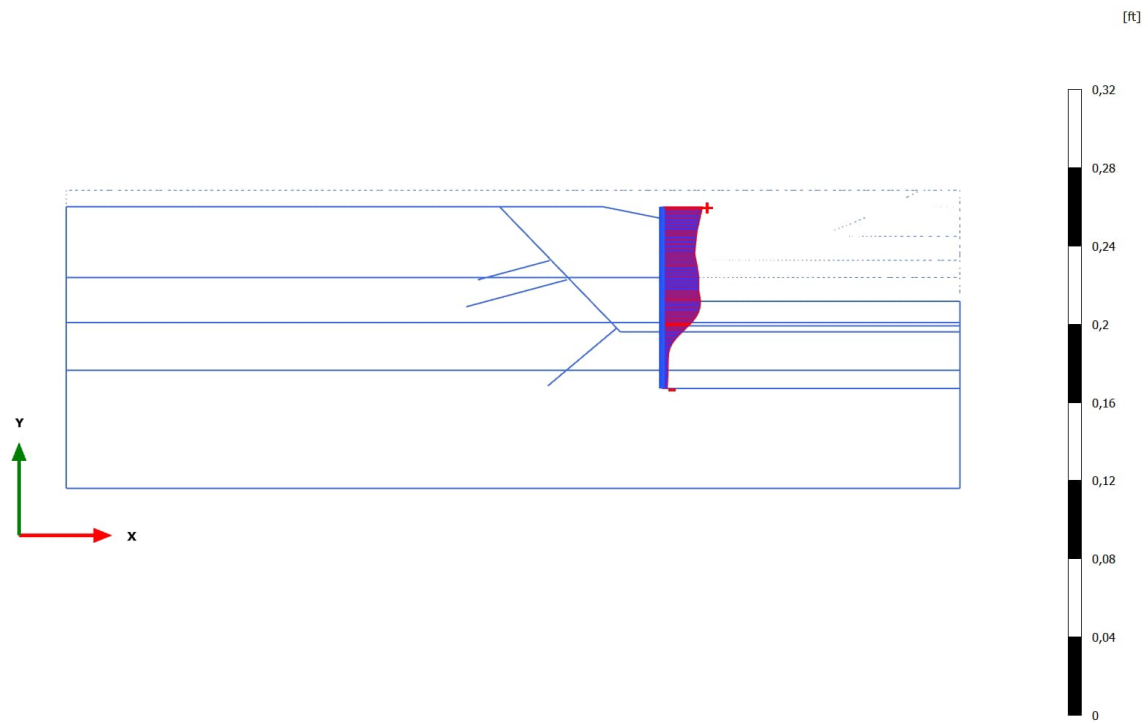


**Total displacements  $u_x$  (scaled up 100 times)**

Maximum value = 0,07218 ft (Element 726 at Node 4293)

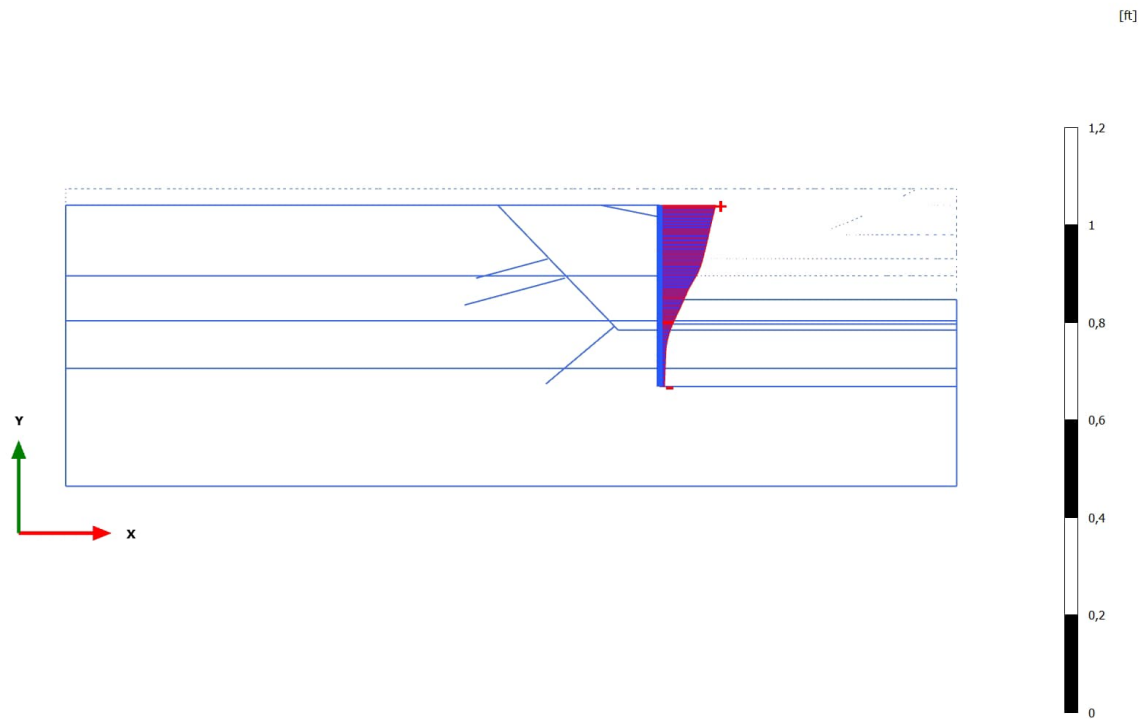
Minimum value = 0,000 ft (Element 1152 at Node 13310)

### 3.1.1.1.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_16] (16/176), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,06848 ft (Element 63 at Node 4440)

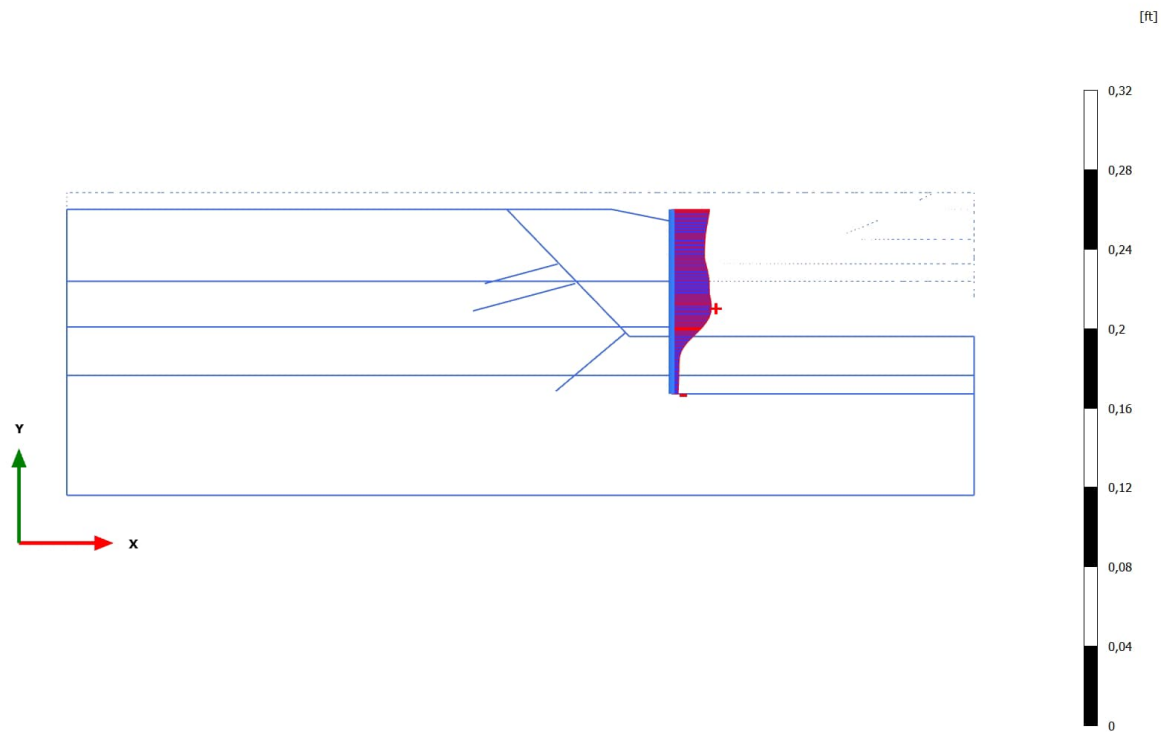
3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/193), Total displacements |u|



**Total displacements |u| (scaled up 50,0 times)**

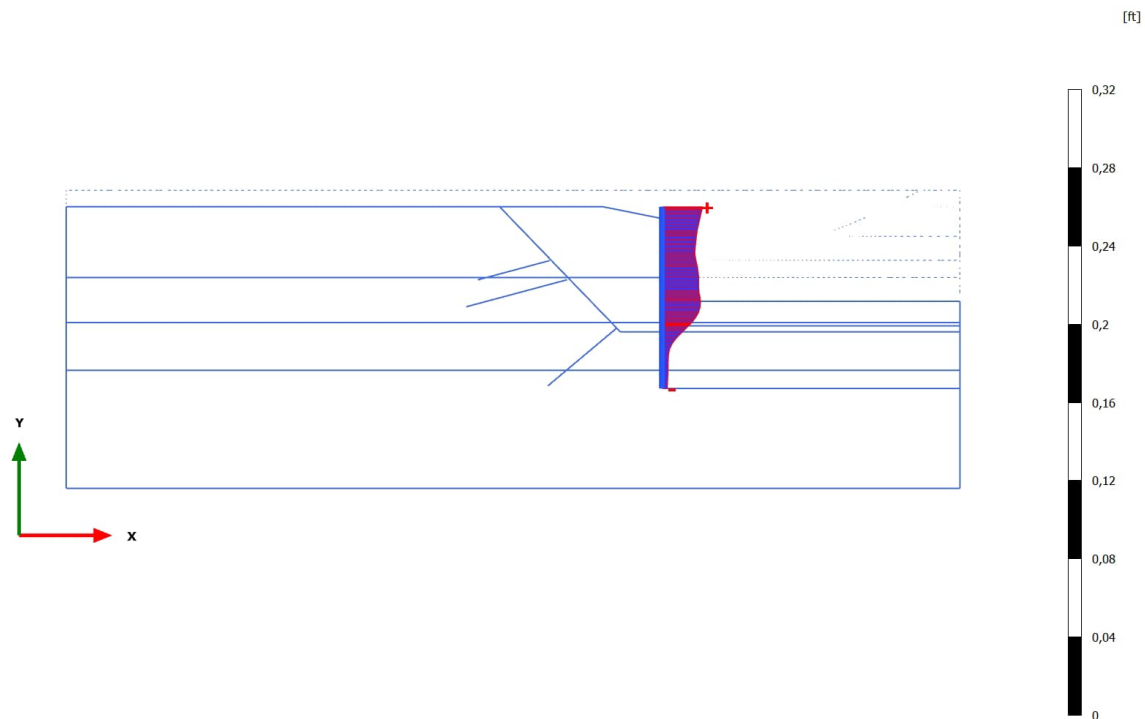
Maximum value = 0,3781 ft (Element 63 at Node 4440)

### 3.1.1.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/959), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,06582 ft (Element 75 at Node 15651)

### 3.1.1.1.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_16] (16/176), Total displacements $u_x$

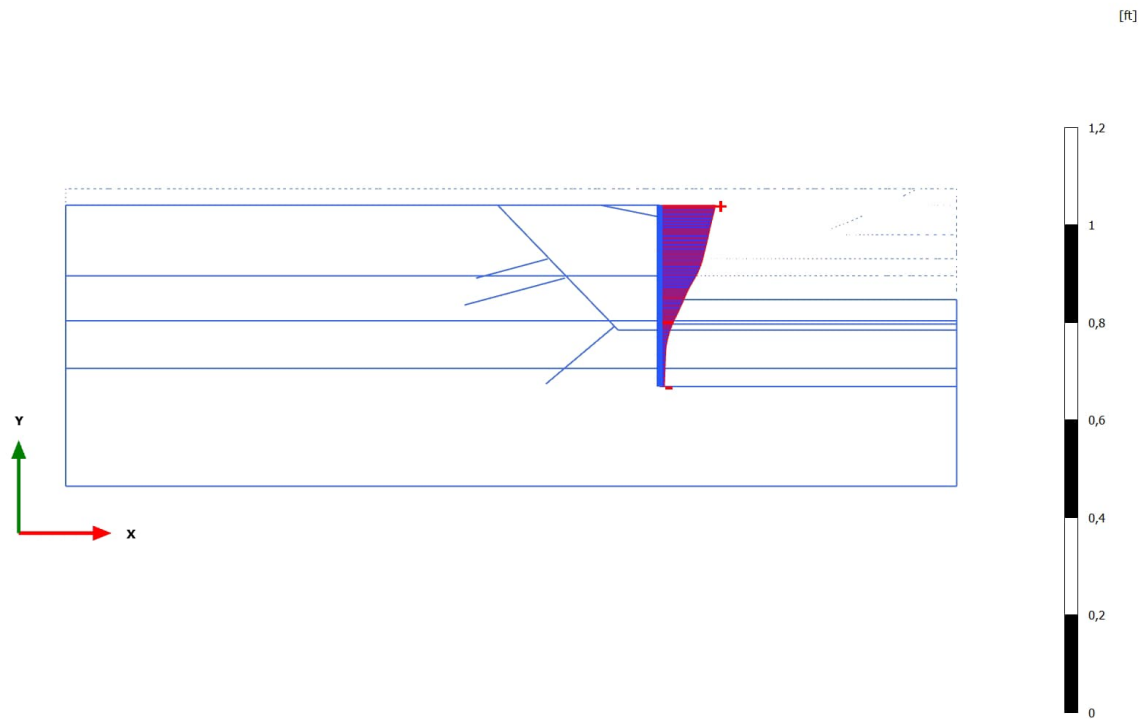


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,06836 ft (Element 63 at Node 4440)

Minimum value =  $8,998 \cdot 10^{-3}$  ft (Element 83 at Node 24110)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/193), Total displacements  $u_x$

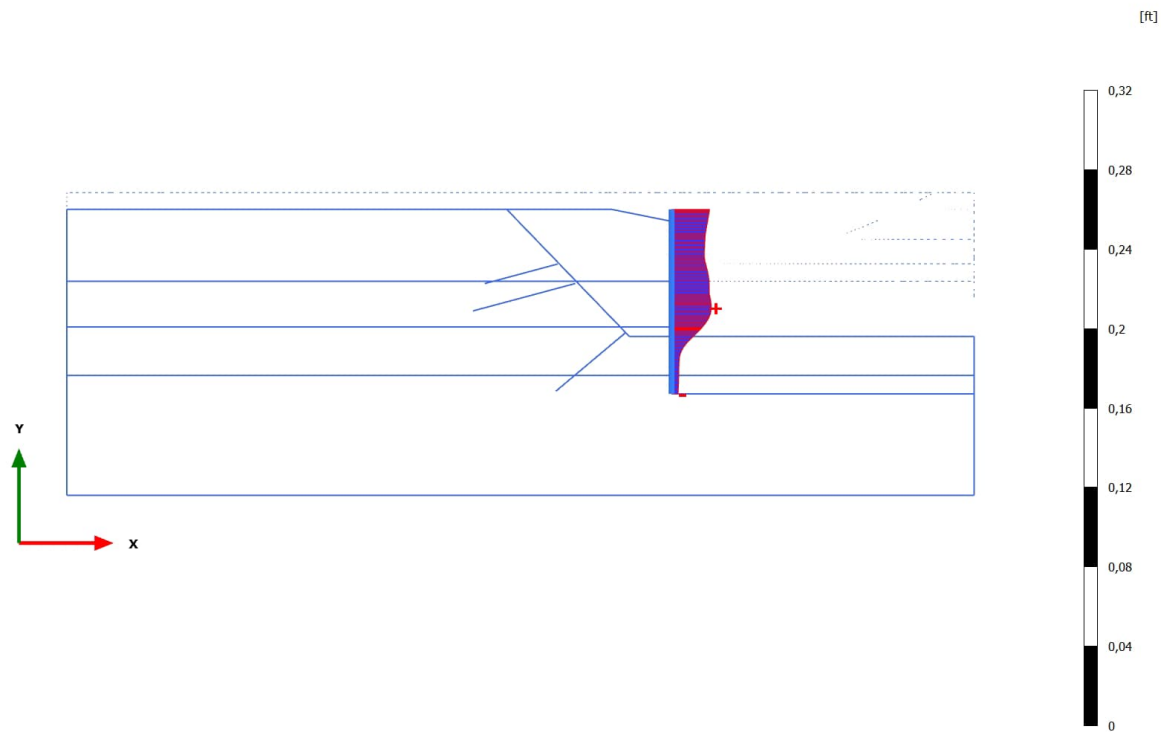


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,3776 ft (Element 63 at Node 4440)

Minimum value = 0,03249 ft (Element 83 at Node 24110)

### 3.1.1.1.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/959), Total displacements $u_x$

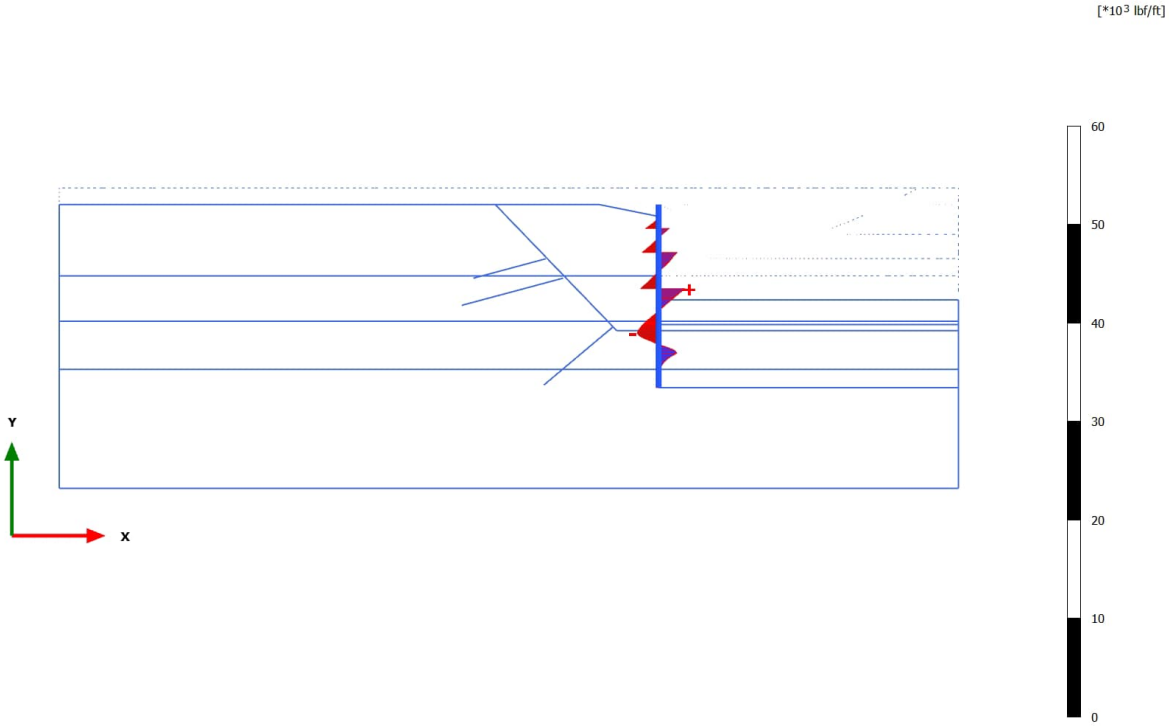


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,06568 ft (Element 75 at Node 15651)

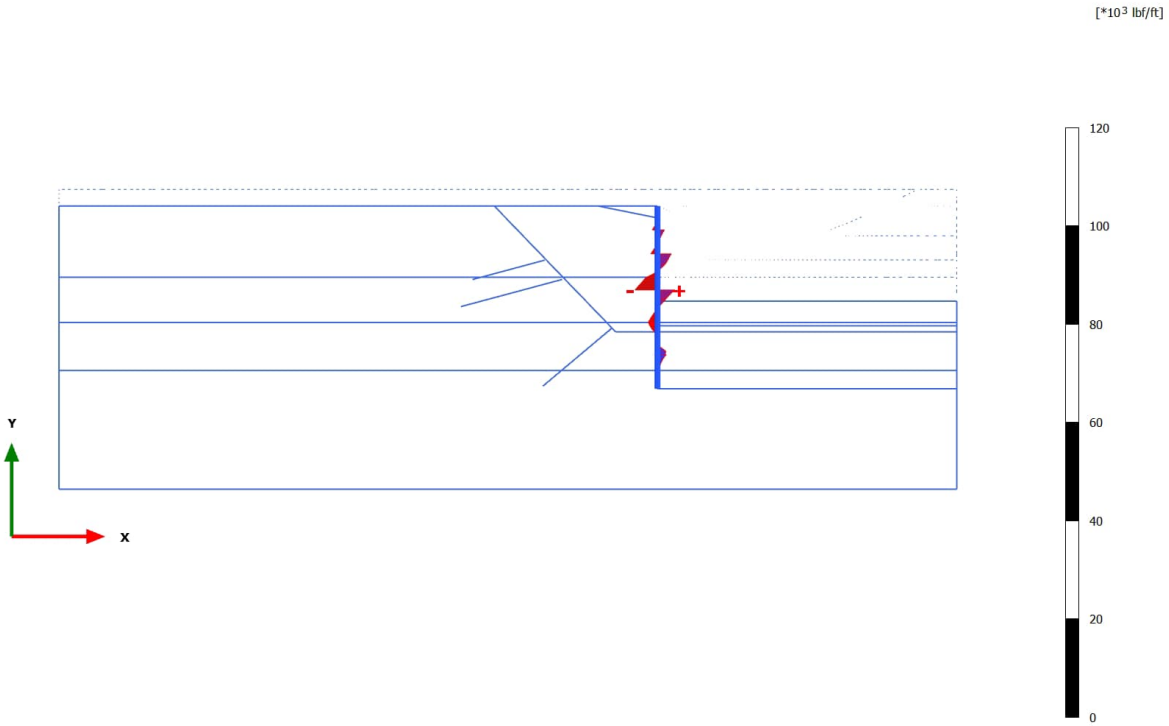
Minimum value = 0,01068 ft (Element 83 at Node 24110)

3.1.2.1.1 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_16] (16/176), Shear forces Q



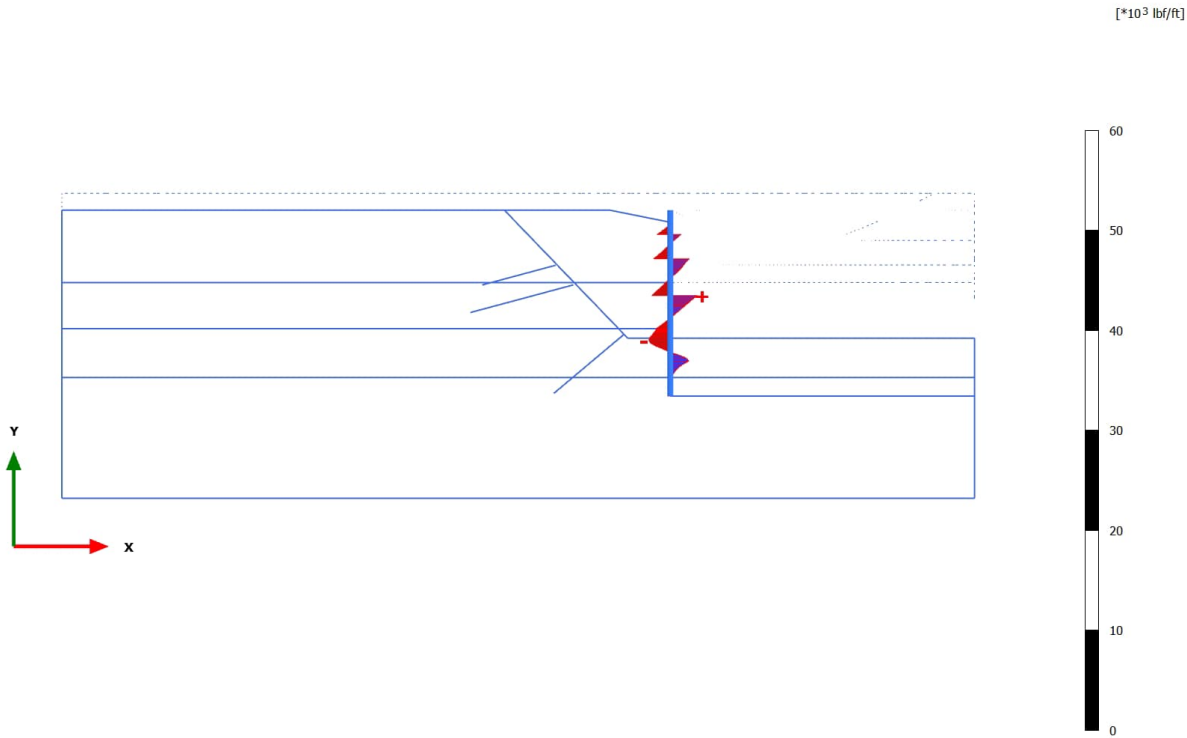
**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**  
Maximum value = 8790 lbf/ft (Element 73 at Node 14040)  
Minimum value = -7157 lbf/ft (Element 80 at Node 21125)

3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/193), Shear forces Q



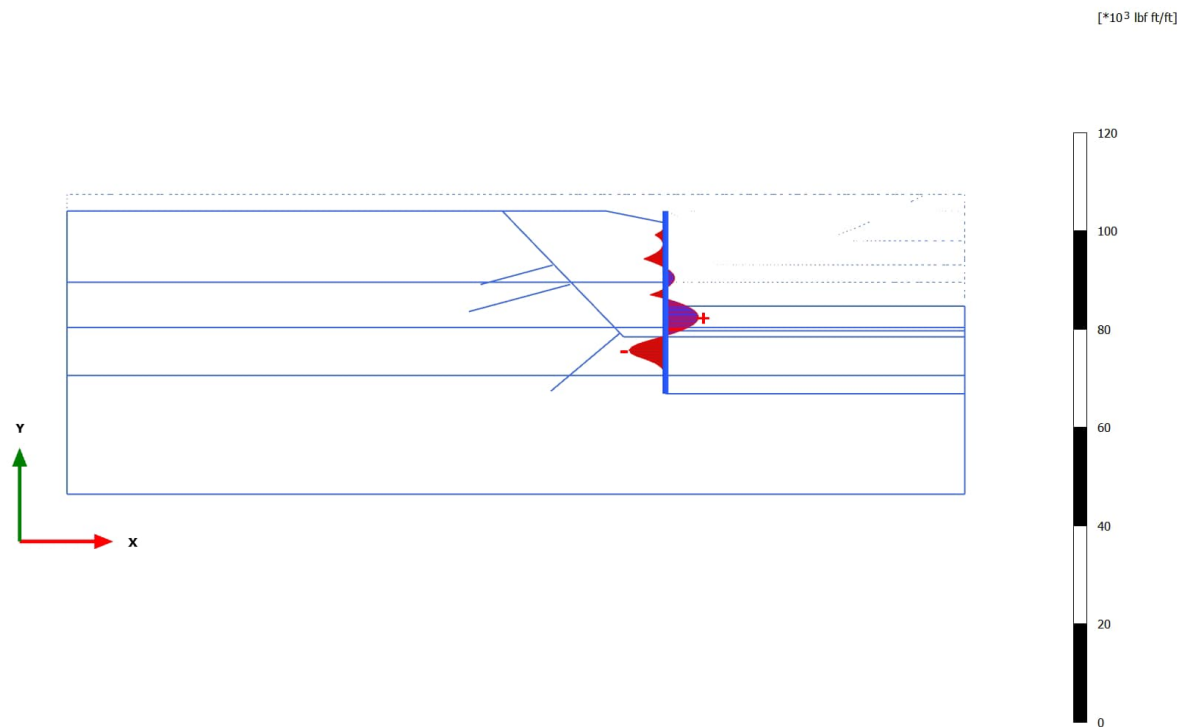
**Shear forces Q (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 11,24\*10<sup>3</sup> lbf/ft (Element 73 at Node 14040)  
Minimum value = -14,97\*10<sup>3</sup> lbf/ft (Element 72 at Node 14040)

3.1.2.1.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/959), Shear forces Q



**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**  
Maximum value = 8821 lbf/ft (Element 73 at Node 14040)  
Minimum value = -7056 lbf/ft (Element 80 at Node 21125)

### 3.1.2.2.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_16] (16/176), Bending moments M

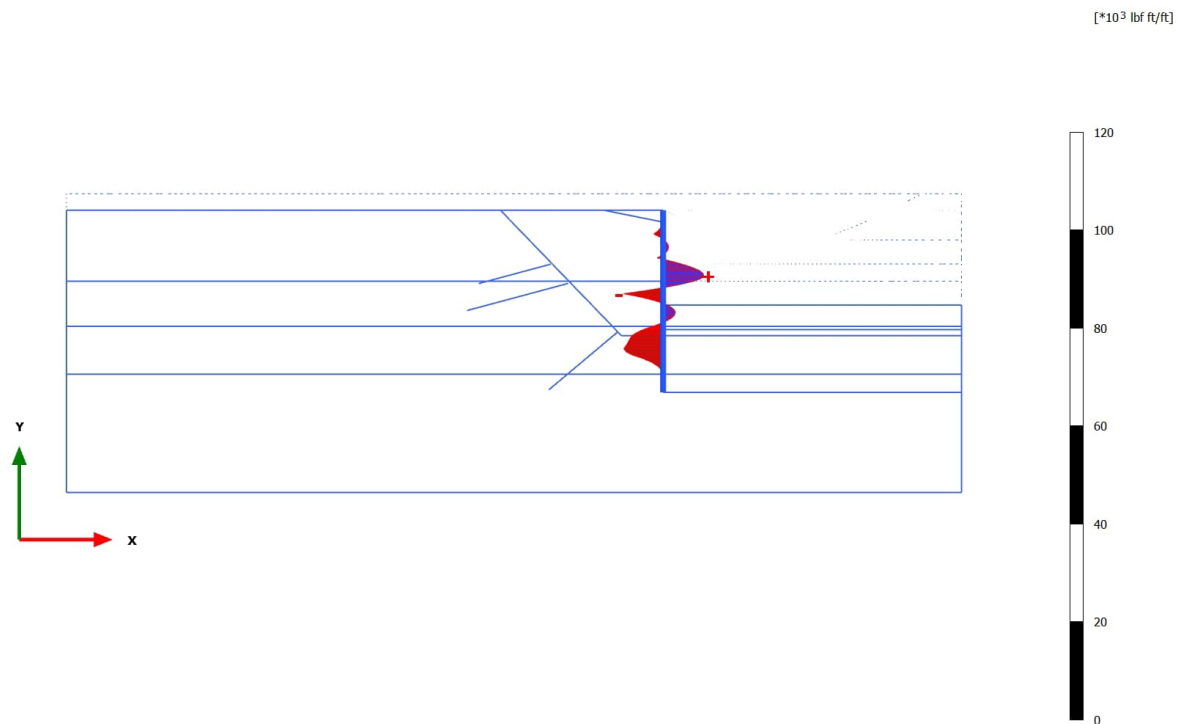


#### Bending moments M (scaled up $0,500 * 10^{-3}$ times)

Maximum value =  $22,04 * 10^3 \text{ lbf ft/ft}$  (Element 76 at Node 16917)

Minimum value =  $-24,32 * 10^3 \text{ lbf ft/ft}$  (Element 81 at Node 22127)

### 3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/193), Bending moments M

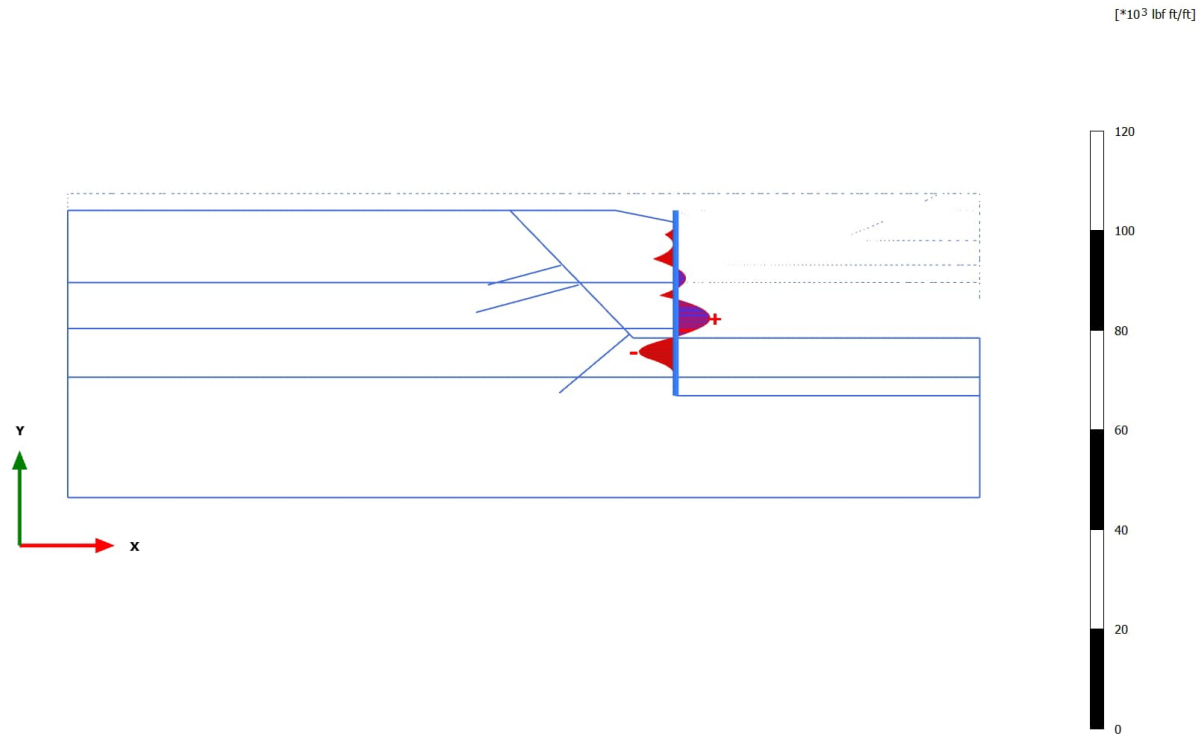


**Bending moments M (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value =  $27,22 \cdot 10^3$  lbf ft/ft (Element 71 at Node 11284)

Minimum value =  $-26,48 \cdot 10^3$  lbf ft/ft (Element 72 at Node 14040)

### 3.1.2.2.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/959), Bending moments M

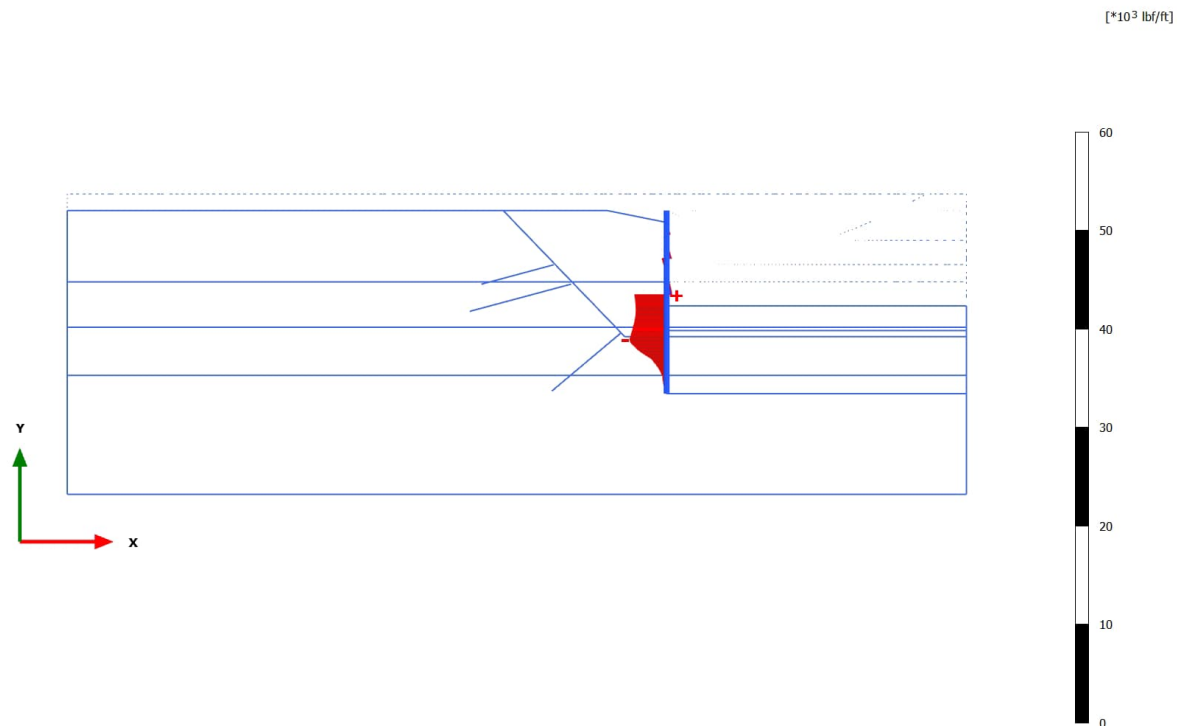


#### Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)

Maximum value = 22,54\*10<sup>3</sup> lbf ft/ft (Element 76 at Node 16917)

Minimum value = -24,24\*10<sup>3</sup> lbf ft/ft (Element 81 at Node 22127)

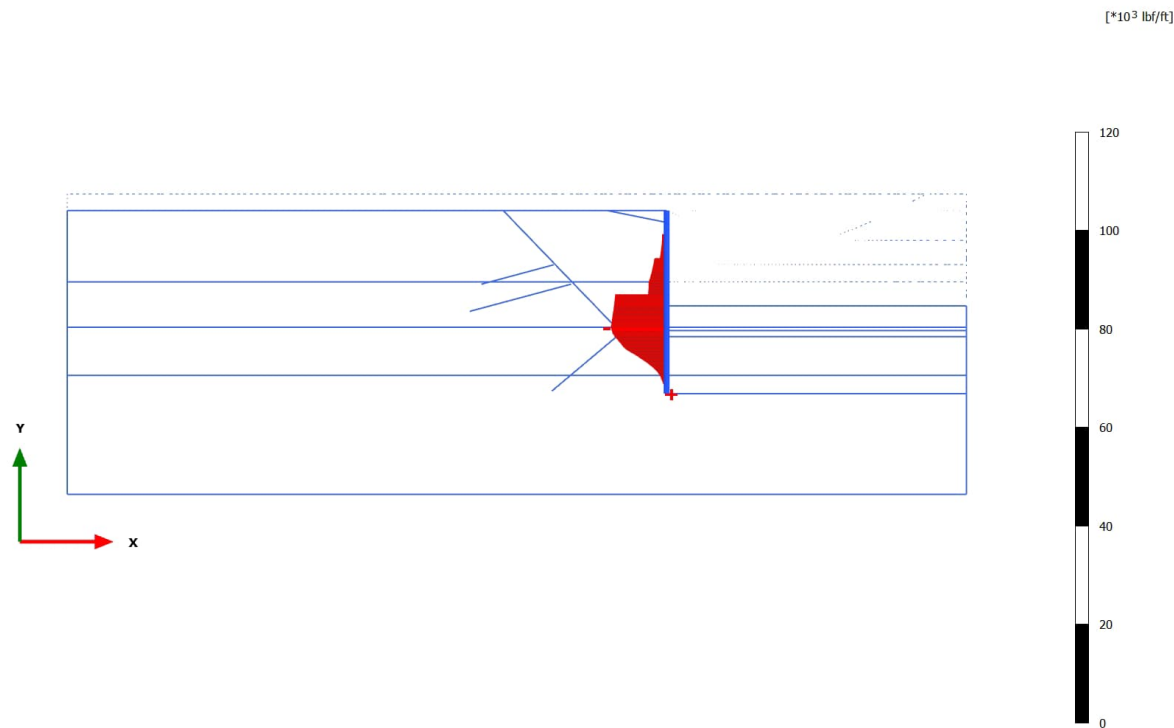
### 3.1.2.3.1 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_16] (16/176), Axial forces N



#### Axial forces N (scaled up $1,00 \times 10^{-3}$ times)

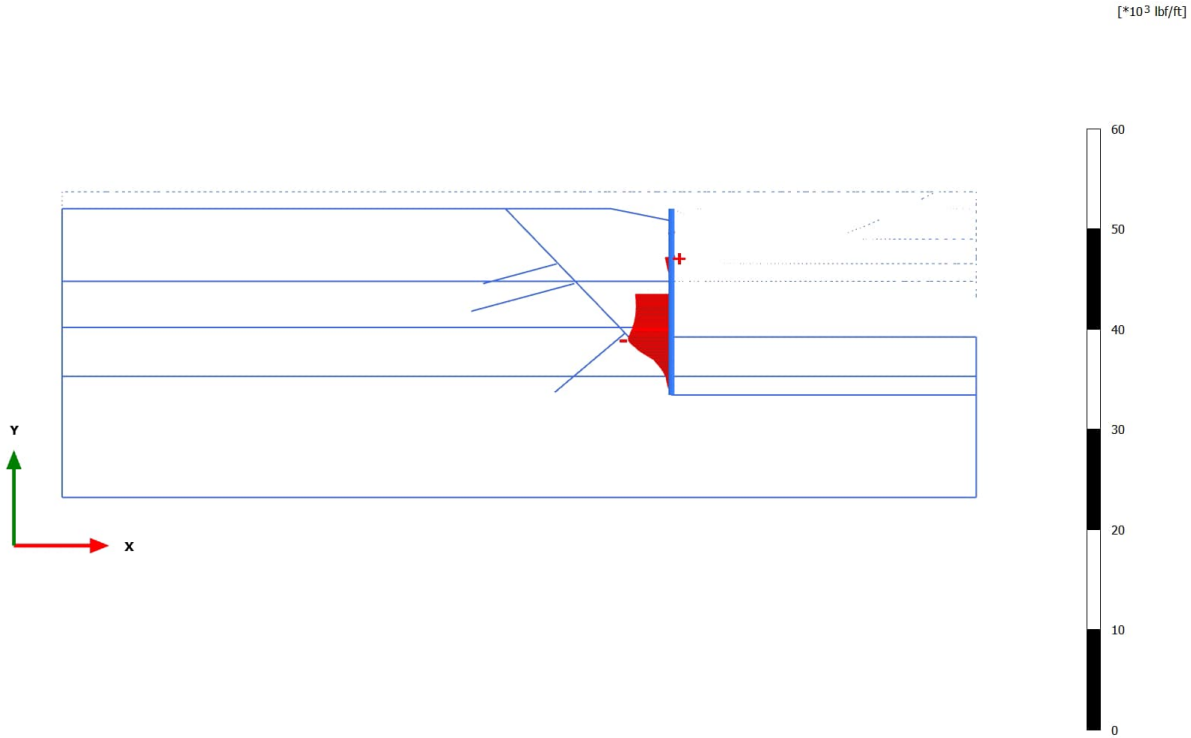
Maximum value = 1760 lbf/ft (Element 72 at Node 14040)  
Minimum value =  $-12,29 \times 10^3$  lbf/ft (Element 80 at Node 21125)

### 3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/193), Axial forces N



**Axial forces N (scaled up  $0,500 \cdot 10^{-3}$  times)**  
Maximum value = 24,78 lbf/ft (Element 83 at Node 24110)  
Minimum value =  $-36,99 \cdot 10^3$  lbf/ft (Element 77 at Node 19012)

3.1.2.3.3 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/959), Axial forces N



**Axial forces N (scaled up  $1,00*10^{-3}$  times)**  
Maximum value = 1105 lbf/ft (Element 68 at Node 9542)  
Minimum value =  $-14,17*10^3$  lbf/ft (Element 80 at Node 21125)

### 3.2.1.1.1 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_16] (16/176), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	5330	1	100,000	86,500	48,868	0,000	54,167
Element 1-1 (Node-to-node anchor)	28396	2	62,329	76,406	48,868	0,000	54,167
NodeToNodeAnchor\_1\_1	9542	1	100,000	78,500	72,937	0,000	76,506
Element 2-2 (Node-to-node anchor)	28481	2	68,124	69,959	72,937	0,000	76,506
NodeToNodeAnchor\_2\_1	14040	1	100,000	66,500	116,018	0,000	116,713
Element 3-3 (Node-to-node anchor)	28538	2	84,679	53,644	116,018	0,000	116,713

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/193), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	5330	1	100,000	86,500	49,982	0,000	54,167
Element 1-1 (Node-to-node anchor)	28396	2	62,329	76,406	49,982	0,000	54,167
NodeToNodeAnchor\_1\_1	9542	1	100,000	78,500	85,012	0,000	85,152
Element 2-2 (Node-to-node anchor)	28481	2	68,124	69,959	85,012	0,000	85,152
NodeToNodeAnchor\_2\_1	14040	1	100,000	66,500	205,368	0,000	205,368
Element 3-3 (Node-to-node anchor)	28538	2	84,679	53,644	205,368	0,000	205,368

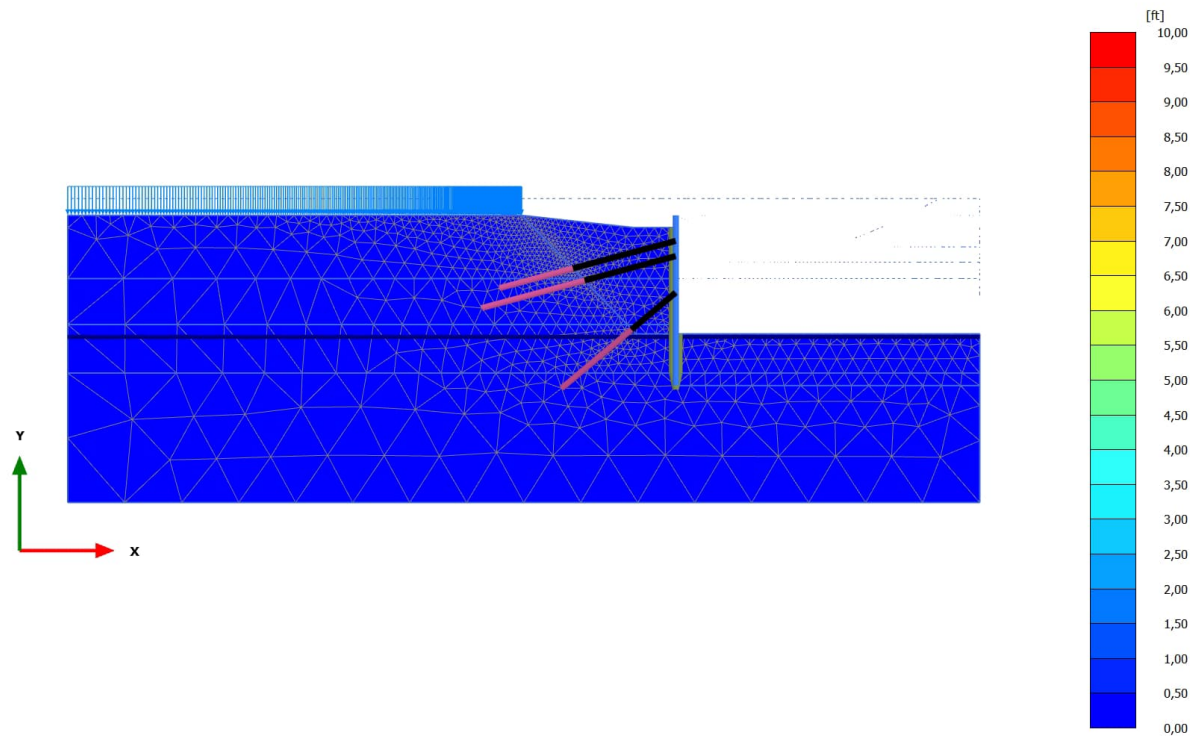
### 3.2.1.1.3 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10] (10/959), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	5330	1	100,000	86,500	48,795	0,000	54,167
Element 1-1 (Node-to-node anchor)	28396	2	62,329	76,406	48,795	0,000	54,167
NodeToNodeAnchor\_1\_1	9542	1	100,000	78,500	73,272	0,000	76,506
Element 2-2 (Node-to-node anchor)	28481	2	68,124	69,959	73,272	0,000	76,506
NodeToNodeAnchor\_2\_1	14040	1	100,000	66,500	116,713	0,000	116,713
Element 3-3 (Node-to-node anchor)	28538	2	84,679	53,644	116,713	0,000	116,713

# PLAXIS Report

**Plaxis Model Wingwall 4\_Section 2: WW4-2  
STA. 6+15.49 to 6+33.49**

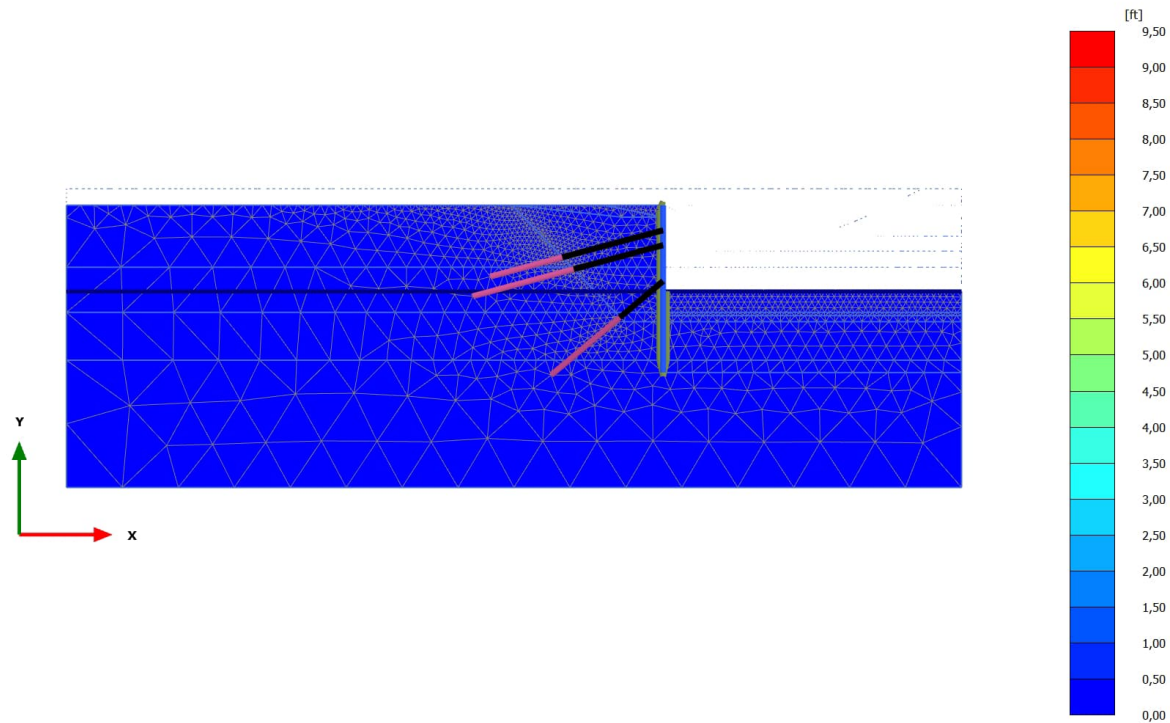
### 2.1.1.1.1 Calculation results, Exc. to bottom [Phase\_10] (10/211), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 0,500 times)**

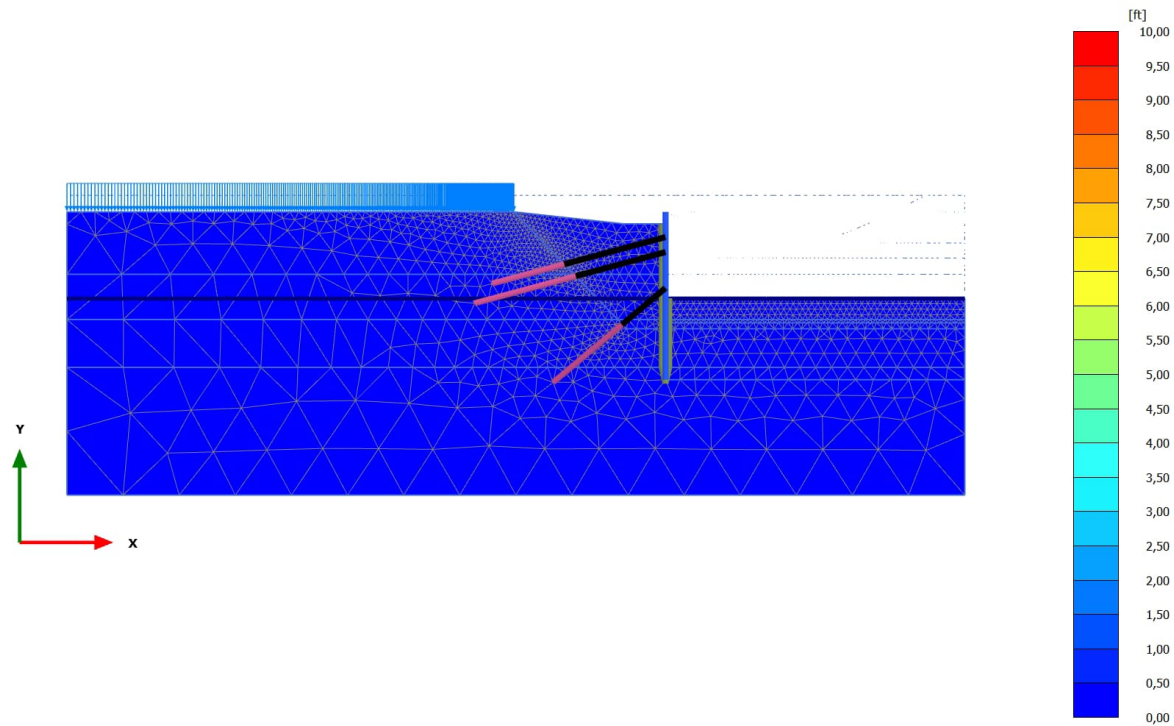
Maximum value = 9,658 ft (Element 873 at Node 5128)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15]  
(15/402), Total displacements  $|u|$

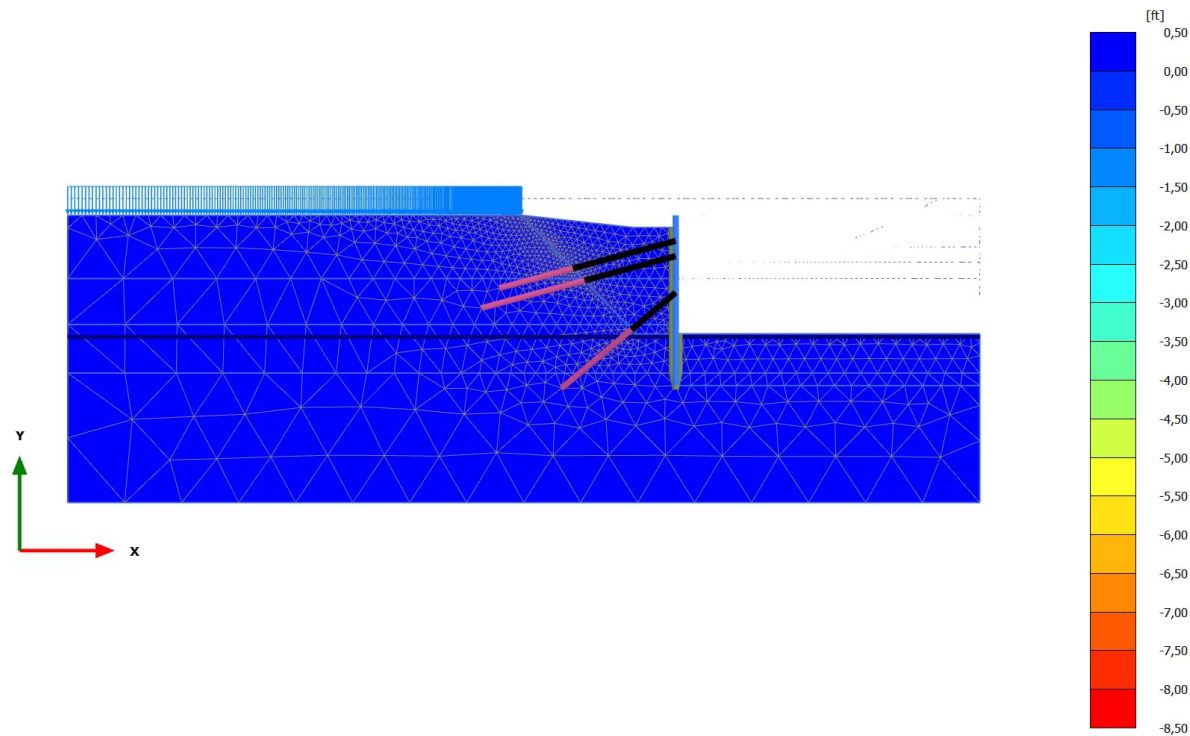


**Total displacements  $|u|$  (scaled up 5,00 times)**  
Maximum value = 9,425 ft (Element 351 at Node 5128)

2.1.1.1.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18]  
(18/1640), Total displacements  $|u|$



### 2.1.1.2.1 Calculation results, Exc. to bottom [Phase\_10] (10/211), Total displacements $u_x$

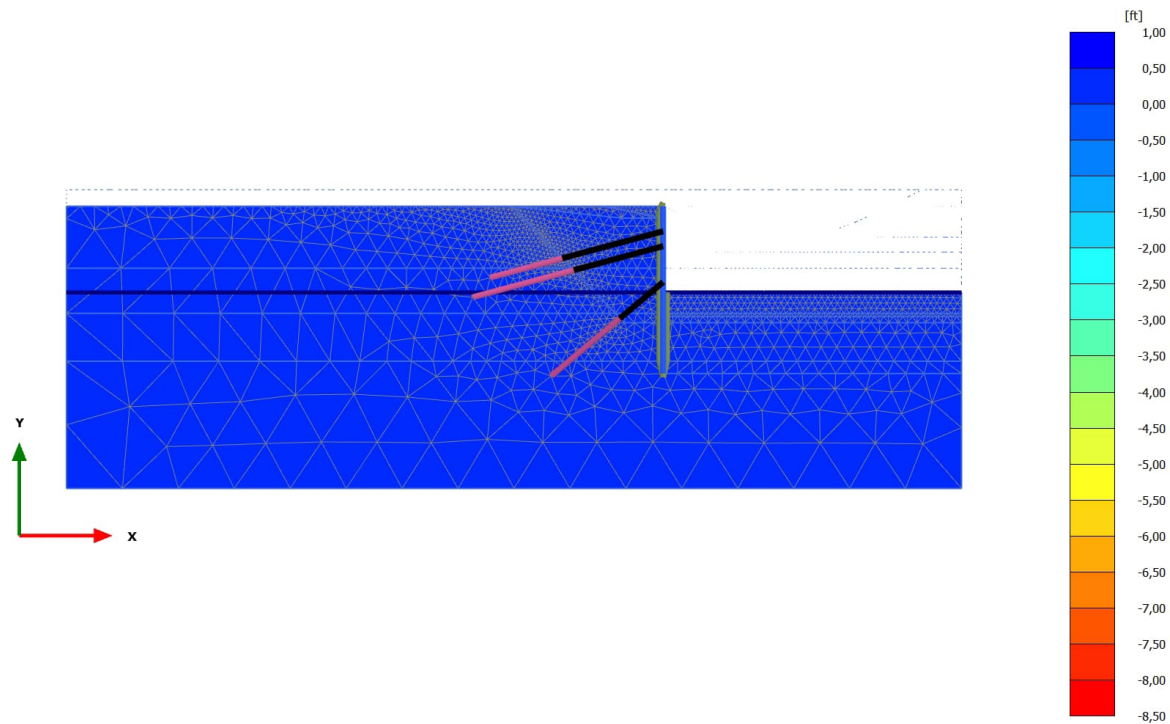


**Total displacements  $u_x$  (scaled up 5,00 times)**

Maximum value = 0,3172 ft (Element 873 at Node 5137)

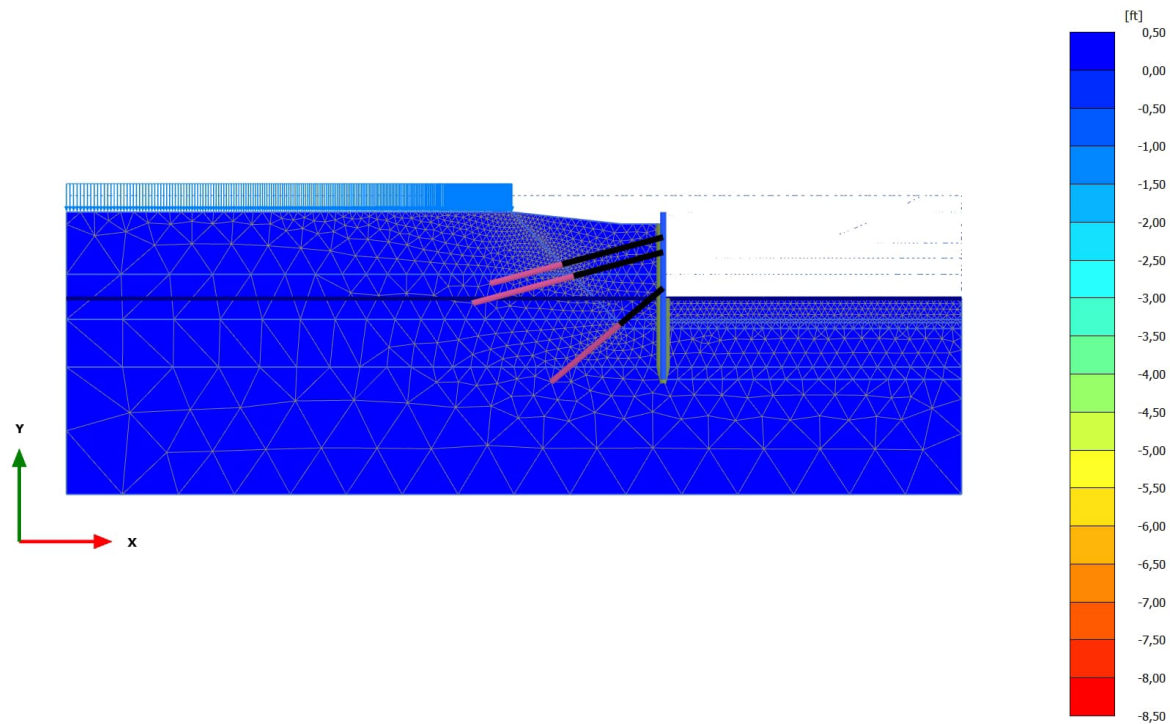
Minimum value = -8,358 ft (Element 873 at Node 5128)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15]  
(15/402), Total displacements  $u_x$



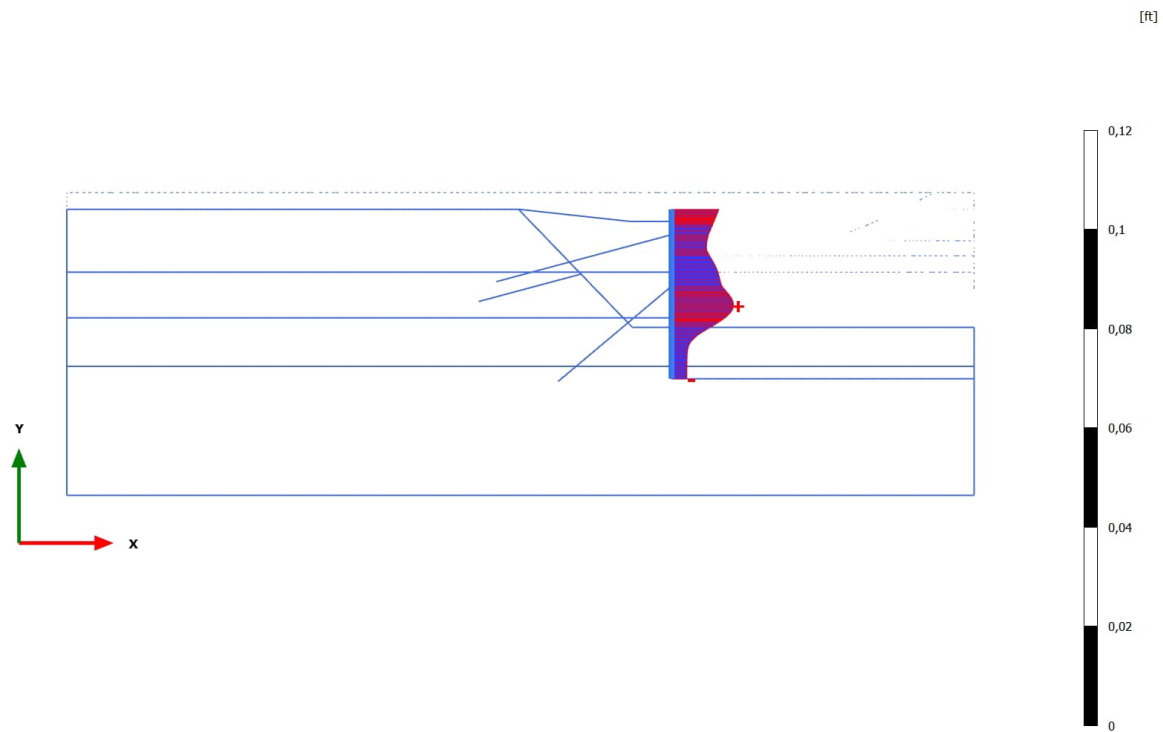
**Total displacements  $u_x$  (scaled up 5,00 times)**  
Maximum value = 0,5664 ft (Element 873 at Node 5137)  
Minimum value = -8,108 ft (Element 351 at Node 5128)

### 2.1.1.2.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Total displacements $u_x$



**Total displacements  $u_x$  (scaled up 5,00 times)**  
Maximum value = 0,3216 ft (Element 873 at Node 5137)  
Minimum value = -8,350 ft (Element 873 at Node 5128)

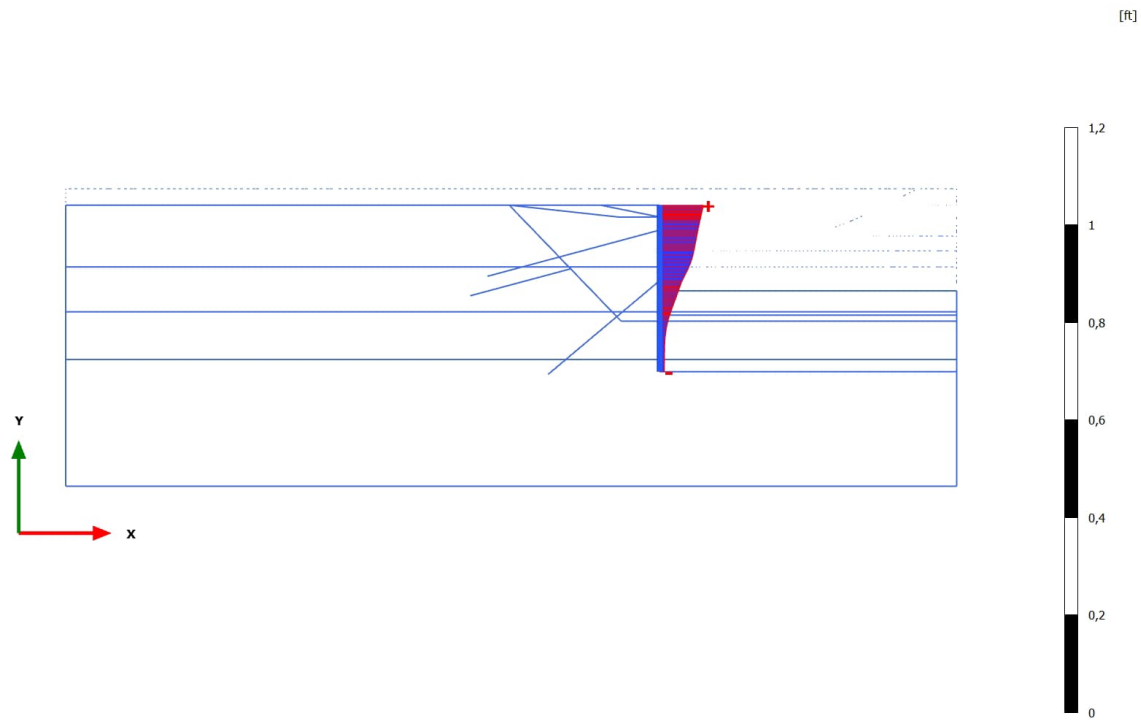
### 3.1.1.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/211), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 500 times)**

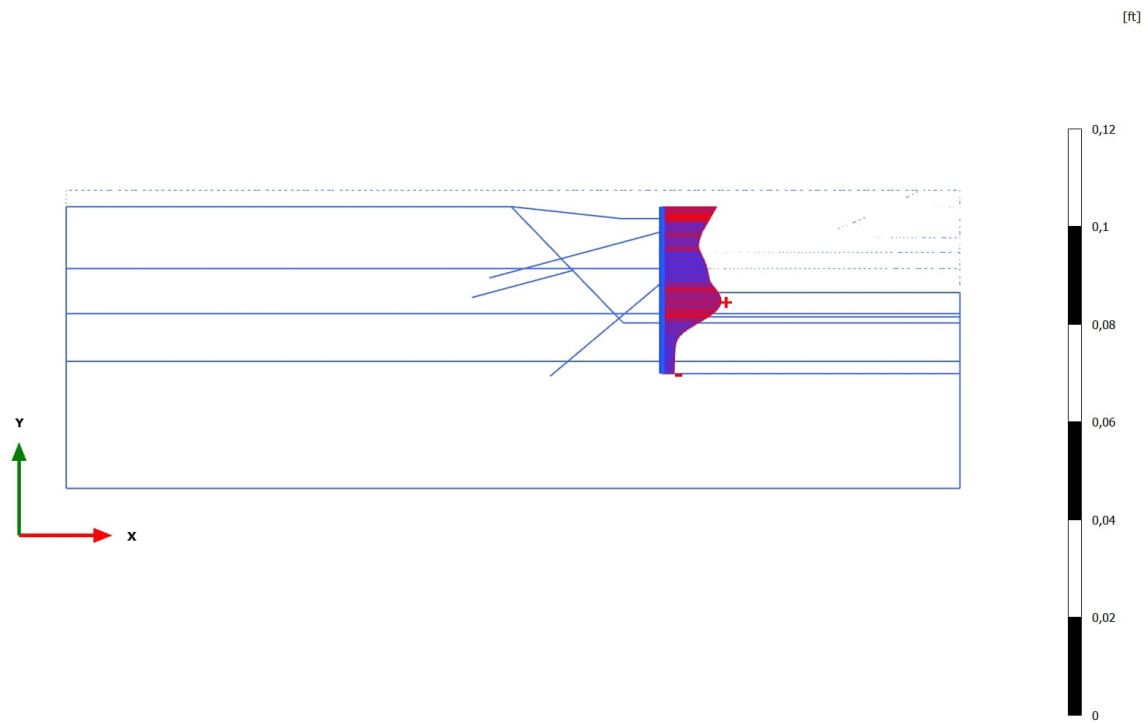
Maximum value = 0,04094 ft (Element 79 at Node 18458)

3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/402), Total displacements |u|



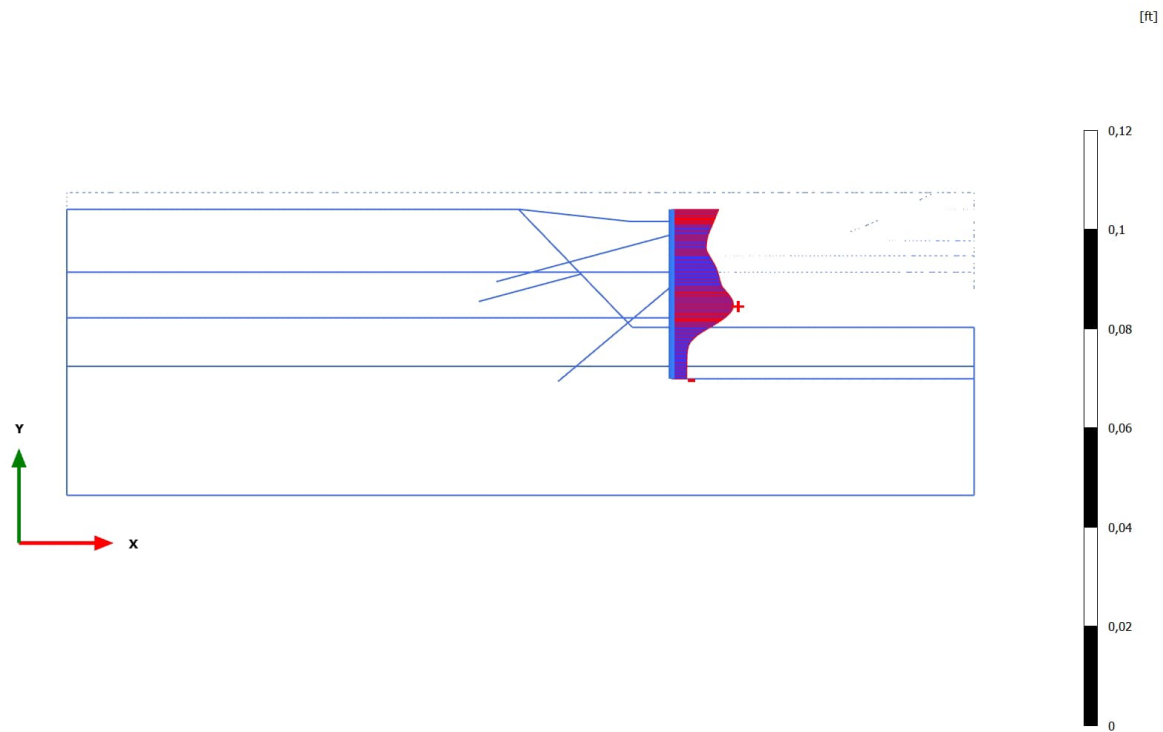
**Total displacements |u| (scaled up 50,0 times)**  
Maximum value = 0,2957 ft (Element 66 at Node 4234)

### 3.1.1.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Total displacements |u|



**Total displacements |u| (scaled up 500 times)**  
Maximum value = 0,03977 ft (Element 79 at Node 18458)

### 3.1.1.1.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/211), Total displacements $u_x$

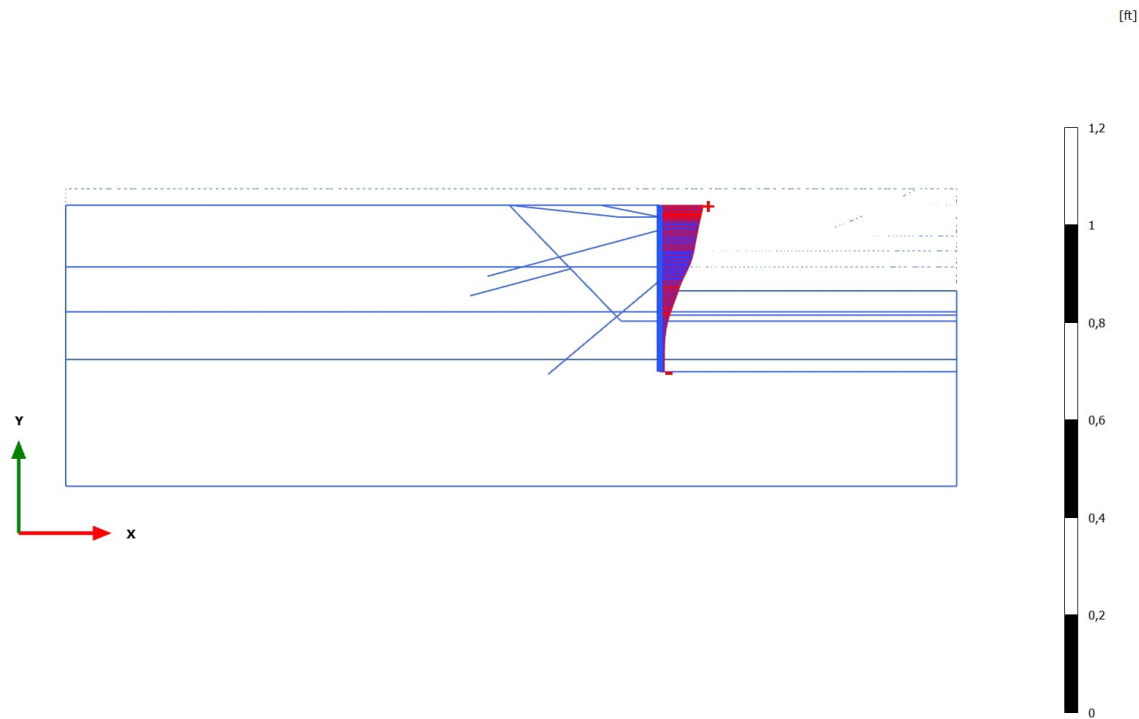


**Total displacements  $u_x$  (scaled up 500 times)**

Maximum value = 0,04092 ft (Element 79 at Node 18458)

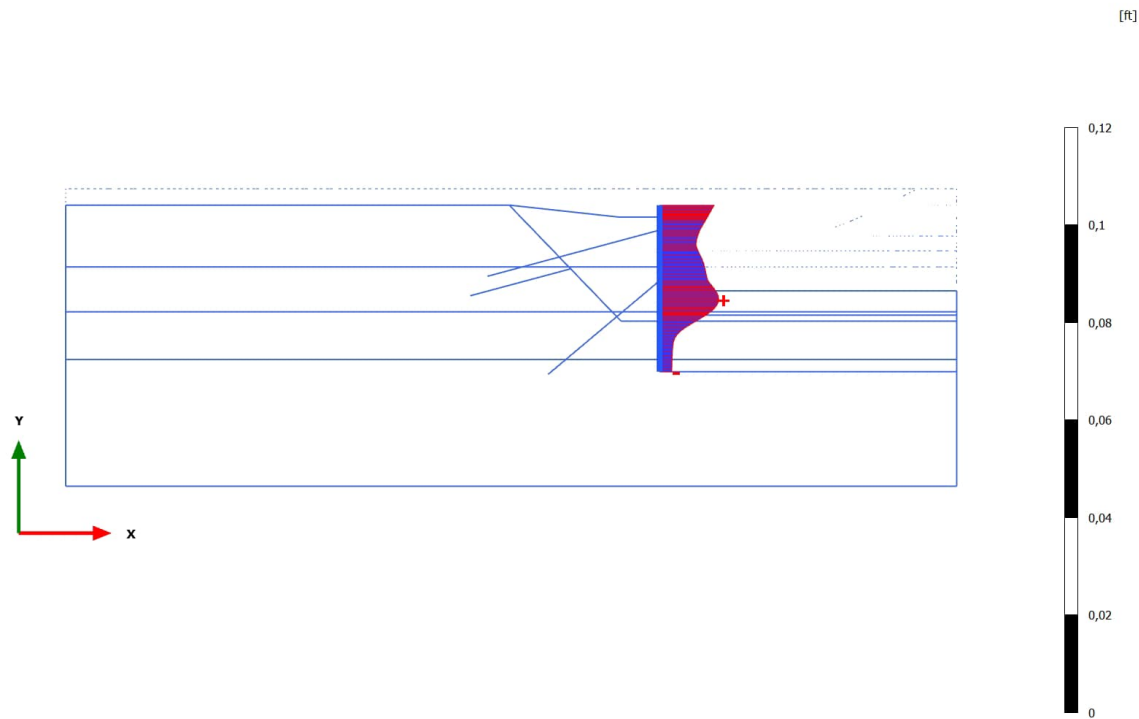
Minimum value =  $9,965 \cdot 10^{-3}$  ft (Element 87 at Node 27178)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/402), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2952 ft (Element 66 at Node 4234)  
Minimum value = 0,03103 ft (Element 87 at Node 27178)

### 3.1.1.1.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Total displacements $u_x$

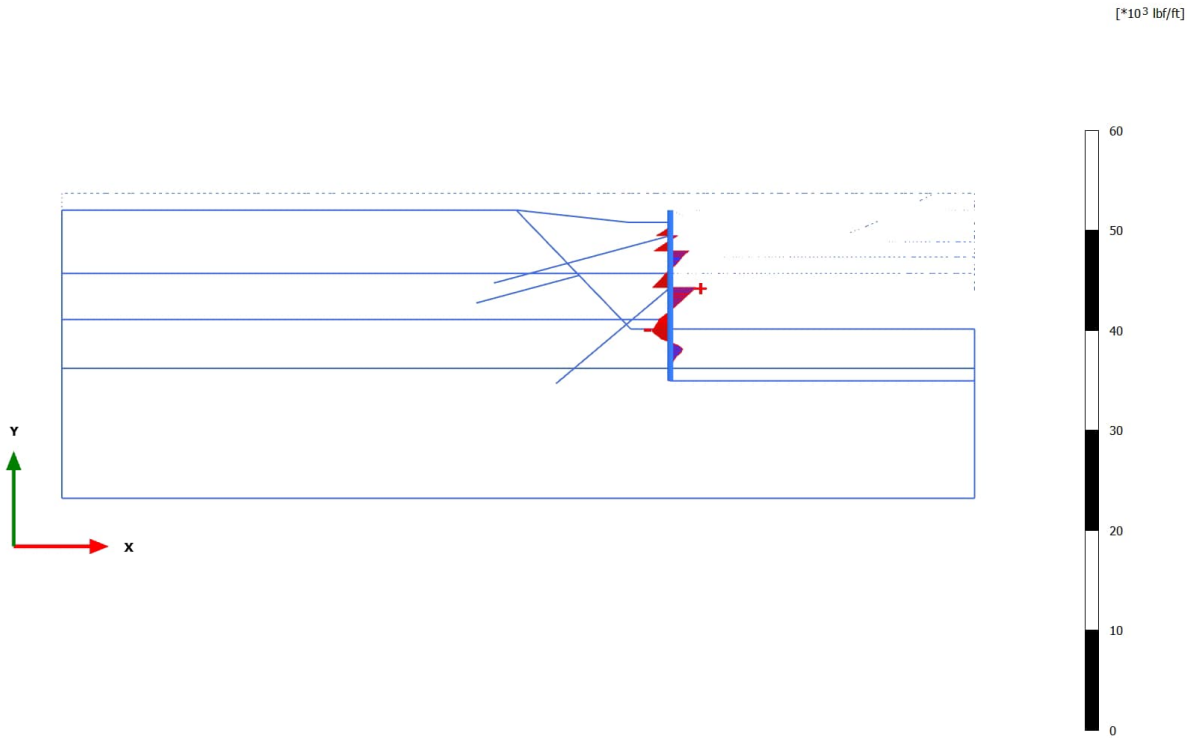


**Total displacements  $u_x$  (scaled up 500 times)**

Maximum value = 0,03976 ft (Element 79 at Node 18458)

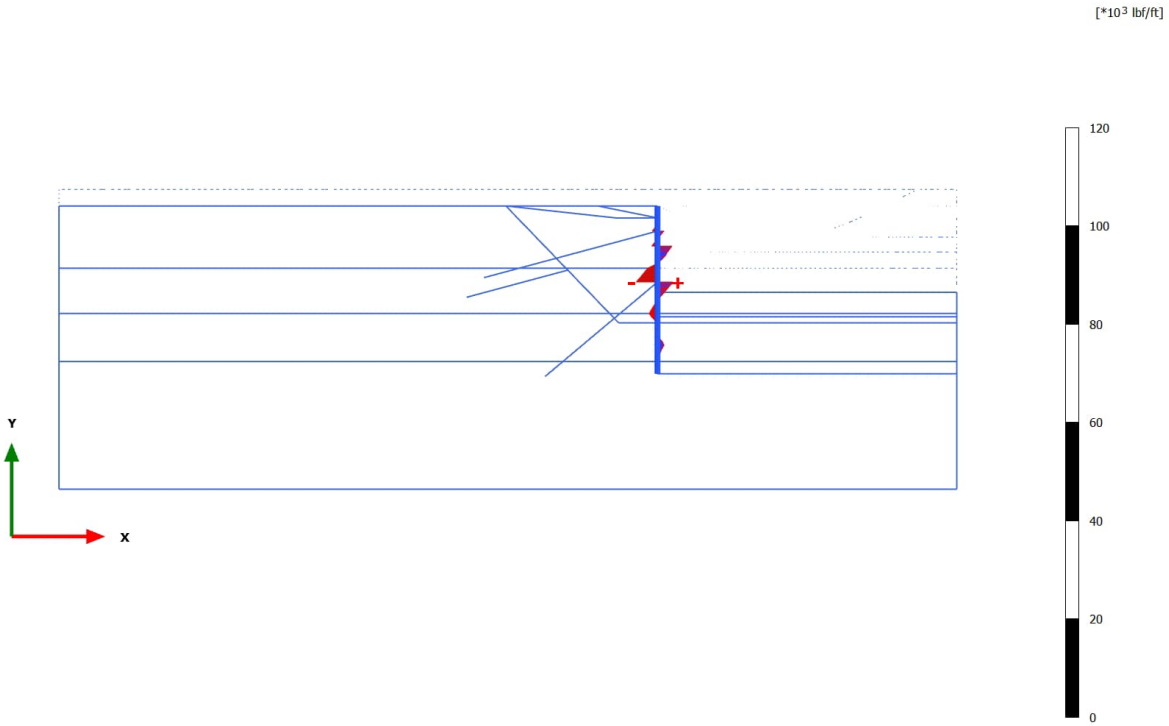
Minimum value =  $8,169 \cdot 10^{-3}$  ft (Element 87 at Node 27178)

3.1.2.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/211), Shear forces Q



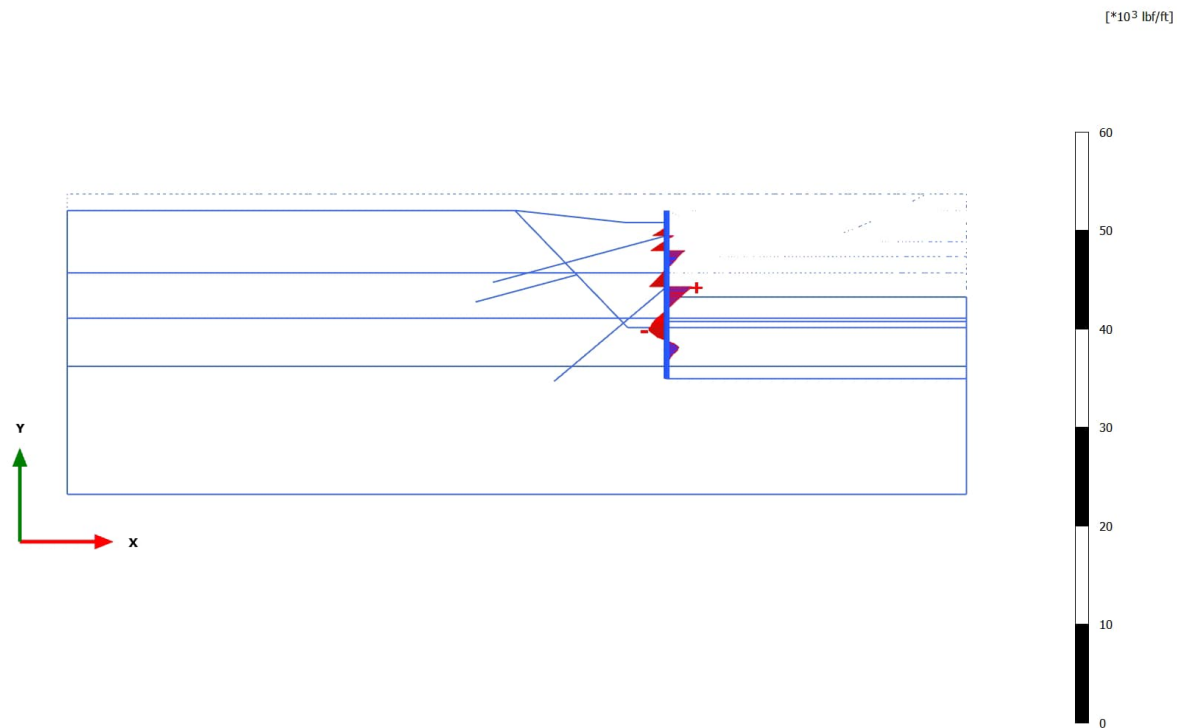
**Shear forces Q (scaled up  $1,00 \cdot 10^{-3}$  times)**  
Maximum value = 8418 lbf/ft (Element 76 at Node 14708)  
Minimum value = -5879 lbf/ft (Element 84 at Node 24318)

3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/402), Shear forces Q



**Shear forces Q (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 10,58\*10<sup>3</sup> lbf/ft (Element 76 at Node 14708)  
Minimum value = -14,19\*10<sup>3</sup> lbf/ft (Element 75 at Node 14708)

### 3.1.2.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Shear forces Q

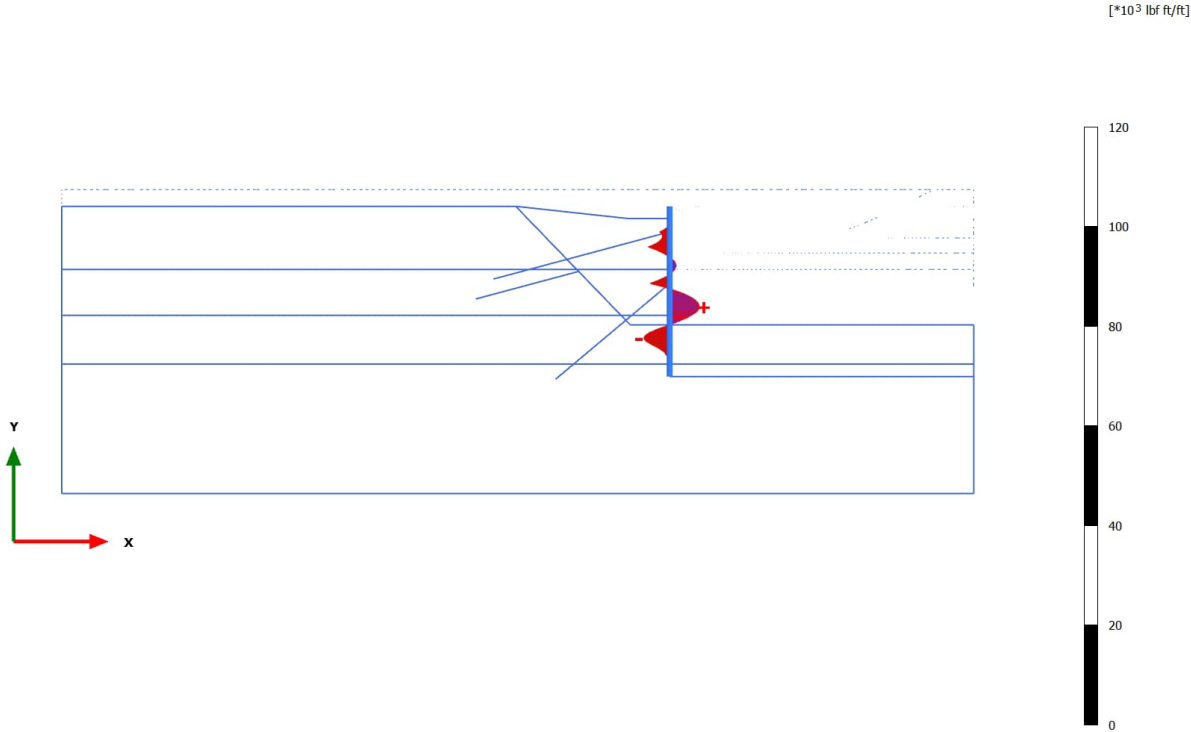


**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**

Maximum value = 8379 lbf/ft (Element 76 at Node 14708)

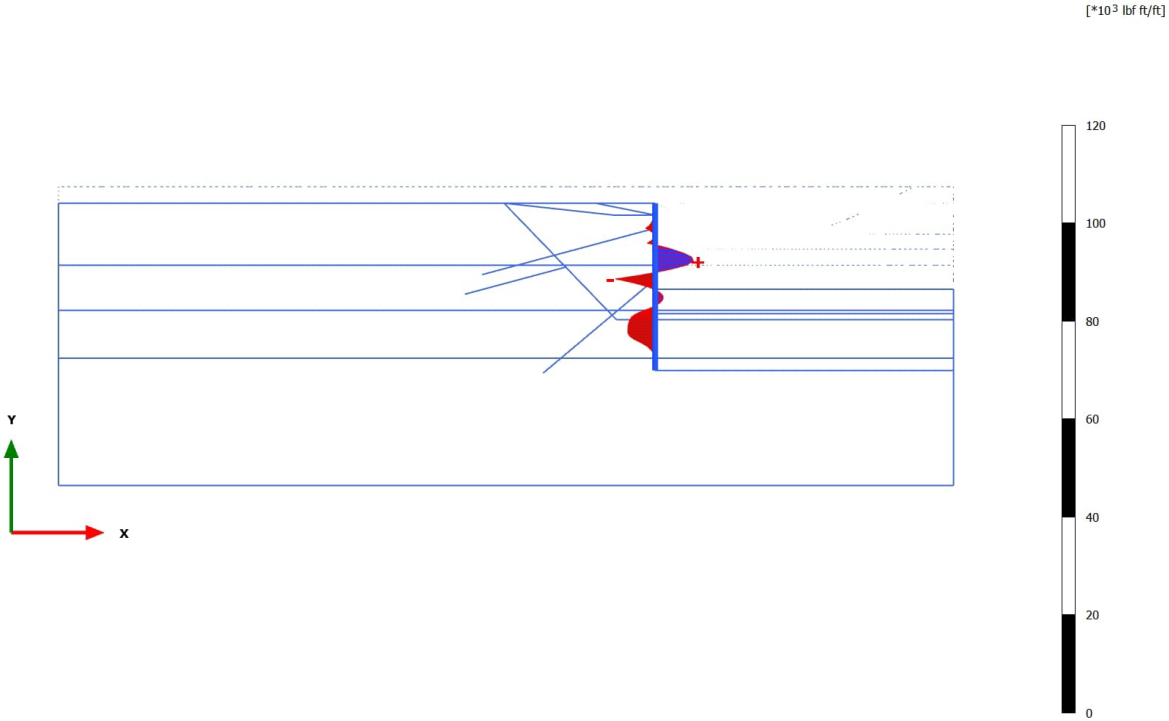
Minimum value = -5969 lbf/ft (Element 84 at Node 24319)

3.1.2.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/211), Bending moments M



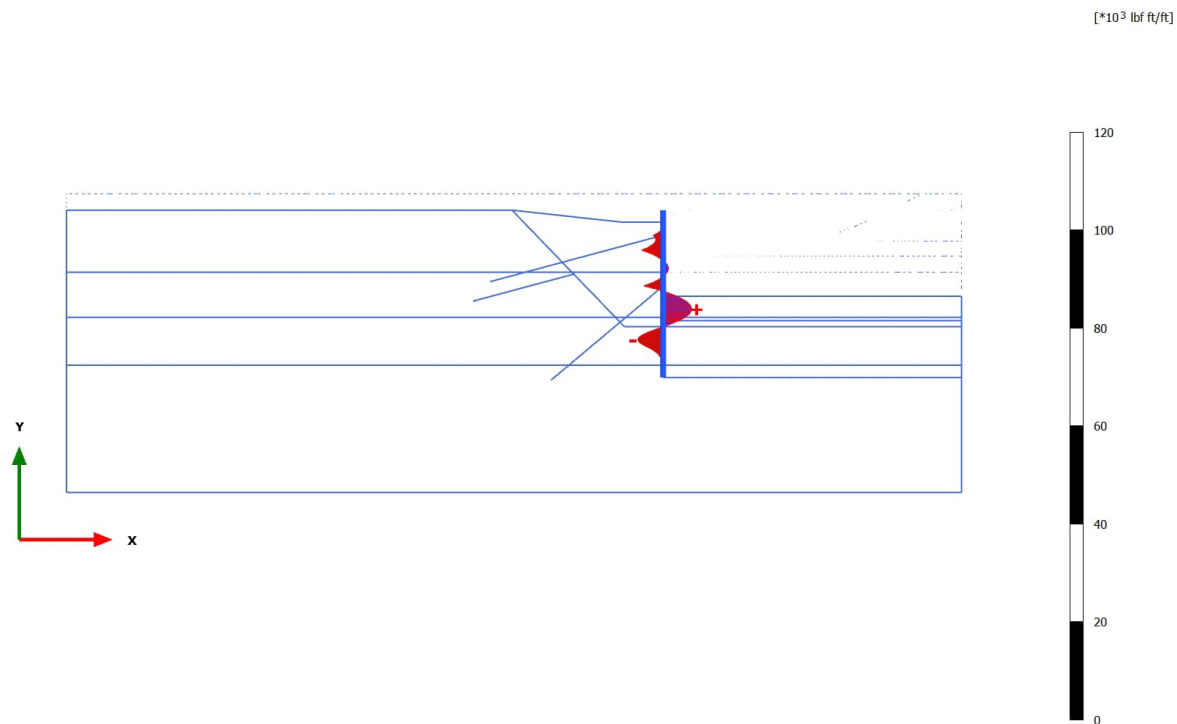
**Bending moments M (scaled up  $0,500*10^{-3}$  times)**  
Maximum value =  $19,50*10^3$  lbf ft/ft (Element 80 at Node 19399)  
Minimum value =  $-17,16*10^3$  lbf ft/ft (Element 85 at Node 25499)

3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/402), Bending moments M



**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 25,65\*10<sup>3</sup> lbf ft/ft (Element 74 at Node 11445)  
Minimum value = -26,76\*10<sup>3</sup> lbf ft/ft (Element 75 at Node 14708)

### 3.1.2.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Bending moments M

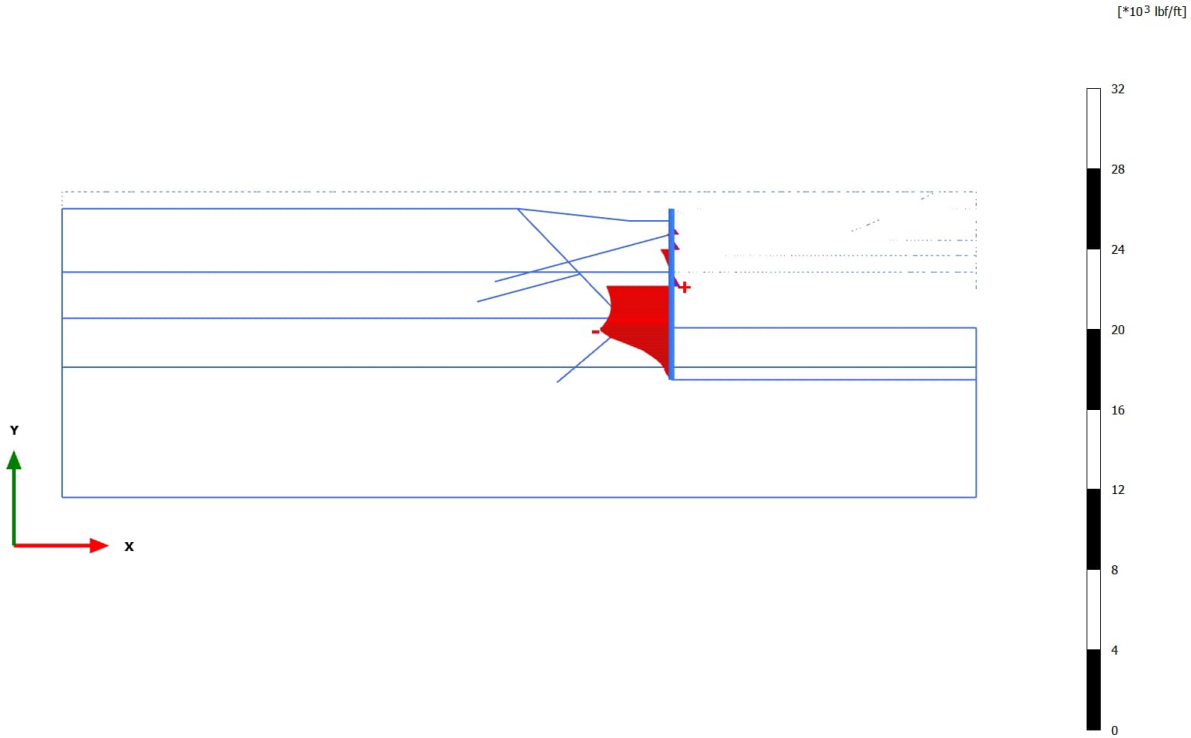


#### **Bending moments M (scaled up $0,500*10^{-3}$ times)**

Maximum value =  $19,06*10^3$  lbf ft/ft (Element 80 at Node 19399)

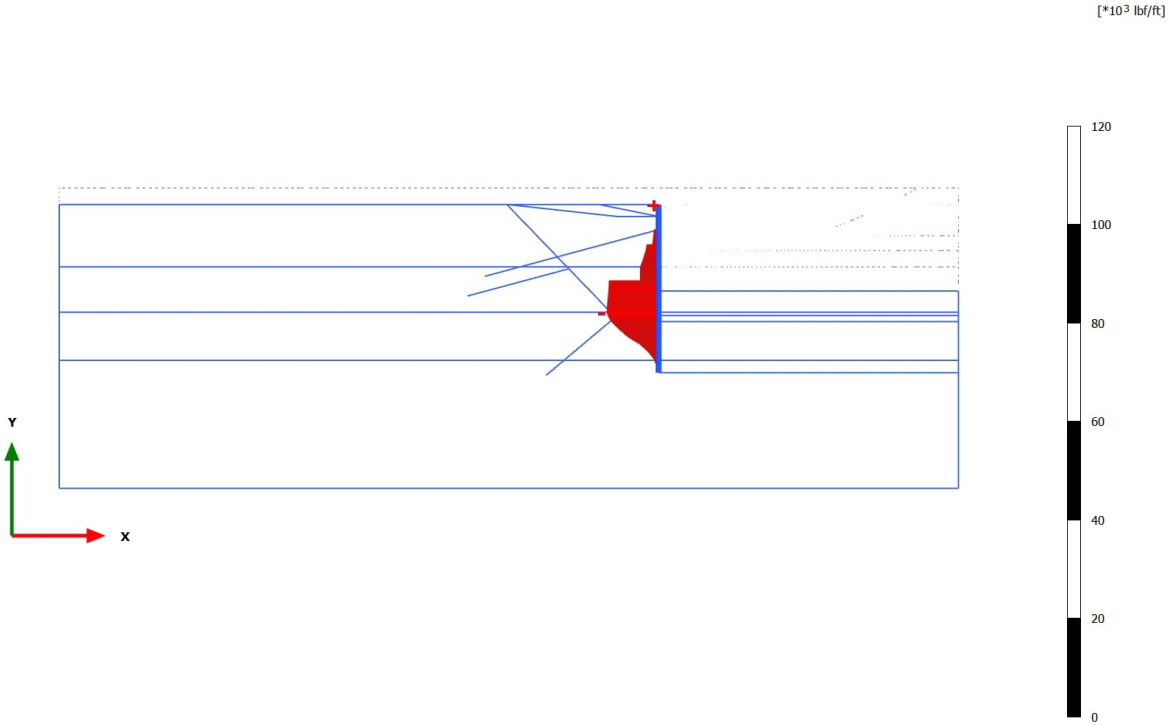
Minimum value =  $-17,22*10^3$  lbf ft/ft (Element 85 at Node 25499)

3.1.2.3.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/211), Axial forces N



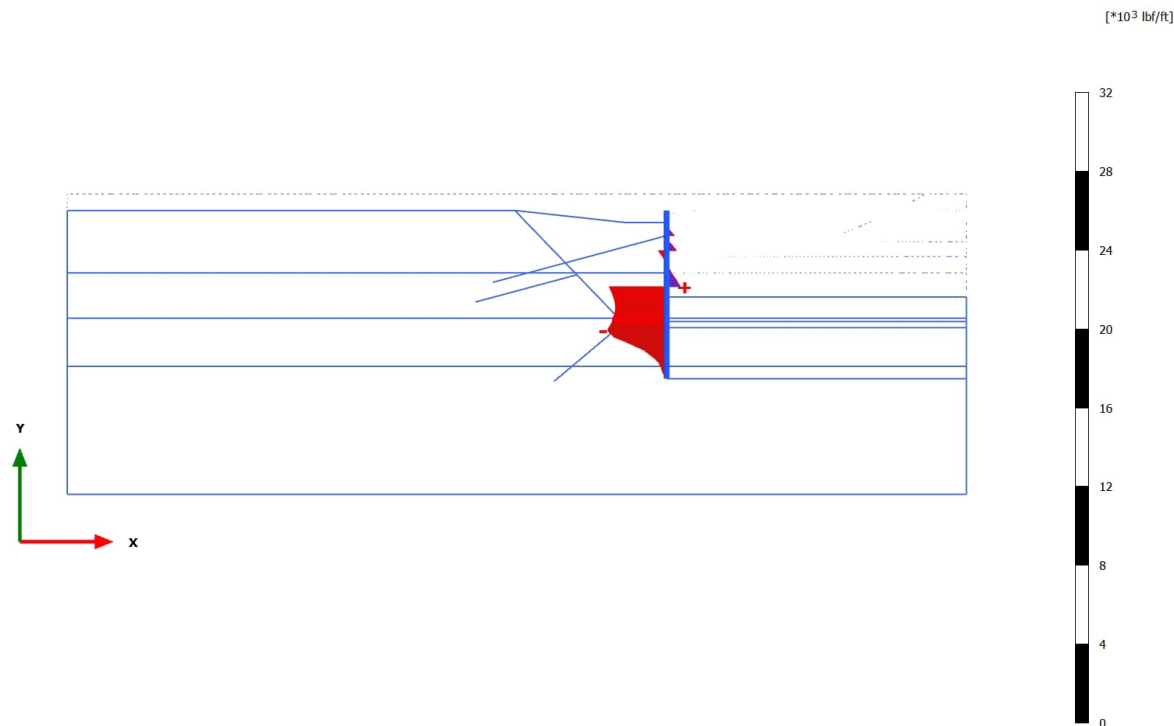
**Axial forces N (scaled up  $2,00*10^{-3}$  times)**  
Maximum value = 1329 lbf/ft (Element 75 at Node 14708)  
Minimum value =  $-11,64*10^3$  lbf/ft (Element 84 at Node 24319)

3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/402), Axial forces N



**Axial forces N (scaled up  $0,500 \cdot 10^{-3}$  times)**  
Maximum value =  $-0,02764$  lbf/ft (Element 66 at Node 4234)  
Minimum value =  $-34,58 \cdot 10^3$  lbf/ft (Element 81 at Node 21814)

### 3.1.2.3.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Axial forces N



**Axial forces N (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 2282 lbf/ft (Element 75 at Node 14708)

Minimum value = -9844 lbf/ft (Element 84 at Node 24319)

3.2.1.1.1 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/211), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	7128	1	100,000	86,100	43,632	0,000	52,359
Element 1-1 (Node-to-node anchor)	31650	2	66,193	77,041	43,632	0,000	52,359
NodeToNodeAnchor\_1\_1	10222	1	100,000	81,100	71,157	0,000	74,912
Element 2-2 (Node-to-node anchor)	31711	2	70,033	73,070	71,157	0,000	74,912
NodeToNodeAnchor\_2\_1	14708	1	100,000	69,100	111,762	0,000	111,762
Element 3-3 (Node-to-node anchor)	31772	2	85,445	56,887	111,762	0,000	111,762

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/402), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	7128	1	100,000	86,100	47,789	0,000	52,359
Element 1-1 (Node-to-node anchor)	31650	2	66,193	77,041	47,789	0,000	52,359
NodeToNodeAnchor\_1\_1	10222	1	100,000	81,100	84,863	0,000	84,863
Element 2-2 (Node-to-node anchor)	31711	2	70,033	73,070	84,863	0,000	84,863
NodeToNodeAnchor\_2\_1	14708	1	100,000	69,100	194,067	0,000	194,067
Element 3-3 (Node-to-node anchor)	31772	2	85,445	56,887	194,067	0,000	194,067

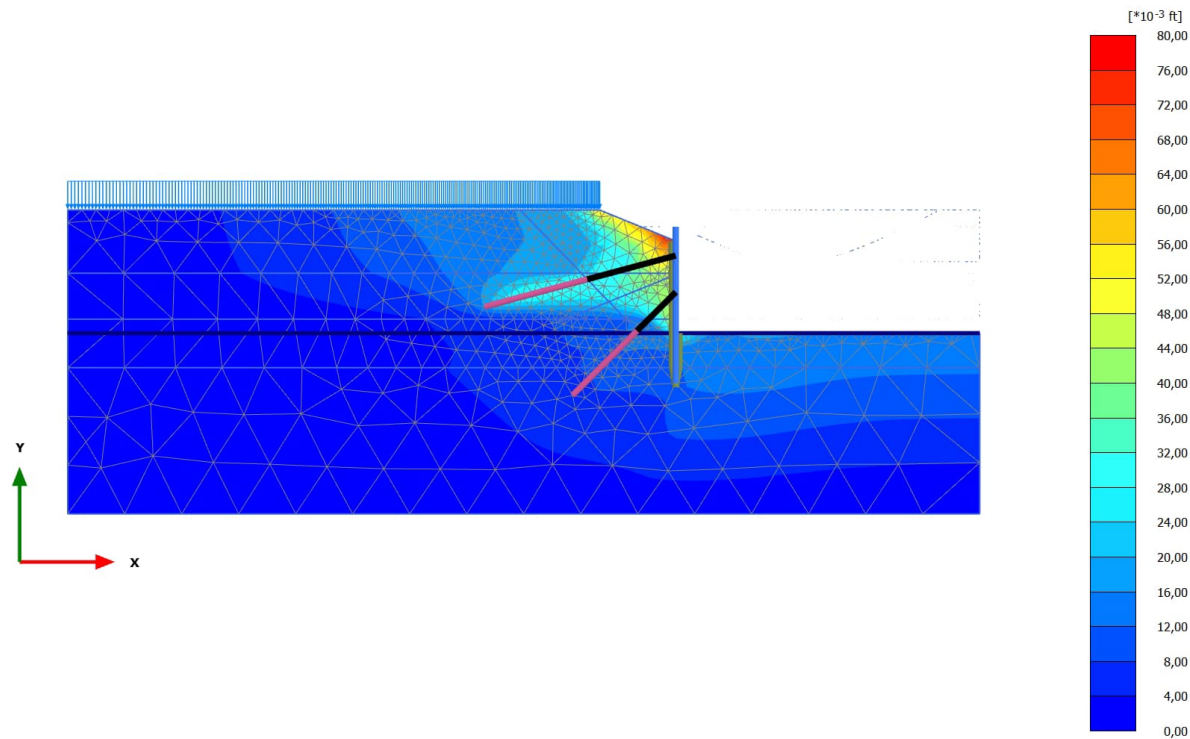
### 3.2.1.1.3 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/1640), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	7128	1	100,000	86,100	43,686	0,000	52,359
Element 1-1 (Node-to-node anchor)	31650	2	66,193	77,041	43,686	0,000	52,359
NodeToNodeAnchor\_1\_1	10222	1	100,000	81,100	70,897	0,000	74,912
Element 2-2 (Node-to-node anchor)	31711	2	70,033	73,070	70,897	0,000	74,912
NodeToNodeAnchor\_2\_1	14708	1	100,000	69,100	110,879	0,000	111,762
Element 3-3 (Node-to-node anchor)	31772	2	85,445	56,887	110,879	0,000	111,762

# PLAXIS Report

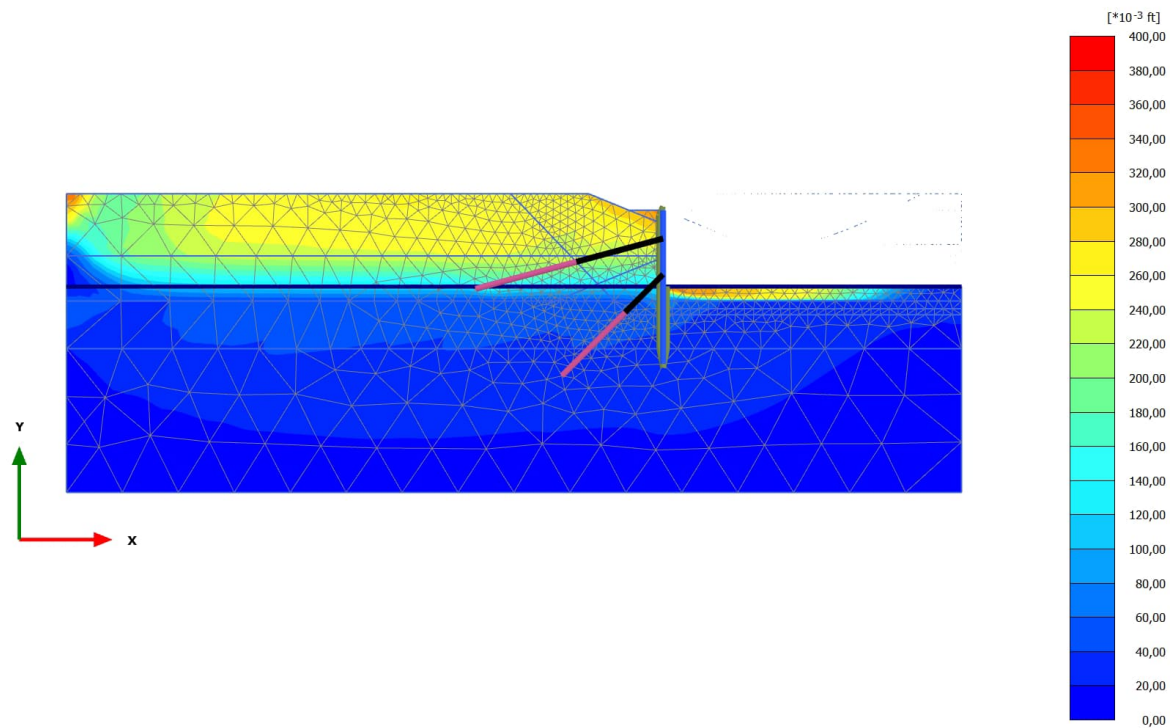
**Plaxis Model Wingwall 4\_Section 3: WW4-3  
STA. 6+33.49 to 6+39.19**

### 2.1.1.1.1 Calculation results, Exc. to bottom [Phase\_10] (10/249), Total displacements $|u|$



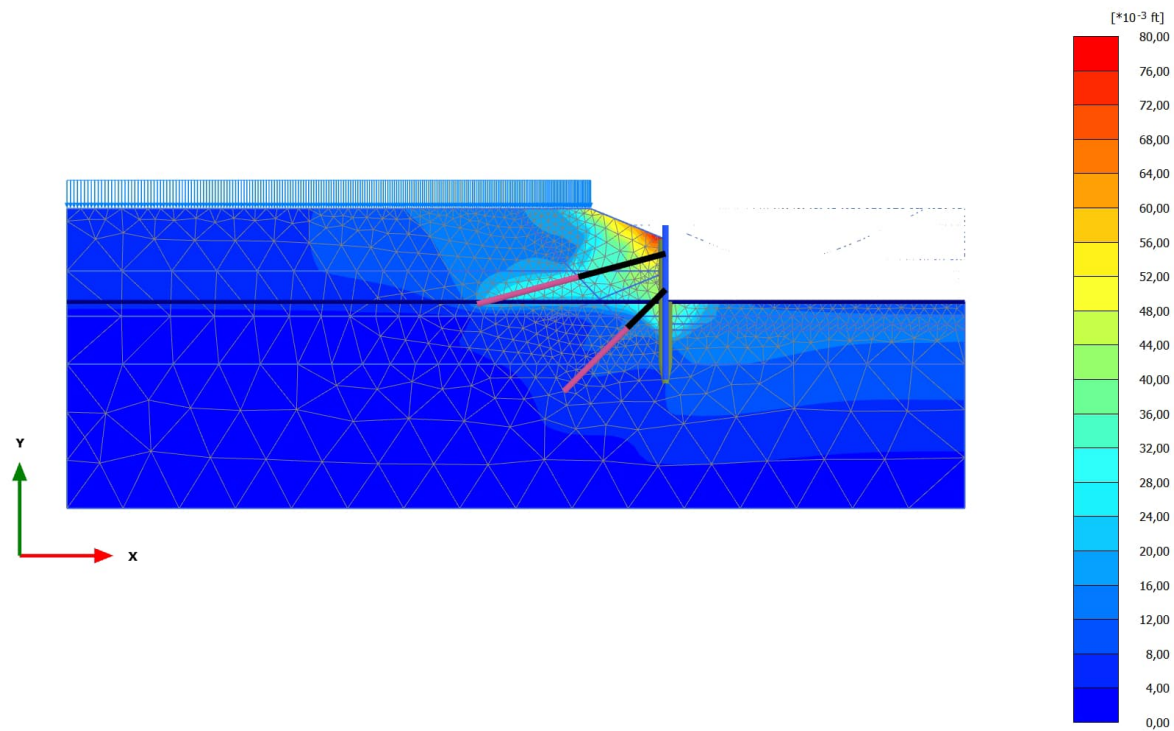
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,07760 ft (Element 238 at Node 4417)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/390), Total displacements  $|u|$



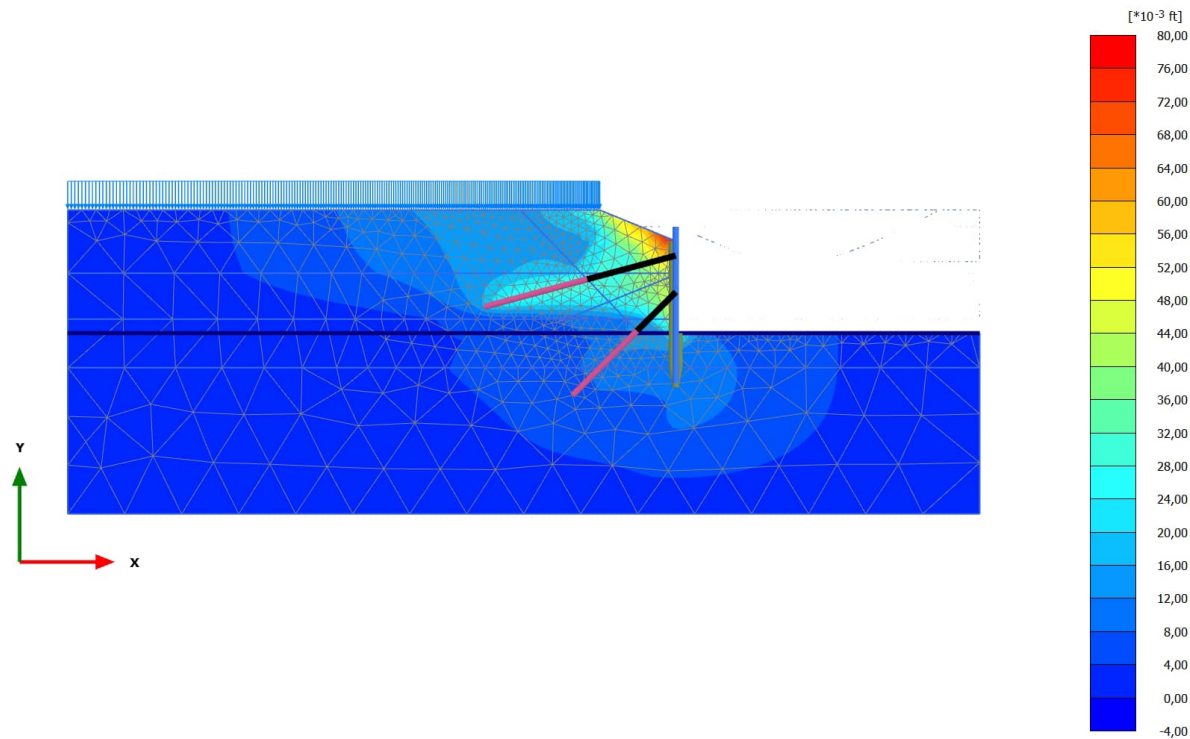
**Total displacements  $|u|$  (scaled up 20,0 times)**  
Maximum value = 0,3971 ft (Element 1753 at Node 11334)

### 2.1.1.1.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/602), Total displacements $|u|$



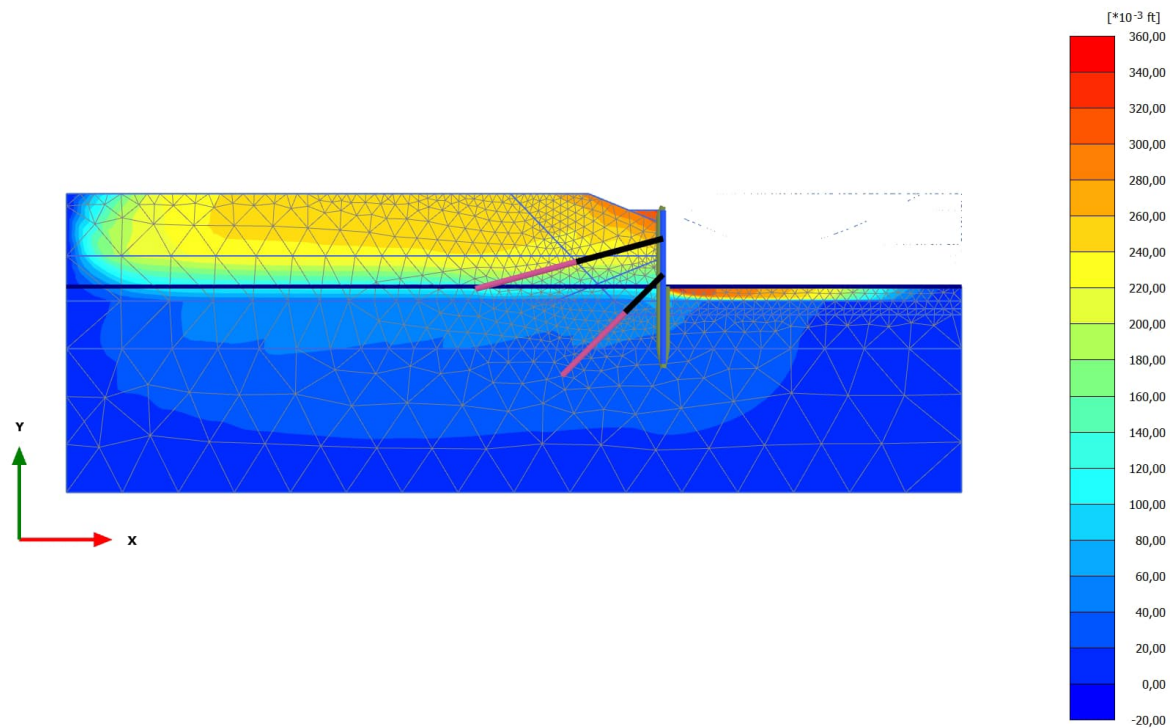
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,07914 ft (Element 238 at Node 4417)

### 2.1.1.2.1 Calculation results, Exc. to bottom [Phase\_10] (10/249), Total displacements $u_x$



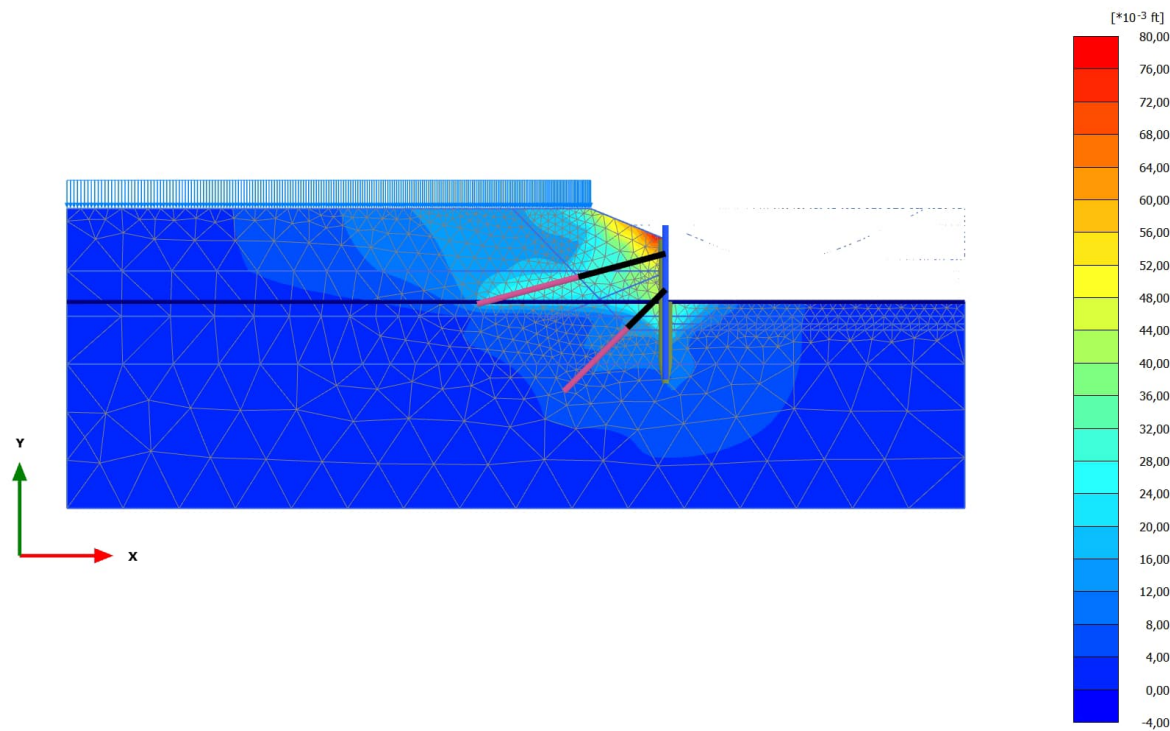
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,07750 ft (Element 210 at Node 5396)  
Minimum value = 0,000 ft (Element 583 at Node 20617)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/390), Total displacements  $u_x$



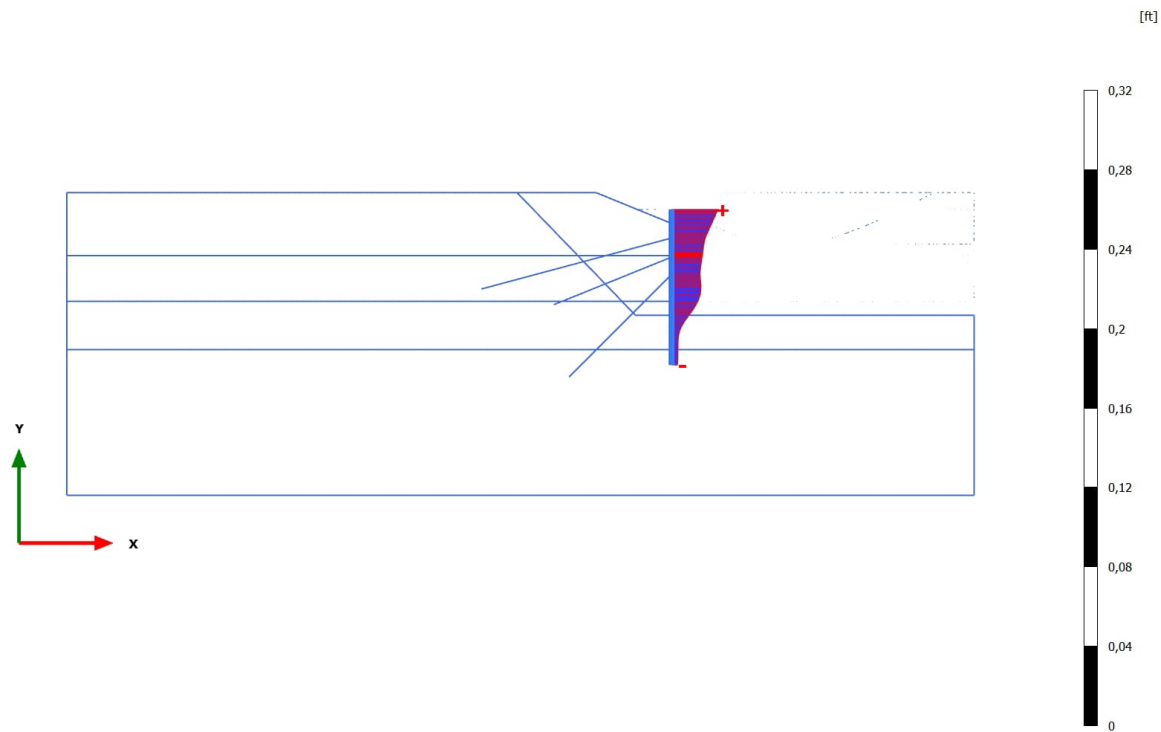
**Total displacements  $u_x$  (scaled up 20,0 times)**  
Maximum value = 0,3513 ft (Element 1753 at Node 11334)  
Minimum value = 0,000 ft (Element 583 at Node 20617)

### 2.1.1.2.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/602), Total displacements $u_x$



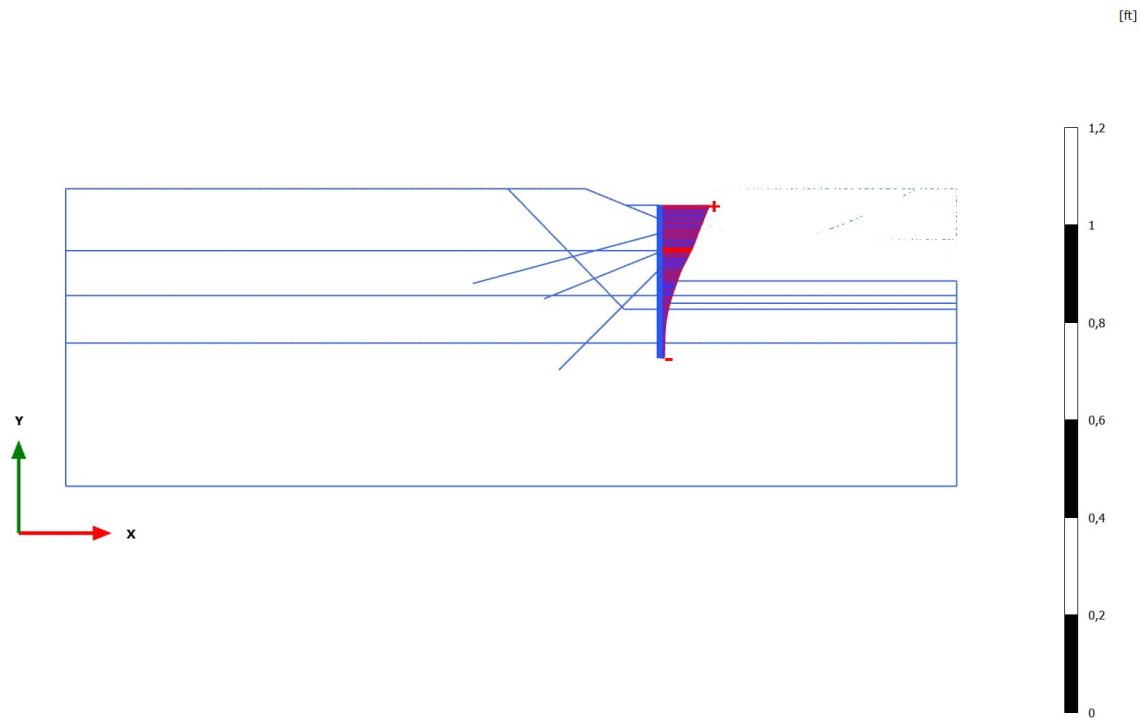
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,07898 ft (Element 210 at Node 5396)  
Minimum value = 0,000 ft (Element 583 at Node 20617)

### 3.1.1.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/249), Total displacements $|u|$



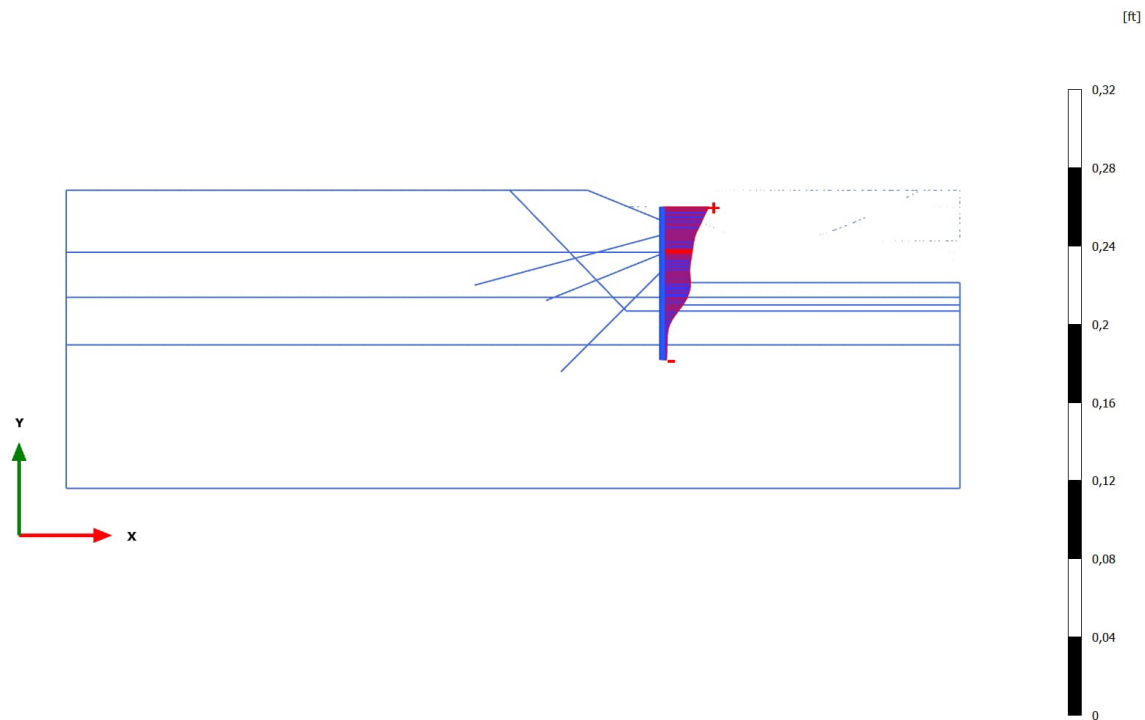
**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,07701 ft (Element 64 at Node 2827)

3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/390), Total displacements |u|



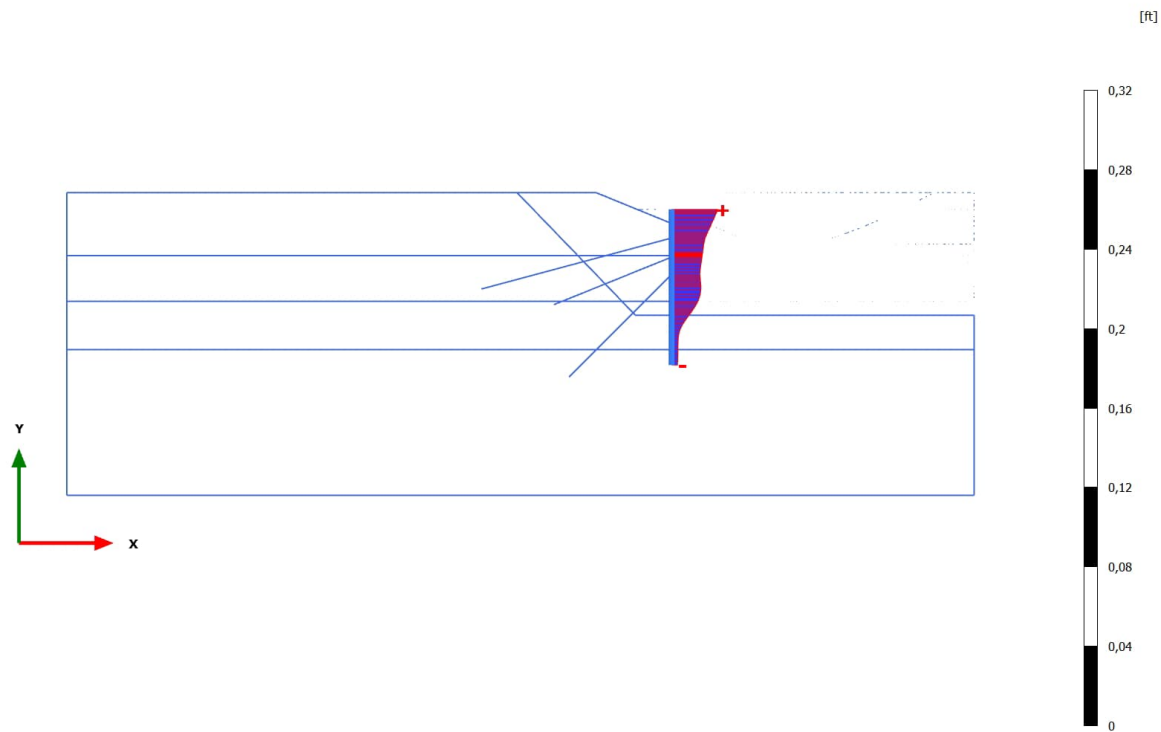
**Total displacements |u| (scaled up 50,0 times)**  
Maximum value = 0,3378 ft (Element 64 at Node 2827)

### 3.1.1.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/602), Total displacements |u|



**Total displacements |u| (scaled up 200 times)**  
Maximum value = 0,07880 ft (Element 64 at Node 2827)

### 3.1.1.1.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/249), Total displacements $u_x$

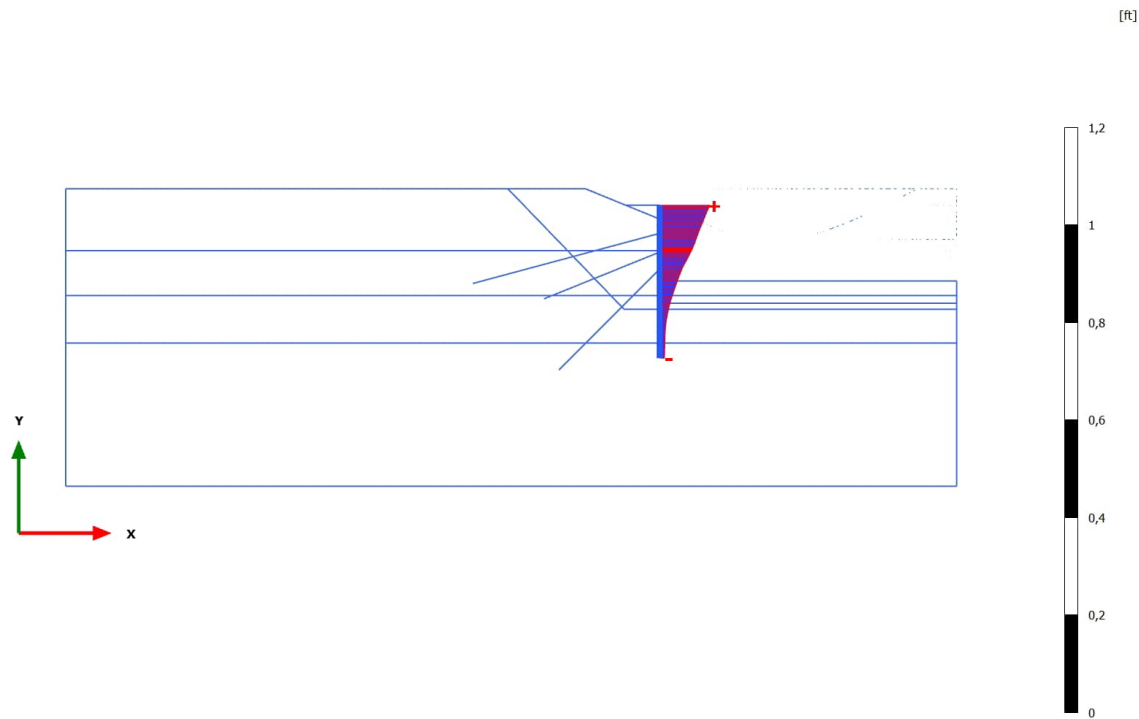


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,07684 ft (Element 64 at Node 2827)

Minimum value =  $9,749 \cdot 10^{-3}$  ft (Element 82 at Node 16286)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/390), Total displacements  $u_x$

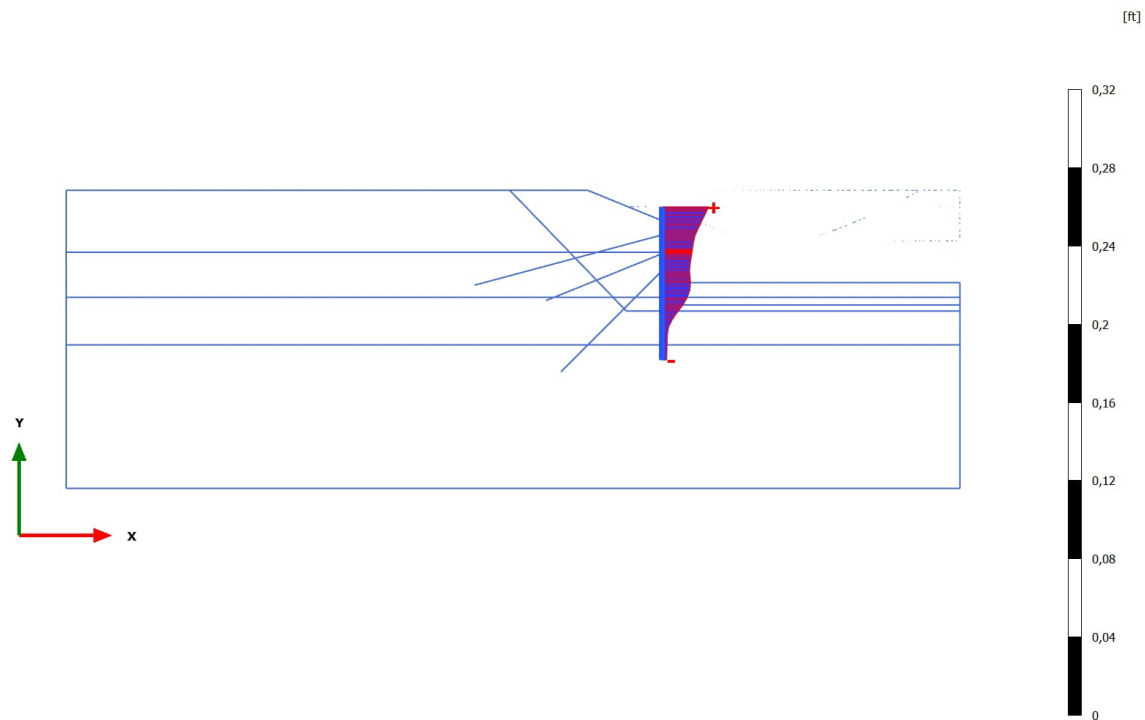


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,3375 ft (Element 64 at Node 2827)

Minimum value = 0,03306 ft (Element 82 at Node 16286)

### 3.1.1.1.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/602), Total displacements $u_x$

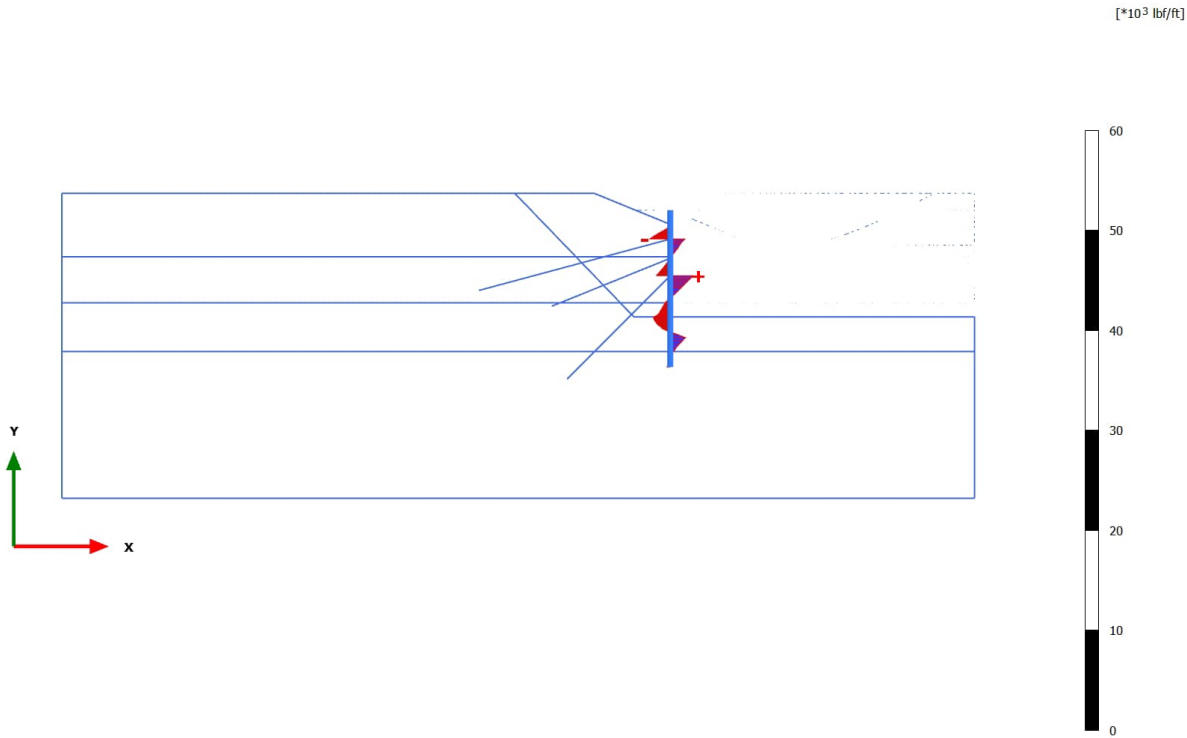


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,07866 ft (Element 64 at Node 2827)

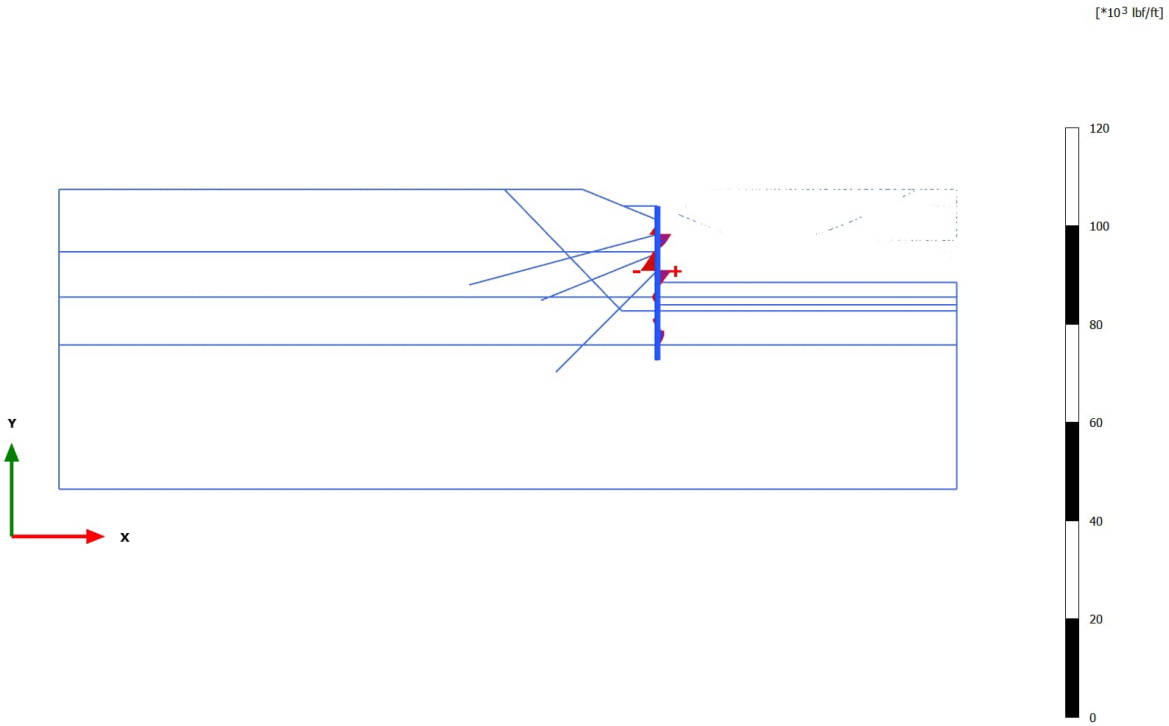
Minimum value =  $7,813 \cdot 10^{-3}$  ft (Element 82 at Node 16286)

3.1.2.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/249), Shear forces Q



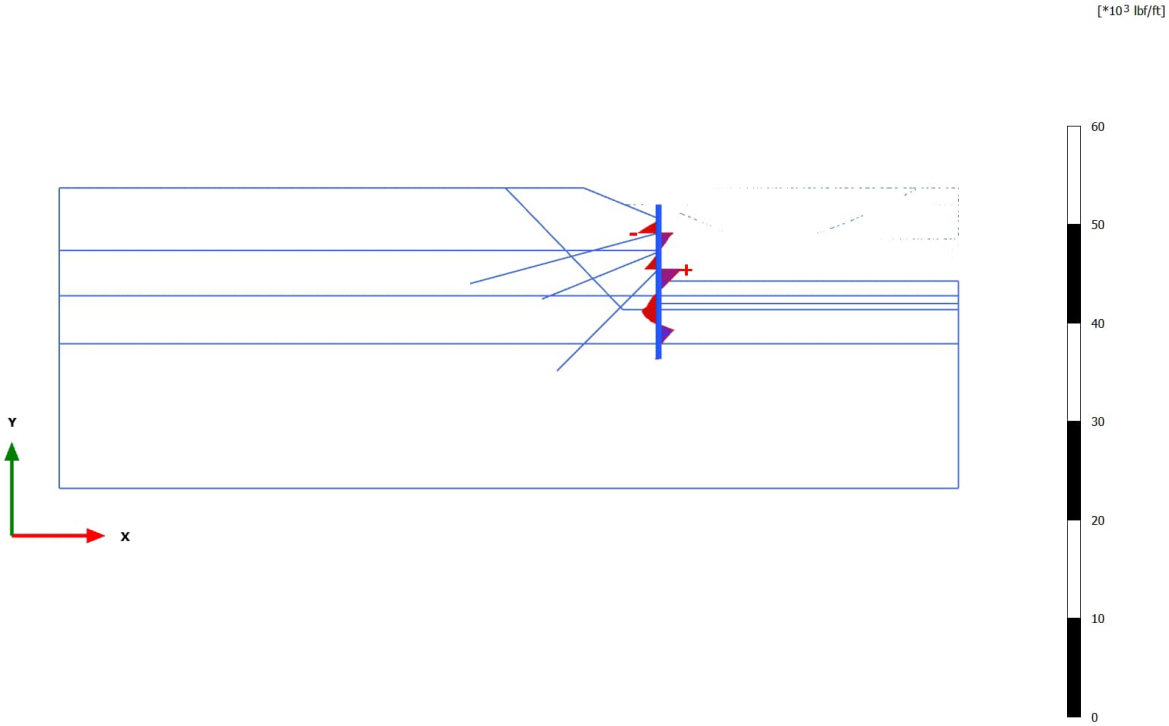
**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**  
Maximum value = 7617 lbf/ft (Element 74 at Node 9946)  
Minimum value = -6785 lbf/ft (Element 67 at Node 4346)

3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/390), Shear forces Q



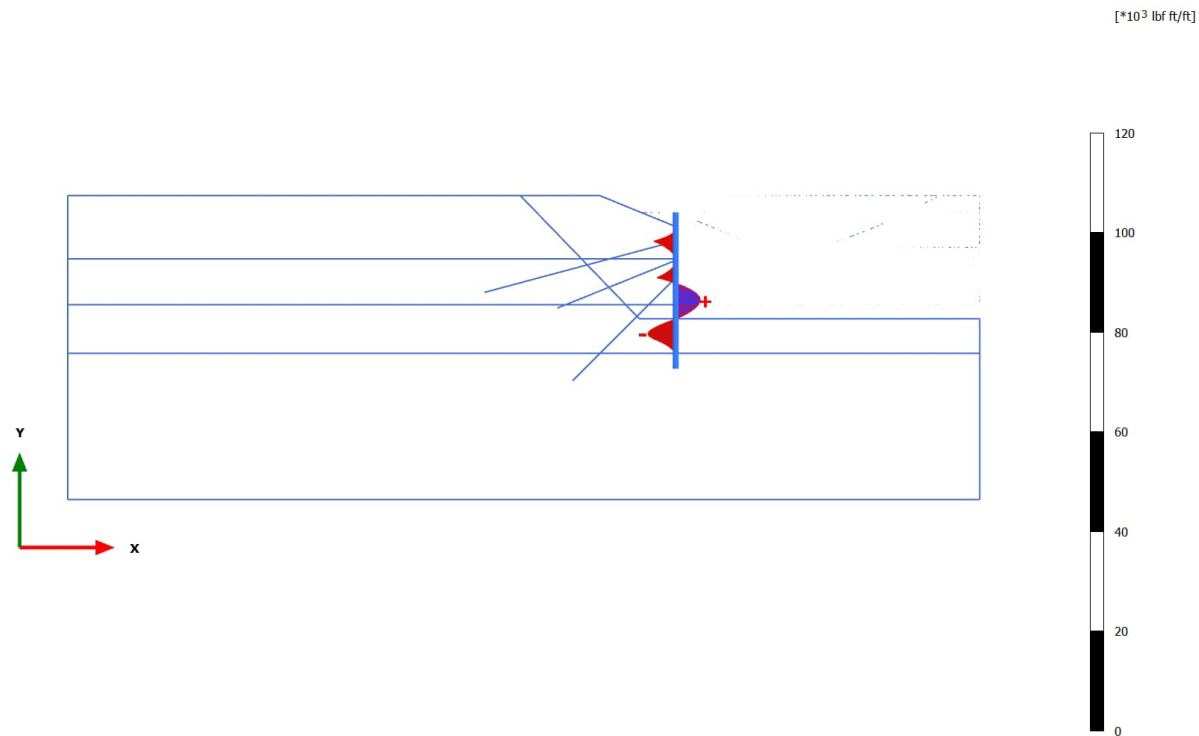
**Shear forces Q (scaled up  $0,500 \cdot 10^{-3}$  times)**  
Maximum value = 9021 lbf/ft (Element 74 at Node 9946)  
Minimum value =  $-10,89 \cdot 10^3$  lbf/ft (Element 73 at Node 9946)

3.1.2.1.3 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_18] (18/602), Shear forces Q



**Shear forces Q (scaled up  $1,00 \cdot 10^{-3}$  times)**  
Maximum value = 7598 lbf/ft (Element 74 at Node 9946)  
Minimum value = -6820 lbf/ft (Element 67 at Node 4346)

### 3.1.2.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/249), Bending moments M

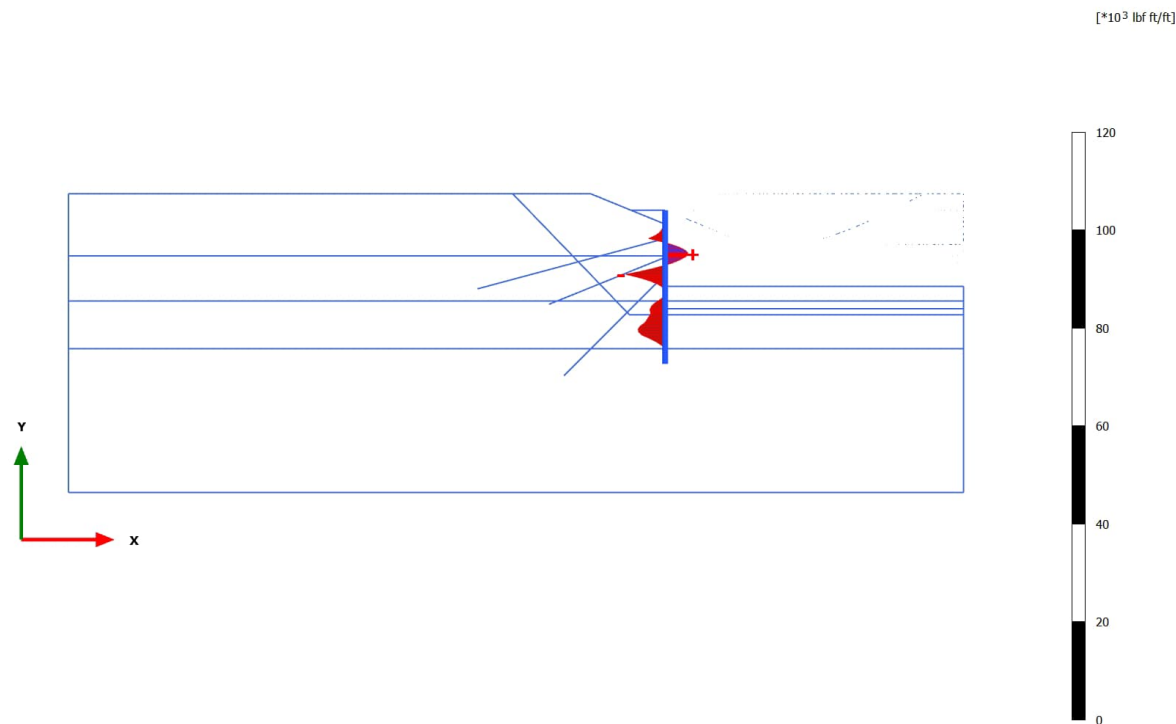


**Bending moments M (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value =  $16,23 \cdot 10^3$  lbf ft/ft (Element 76 at Node 11339)

Minimum value =  $-18,39 \cdot 10^3$  lbf ft/ft (Element 80 at Node 14920)

### 3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/390), Bending moments M

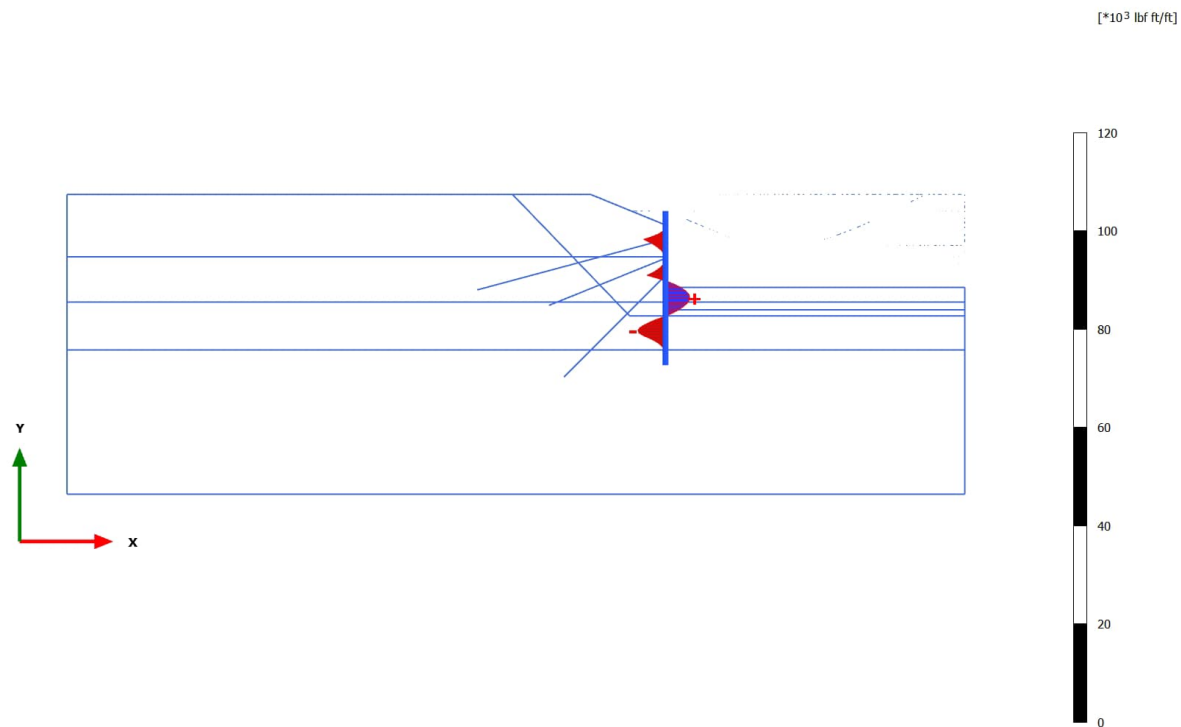


**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 15,22\*10<sup>3</sup> lbf ft/ft (Element 70 at Node 6333)

Minimum value = -26,33\*10<sup>3</sup> lbf ft/ft (Element 74 at Node 9946)

### 3.1.2.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/602), Bending moments M

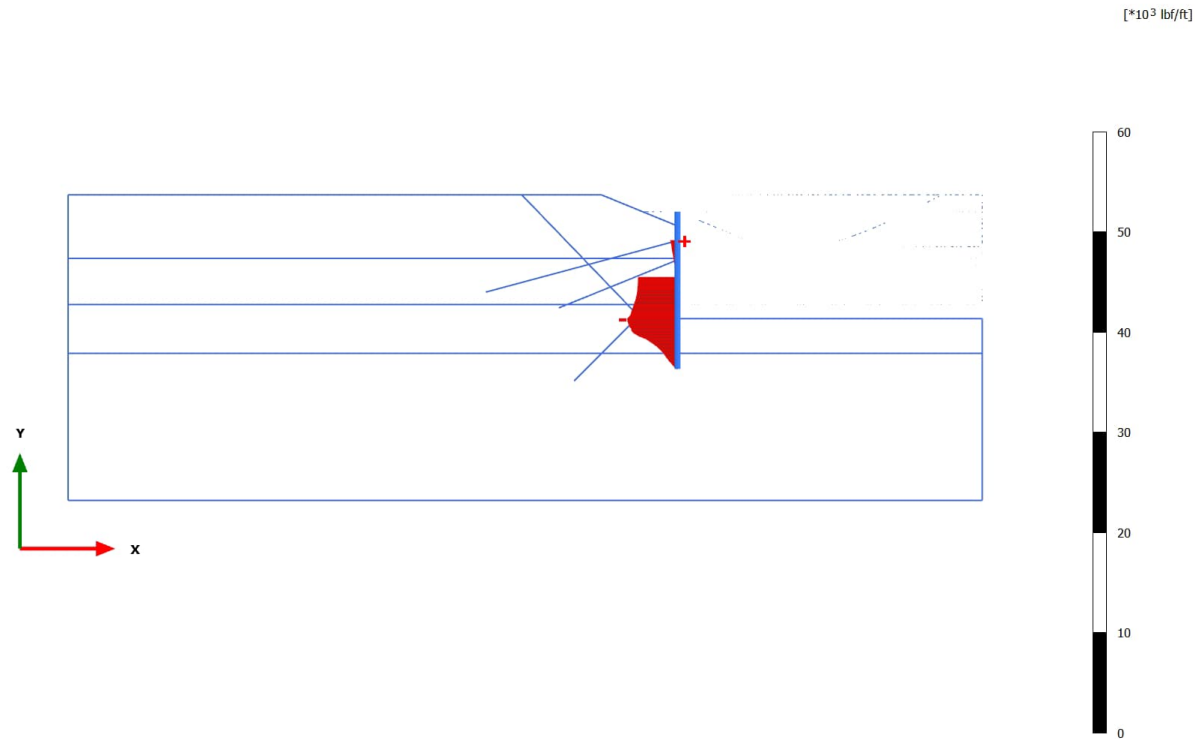


**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 16,28\*10<sup>3</sup> lbf ft/ft (Element 76 at Node 11339)

Minimum value = -18,46\*10<sup>3</sup> lbf ft/ft (Element 80 at Node 14920)

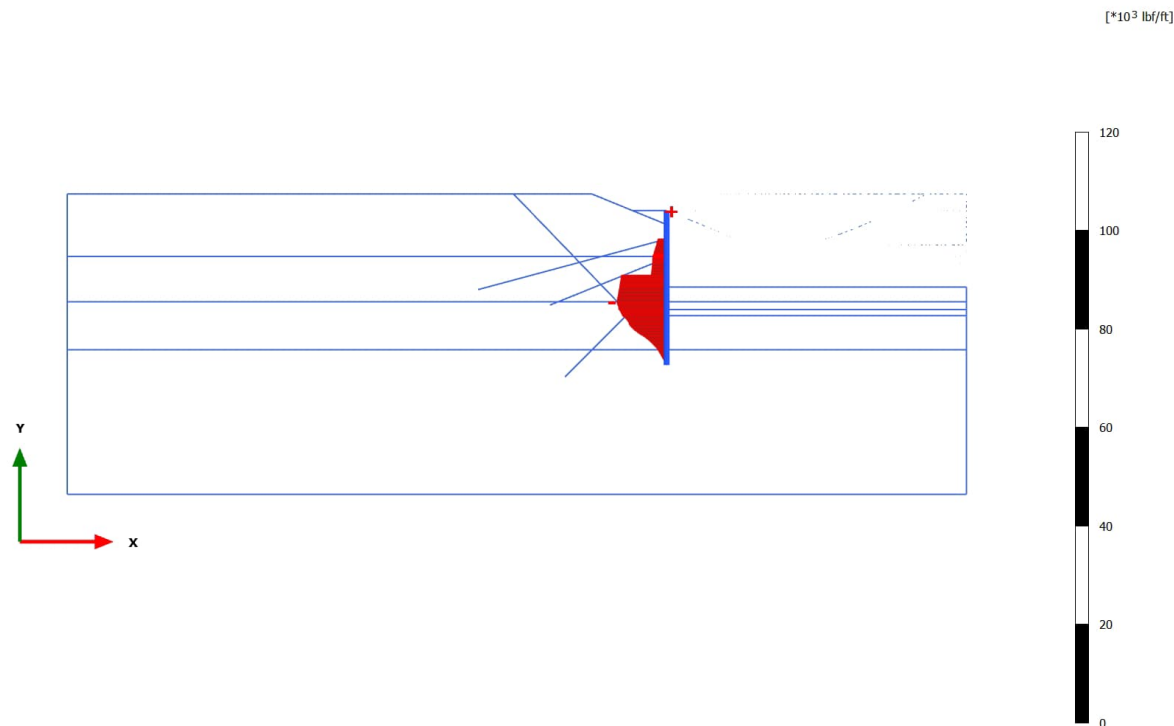
### 3.1.2.3.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/249), Axial forces N



**Axial forces N (scaled up  $1,00 \cdot 10^{-3}$  times)**

Maximum value = 924,8 lbf/ft (Element 67 at Node 4346)  
Minimum value =  $-16,39 \cdot 10^3$  lbf/ft (Element 79 at Node 14110)

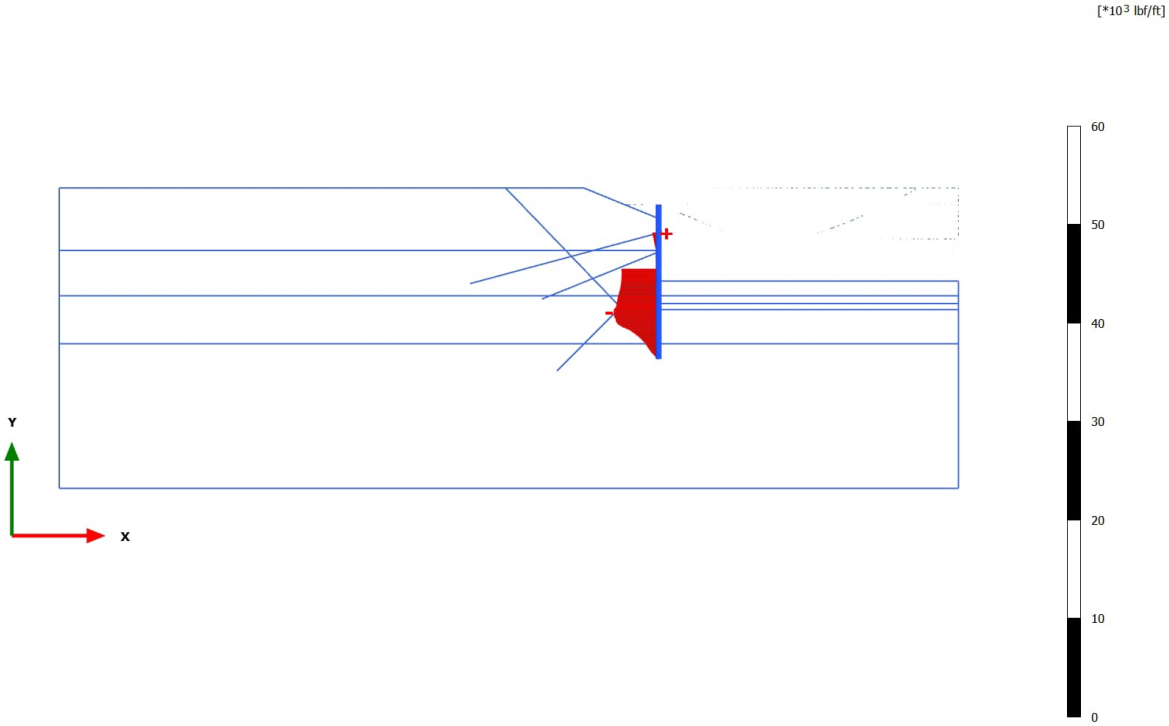
### 3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/390), Axial forces N



**Axial forces N (scaled up  $0,500*10^{-3}$  times)**

Maximum value =  $0,01404 \text{ lbf/ft}$  (Element 64 at Node 2827)  
Minimum value =  $-33,20*10^3 \text{ lbf/ft}$  (Element 76 at Node 12612)

3.1.2.3.3 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_18] (18/602), Axial forces N



**Axial forces N (scaled up  $1,00*10^{-3}$  times)**  
Maximum value = 1086 lbf/ft (Element 67 at Node 4346)  
Minimum value =  $-14,88*10^3$  lbf/ft (Element 79 at Node 14111)

3.2.1.1.1 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/249), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	4346	1	100,000	85,000	72,892	0,000	75,350
Element 1-1 (Node-to-node anchor)	20698	2	70,904	77,204	72,892	0,000	75,350
NodeToNodeAnchor\_1\_1	9946	1	100,000	73,000	104,097	0,000	104,097
Element 3-3 (Node-to-node anchor)	20772	2	87,264	60,262	104,097	0,000	104,097

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/390), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	4346	1	100,000	85,000	88,056	0,000	88,056
Element 1-1 (Node-to-node anchor)	20698	2	70,904	77,204	88,056	0,000	88,056
NodeToNodeAnchor\_1\_1	9946	1	100,000	73,000	169,018	0,000	169,018
Element 3-3 (Node-to-node anchor)	20772	2	87,264	60,262	169,018	0,000	169,018

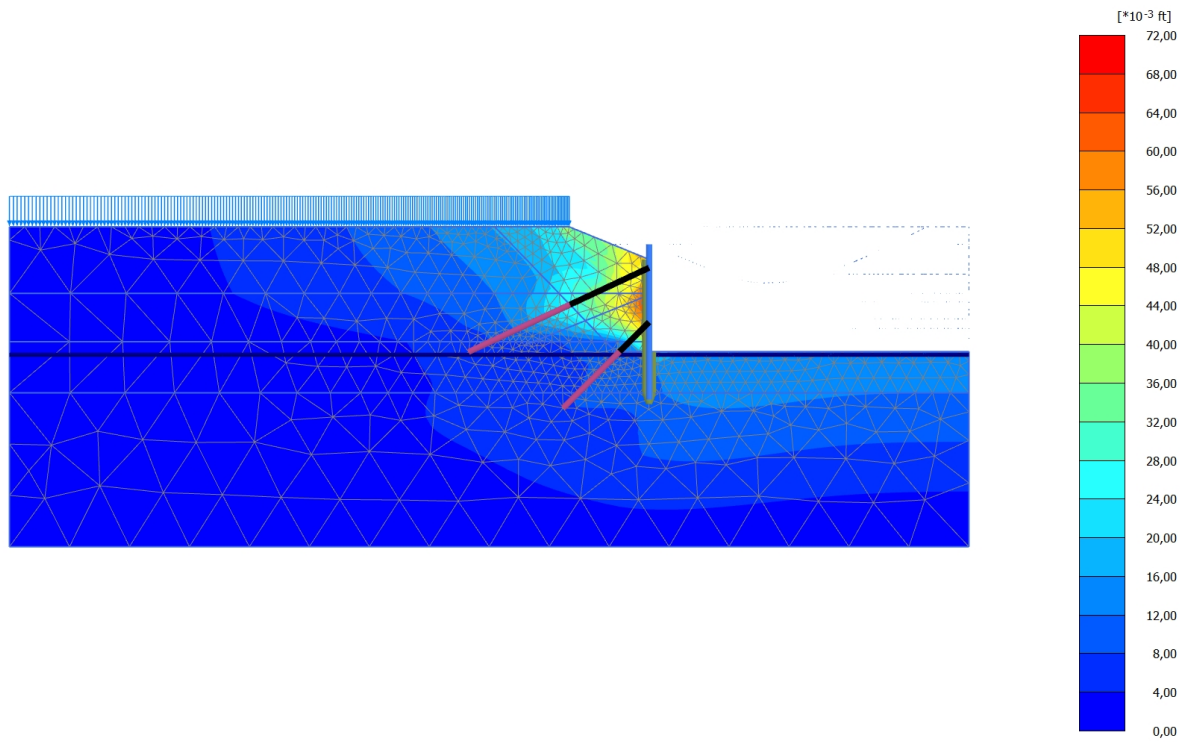
3.2.1.1.3 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/602), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	4346	1	100,000	85,000	72,753	0,000	75,350
Element 1-1 (Node-to-node anchor)	20698	2	70,904	77,204	72,753	0,000	75,350
NodeToNodeAnchor\_1\_1	9946	1	100,000	73,000	103,434	0,000	104,097
Element 3-3 (Node-to-node anchor)	20772	2	87,264	60,262	103,434	0,000	104,097

# PLAXIS Report

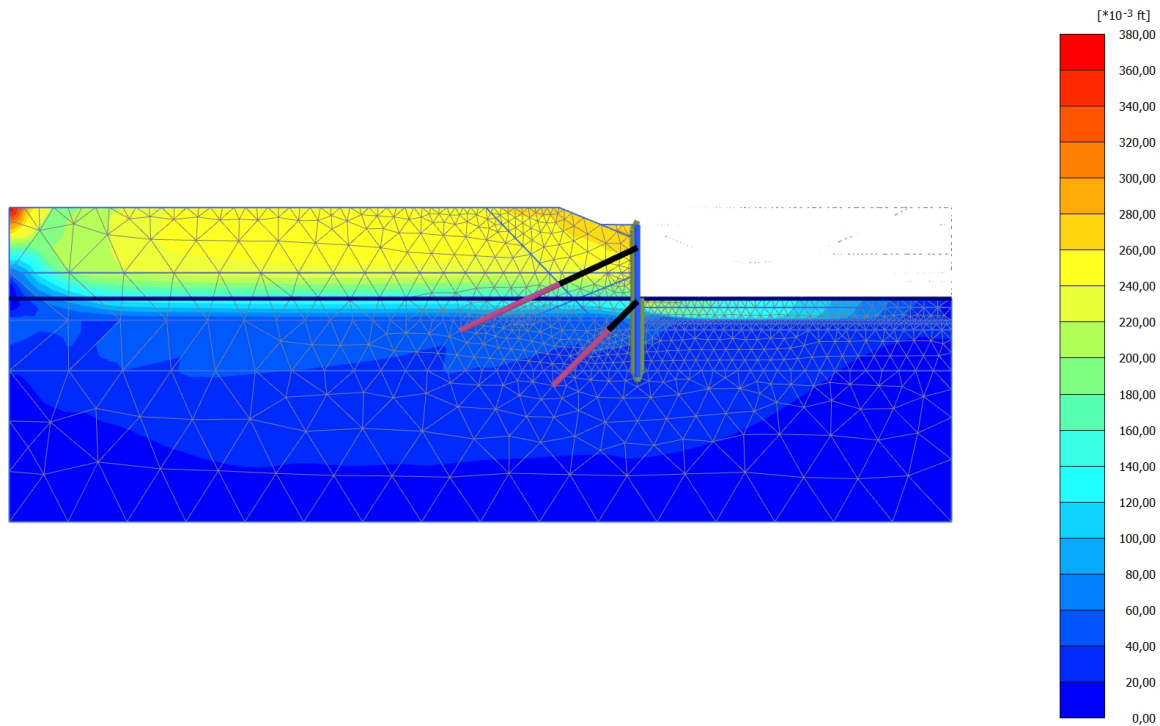
**Plaxis Model Wingwall 4\_Section 4: WW4-4  
STA. 6+39.19 to 6+56.36**

### 2.1.1.1.1 Calculation results, Exc. to bottom [Phase\_10] (10/174), Total displacements $|u|$



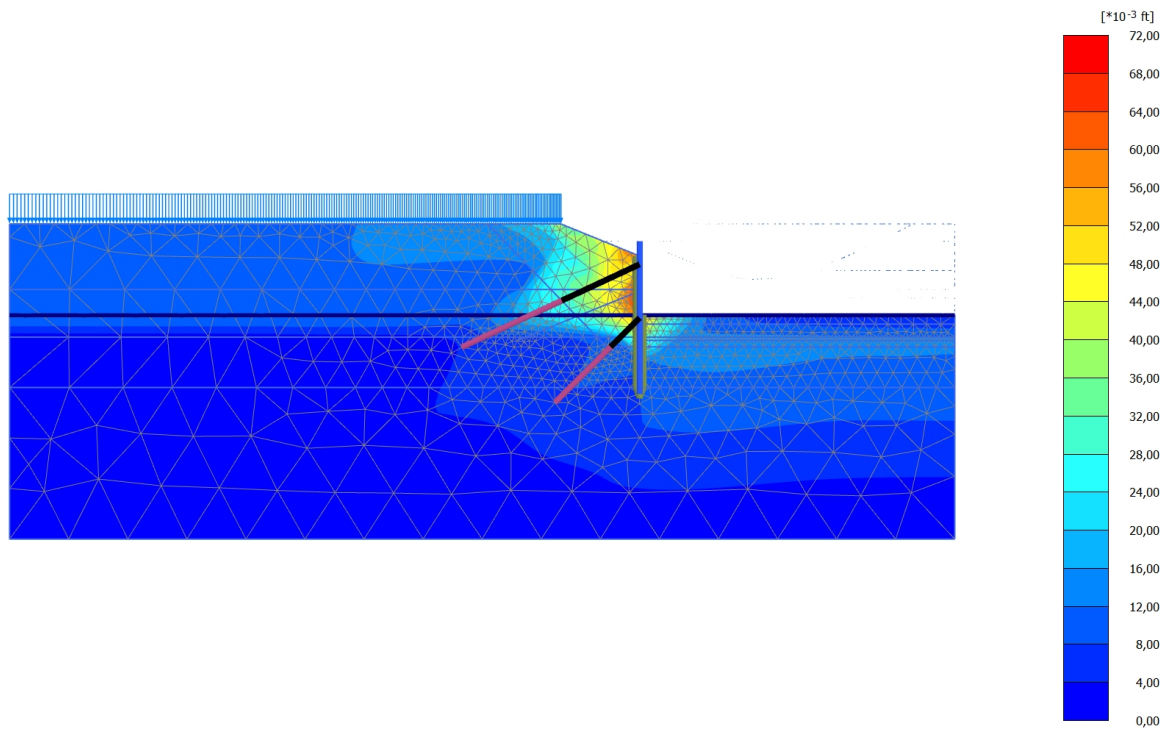
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,07045 ft (Element 878 at Node 1929)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/283), Total displacements  $|u|$



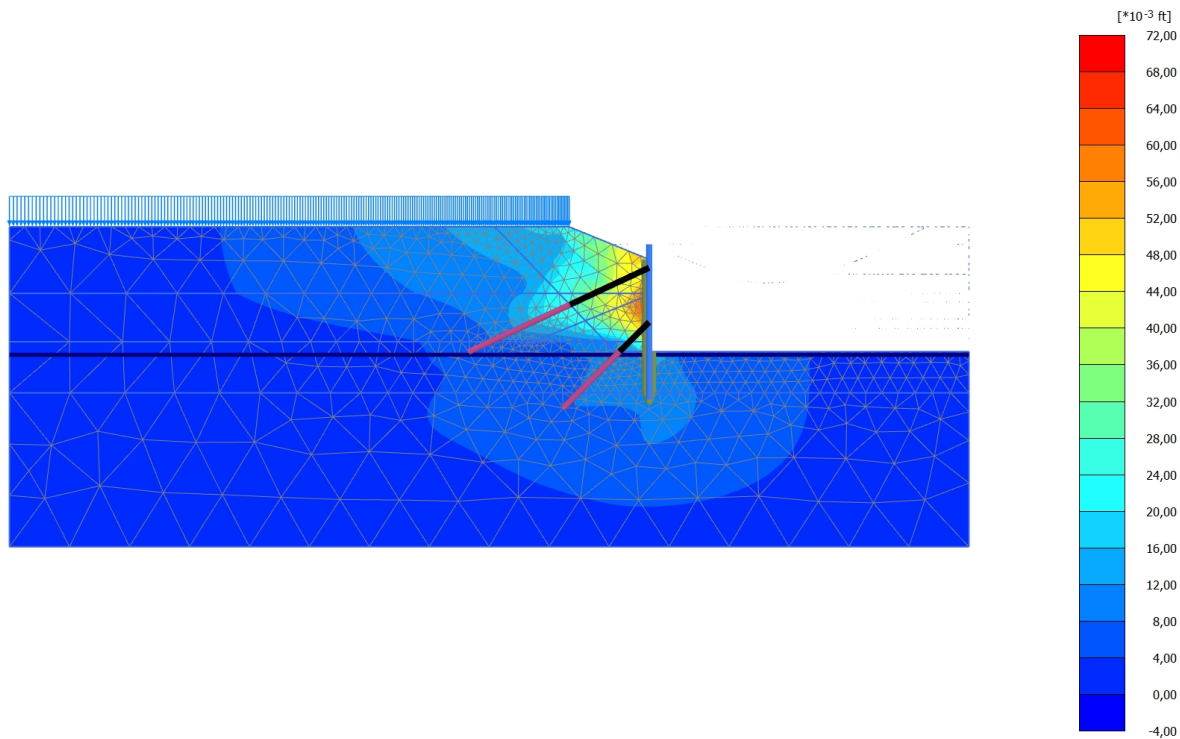
**Total displacements  $|u|$  (scaled up 20,0 times)**  
Maximum value = 0,3708 ft (Element 474 at Node 5716)

### 2.1.1.1.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/296), Total displacements $|u|$



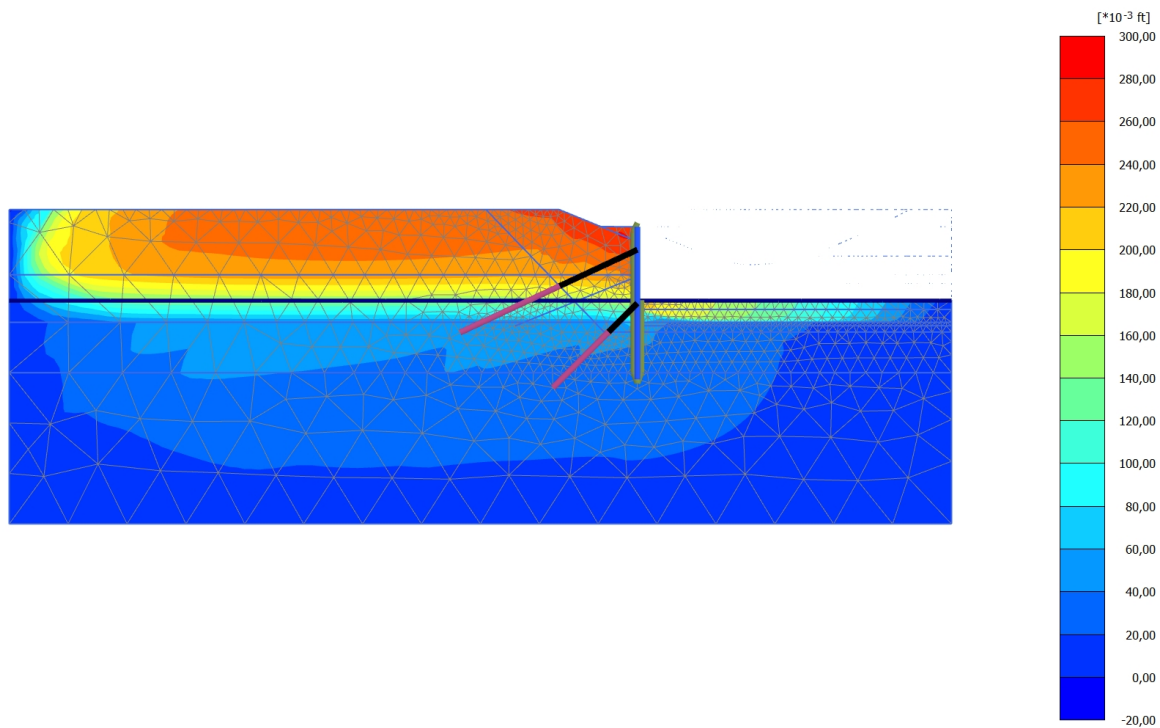
**Total displacements  $|u|$  (scaled up 100 times)**  
Maximum value = 0,07144 ft (Element 878 at Node 1929)

2.1.1.2.1 Calculation results, Exc. to bottom [Phase\_10] (10/174), Total displacements  $u_x$



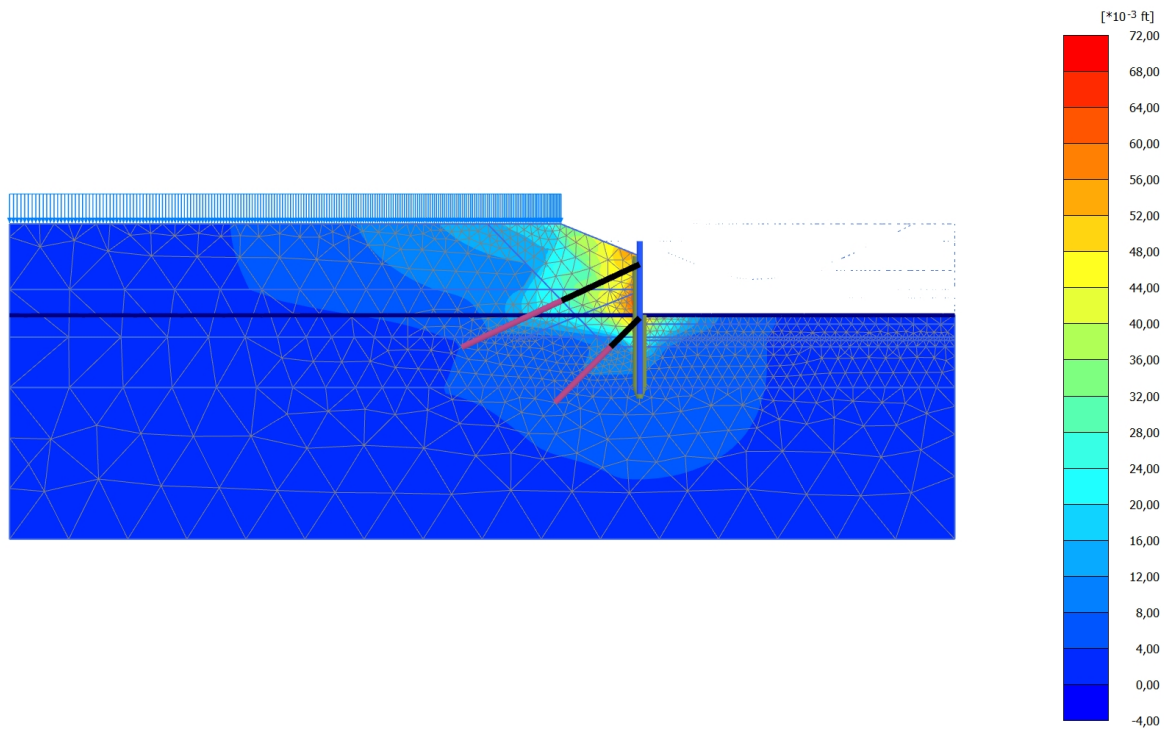
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,06937 ft (Element 1269 at Node 2594)  
Minimum value = 0,000 ft (Element 432 at Node 5768)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/283), Total displacements  $u_x$



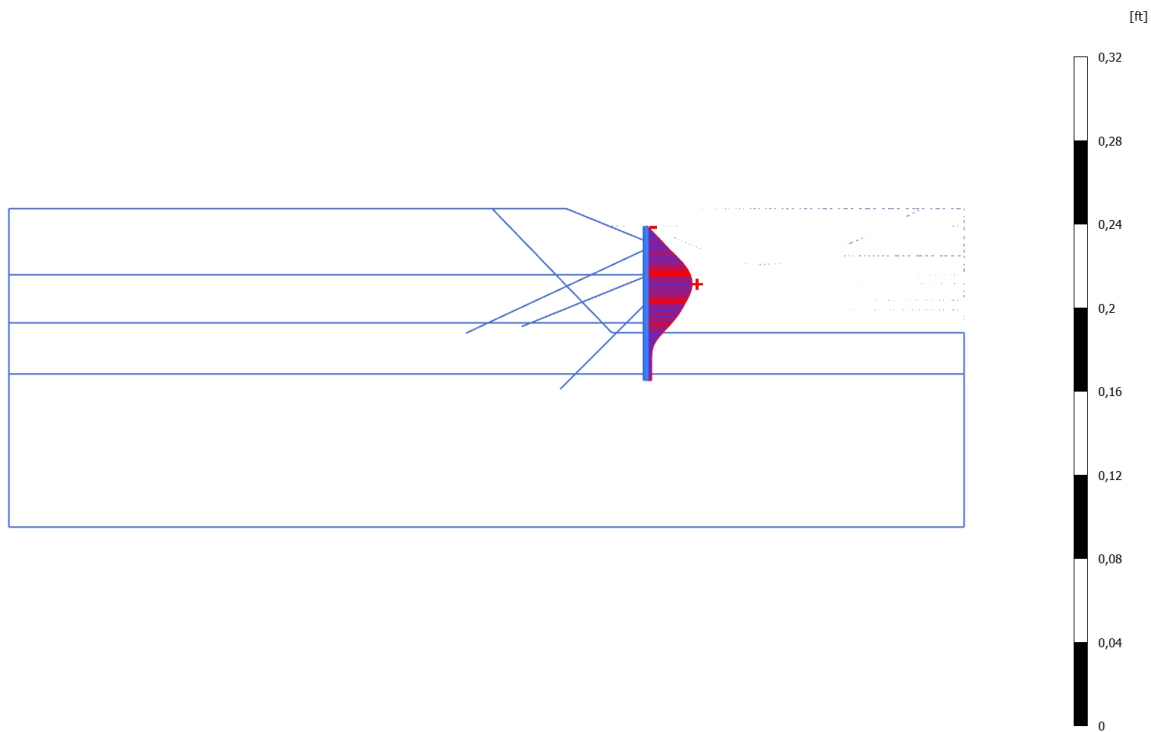
**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2829 ft (Element 168 at Node 1091)  
Minimum value = -0,4814\*10<sup>-3</sup> ft (Element 474 at Node 5714)

### 2.1.1.2.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/296), Total displacements $u_x$



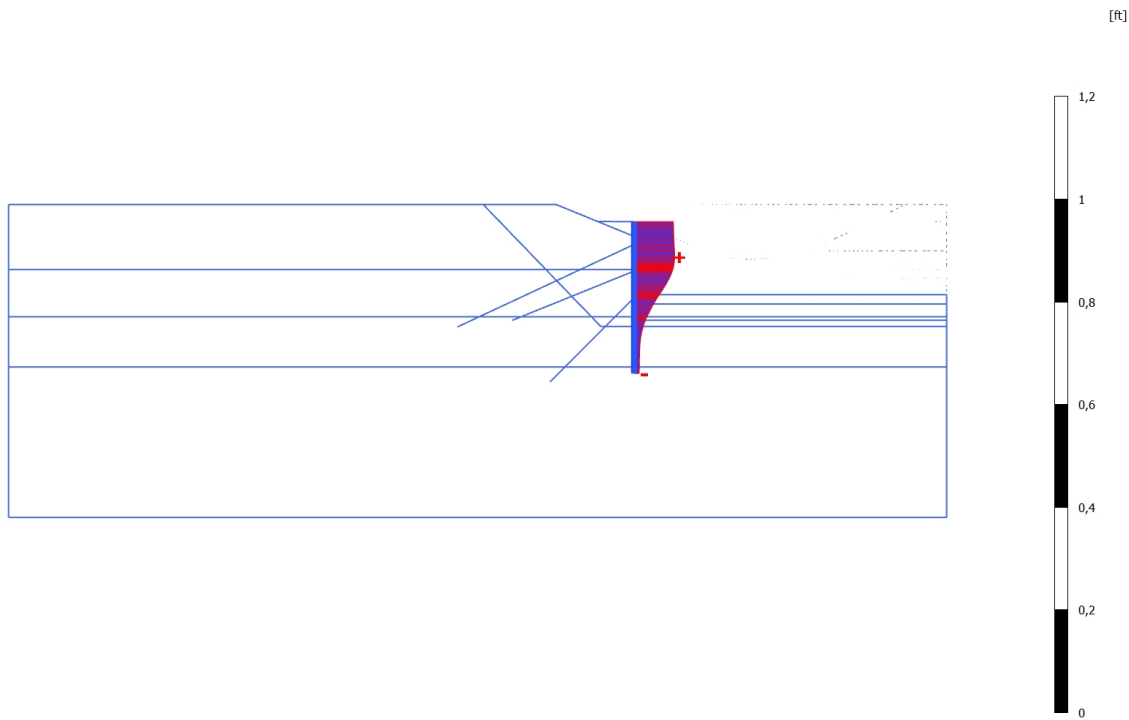
**Total displacements  $u_x$  (scaled up 100 times)**  
Maximum value = 0,06964 ft (Element 1269 at Node 2594)  
Minimum value = 0,000 ft (Element 432 at Node 5768)

### 3.1.1.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/174), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,07303 ft (Element 71 at Node 3320)

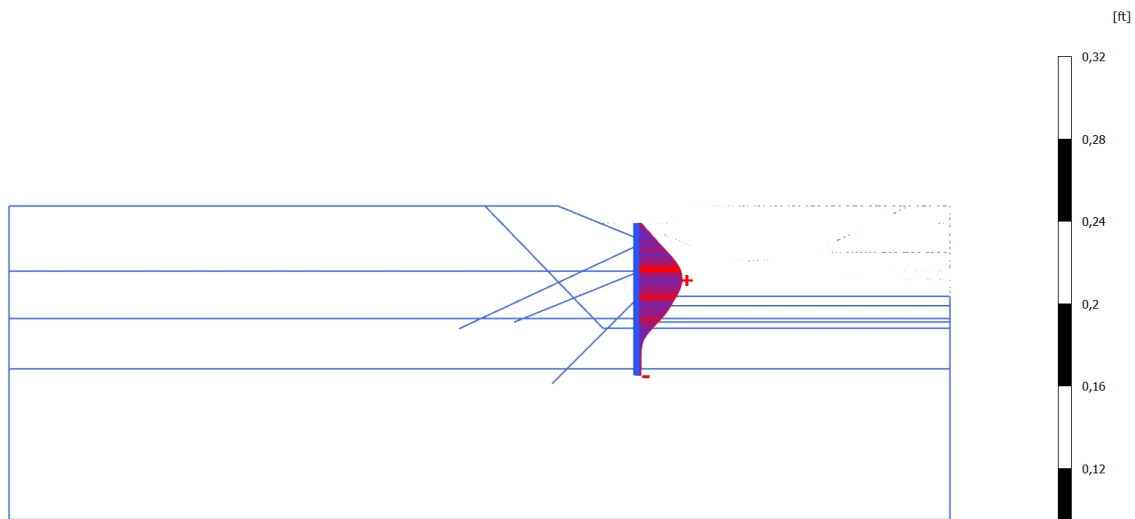
3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/283), Total displacements |u|



**Total displacements |u| (scaled up 50,0 times)**

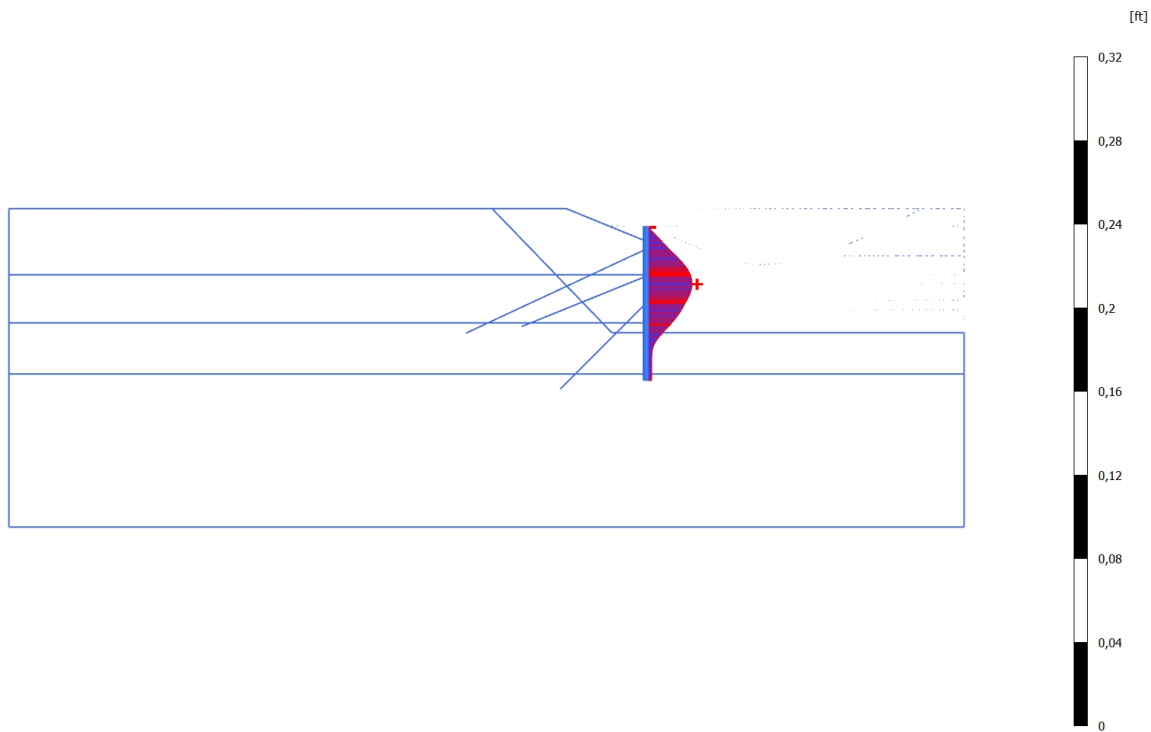
Maximum value = 0,2603 ft (Element 66 at Node 765)

### 3.1.1.1.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/296), Total displacements |u|



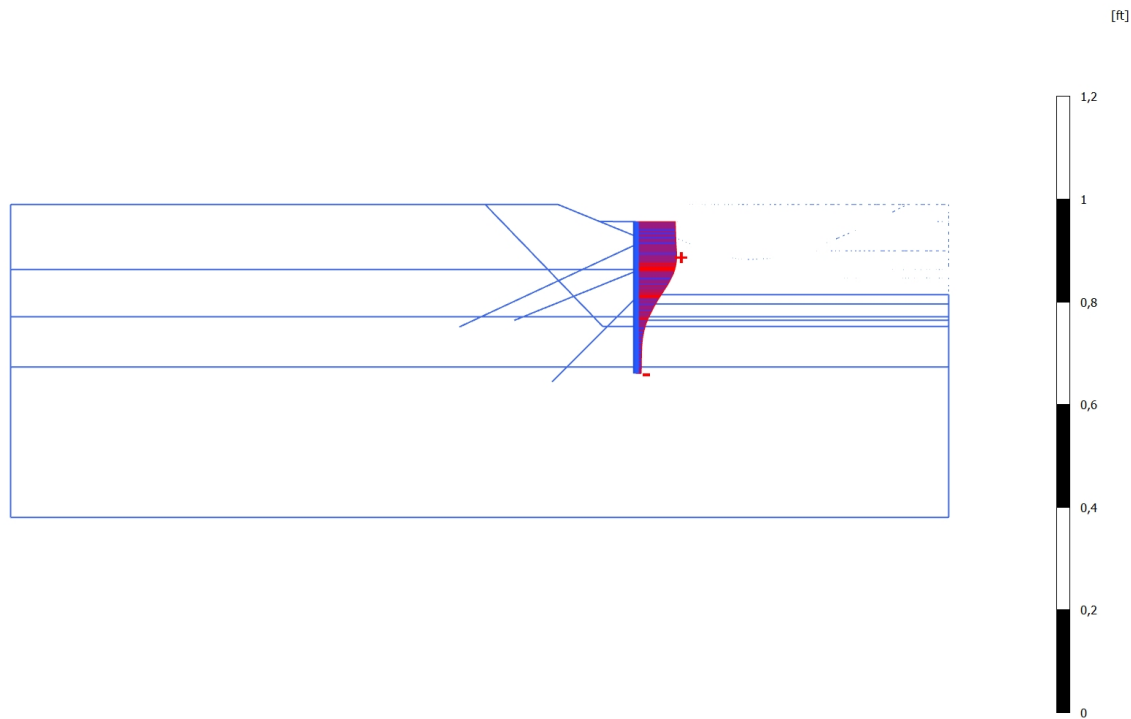
**Total displacements |u| (scaled up 200 times)**  
Maximum value = 0,07314 ft (Element 71 at Node 3320)

### 3.1.1.1.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/174), Total displacements $u_x$



**Total displacements  $u_x$  (scaled up 200 times)**  
Maximum value = 0,07299 ft (Element 71 at Node 3320)  
Minimum value =  $2,282 \cdot 10^{-3}$  ft (Element 62 at Node 171)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/283), Total displacements  $u_x$

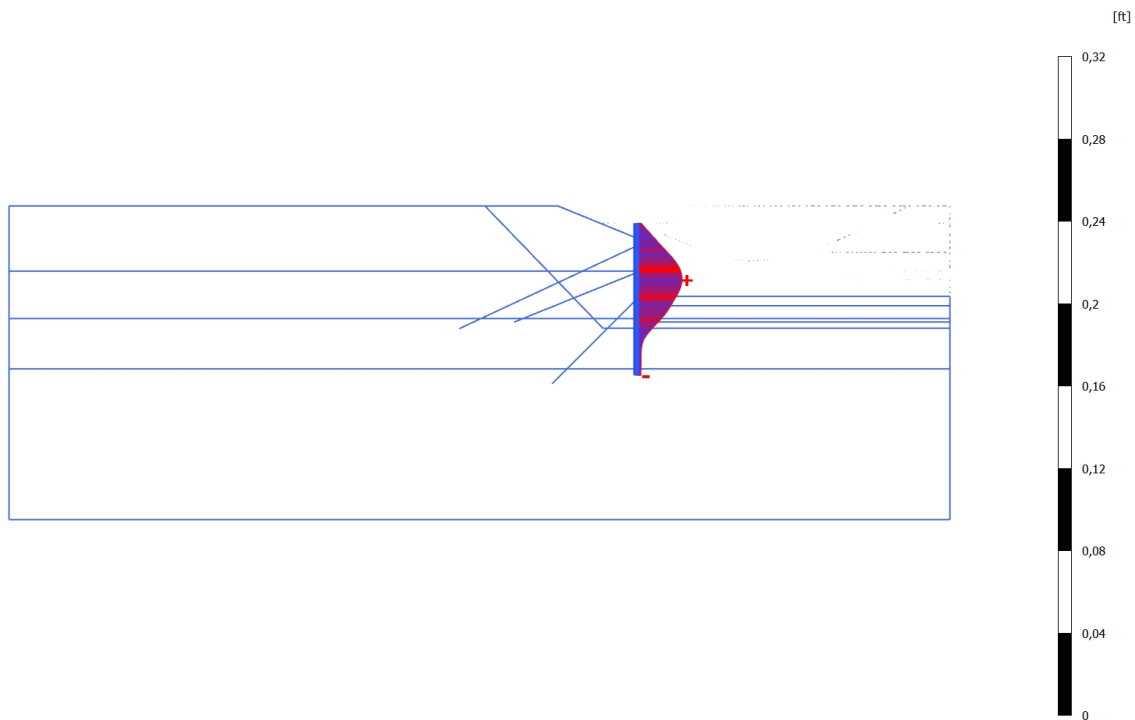


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,2600 ft (Element 66 at Node 765)

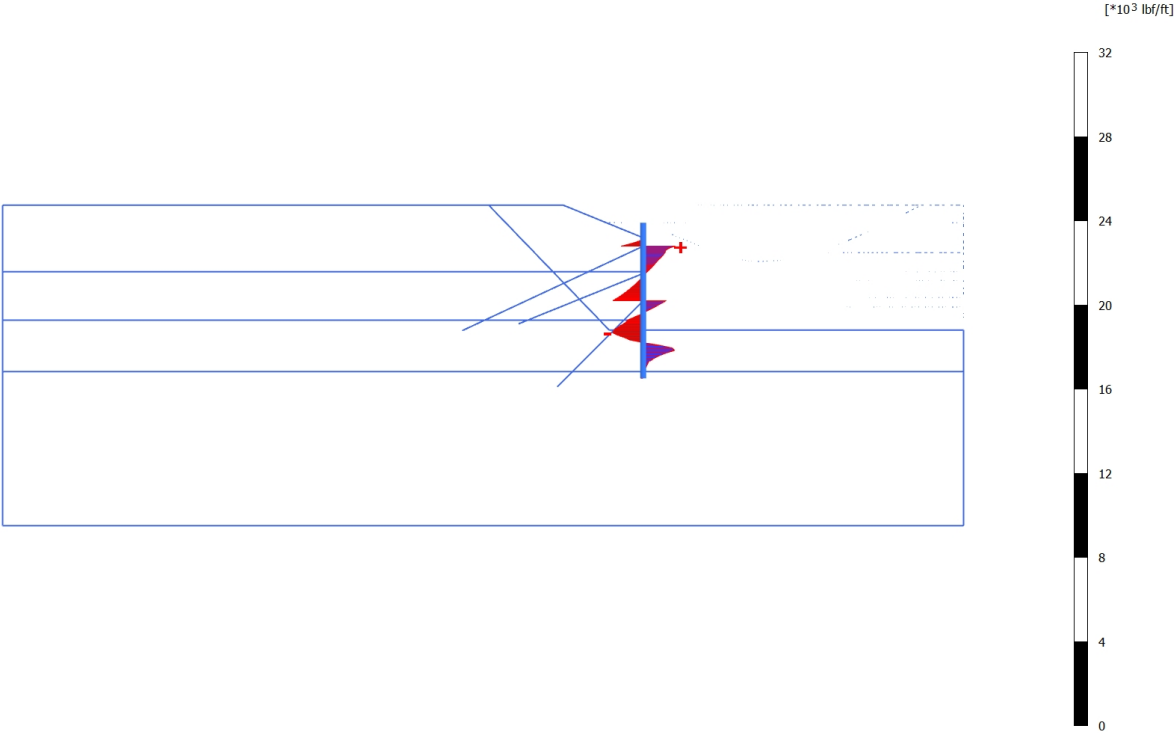
Minimum value = 0,03354 ft (Element 85 at Node 14054)

3.1.1.1.2.3 Calculation results, Plate, Long-term (corroded, final surface level)  
[Phase\_18] (18/296), Total displacements  $u_x$



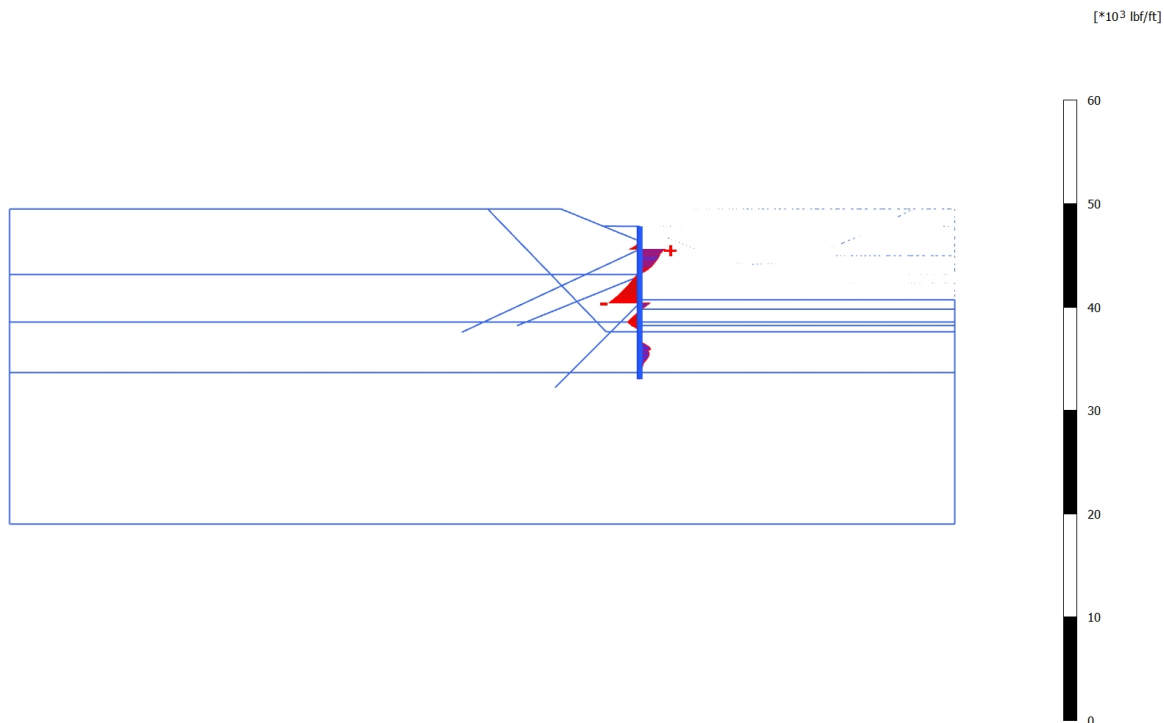
**Total displacements  $u_x$  (scaled up 200 times)**  
Maximum value = 0,07312 ft (Element 71 at Node 3320)  
Minimum value =  $7,452 \cdot 10^{-3}$  ft (Element 85 at Node 14054)

3.1.2.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/174), Shear forces Q



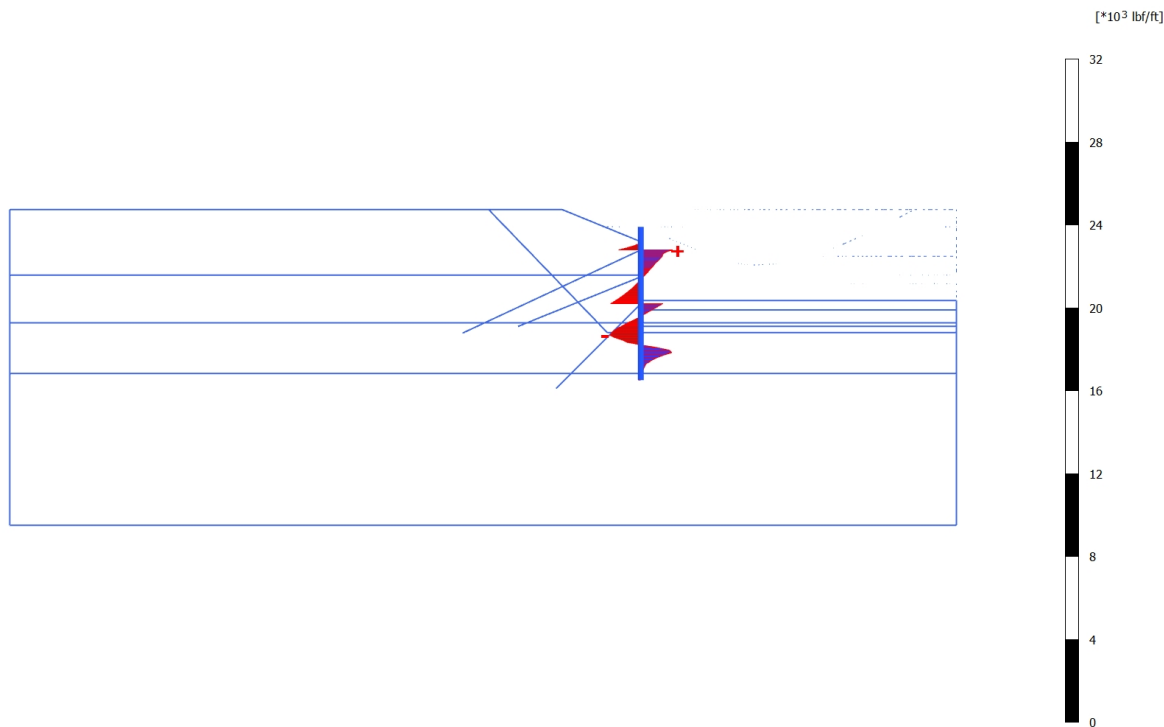
**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**  
Maximum value = 5015 lbf/ft (Element 65 at Node 496)  
Minimum value = -4807 lbf/ft (Element 81 at Node 10373)

3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/283), Shear forces Q



**Shear forces Q (scaled up 1,00\*10<sup>-3</sup> times)**  
Maximum value = 8209 lbf/ft (Element 65 at Node 496)  
Minimum value = -9841 lbf/ft (Element 75 at Node 6548)

### 3.1.2.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/296), Shear forces Q

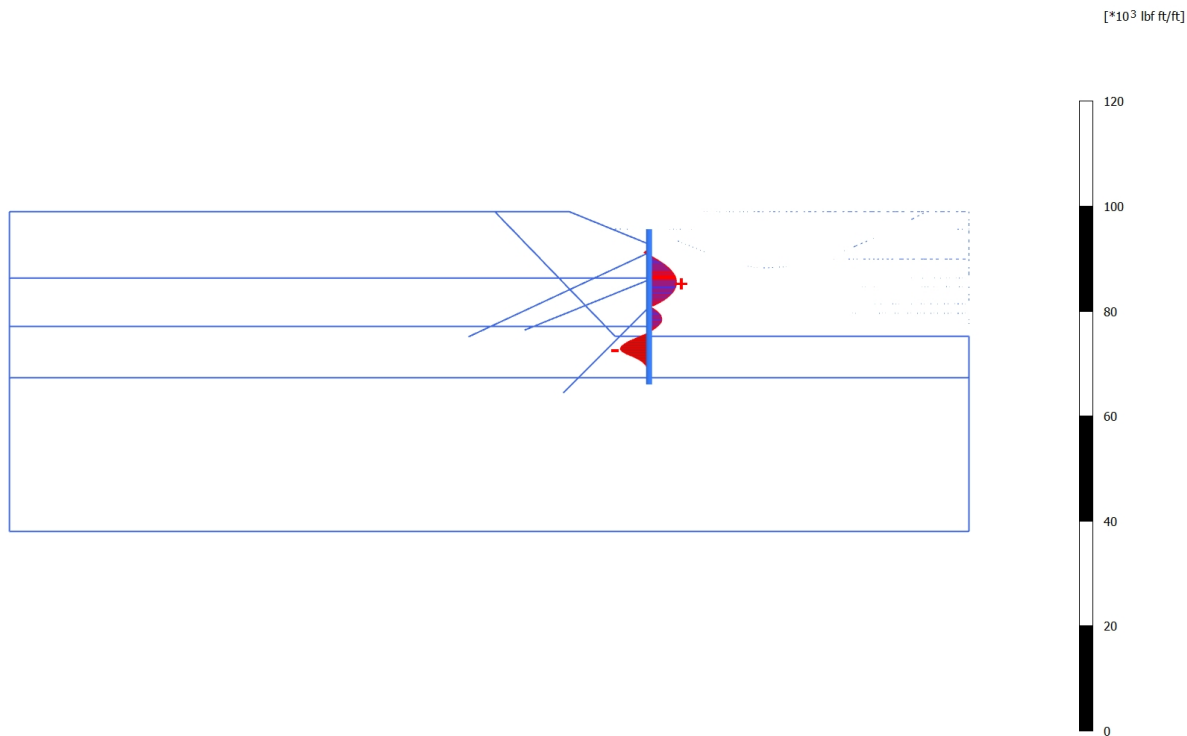


#### Shear forces Q (scaled up $2,00 \cdot 10^{-3}$ times)

Maximum value = 5024 lbf/ft (Element 65 at Node 496)

Minimum value = -4913 lbf/ft (Element 81 at Node 10373)

### 3.1.2.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/174), Bending moments M

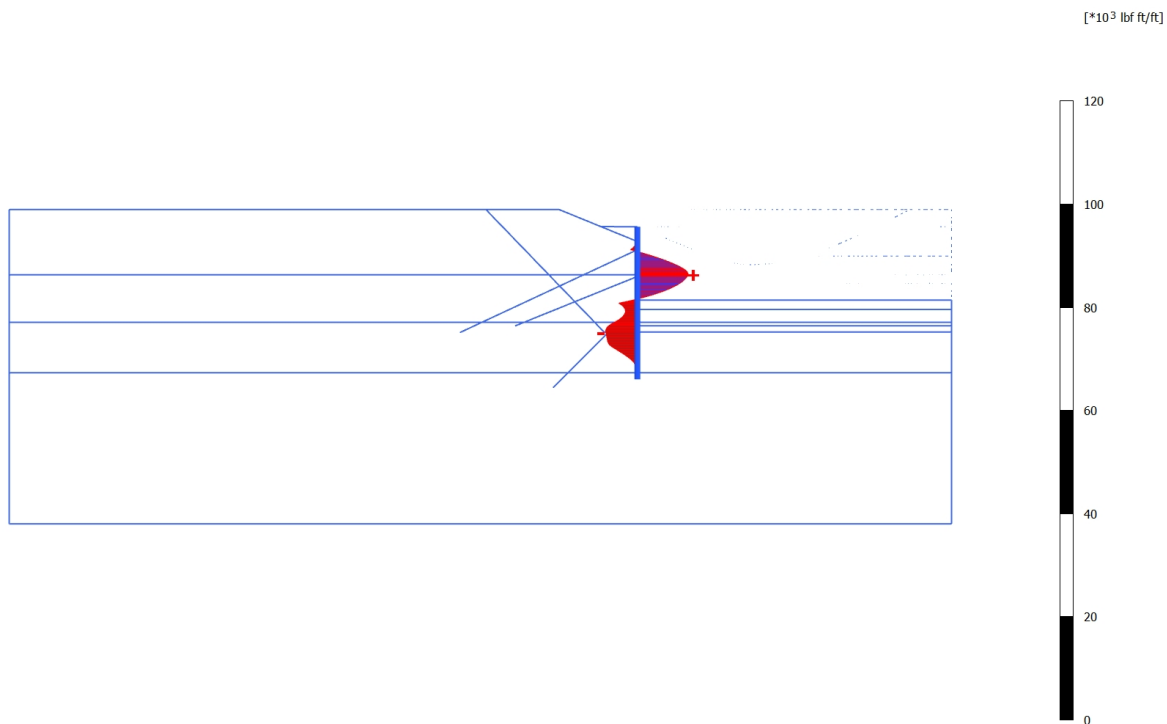


#### **Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 17,17\*10<sup>3</sup> lbf ft/ft (Element 71 at Node 2586)

Minimum value = -18,12\*10<sup>3</sup> lbf ft/ft (Element 82 at Node 11783)

### 3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/283), Bending moments M

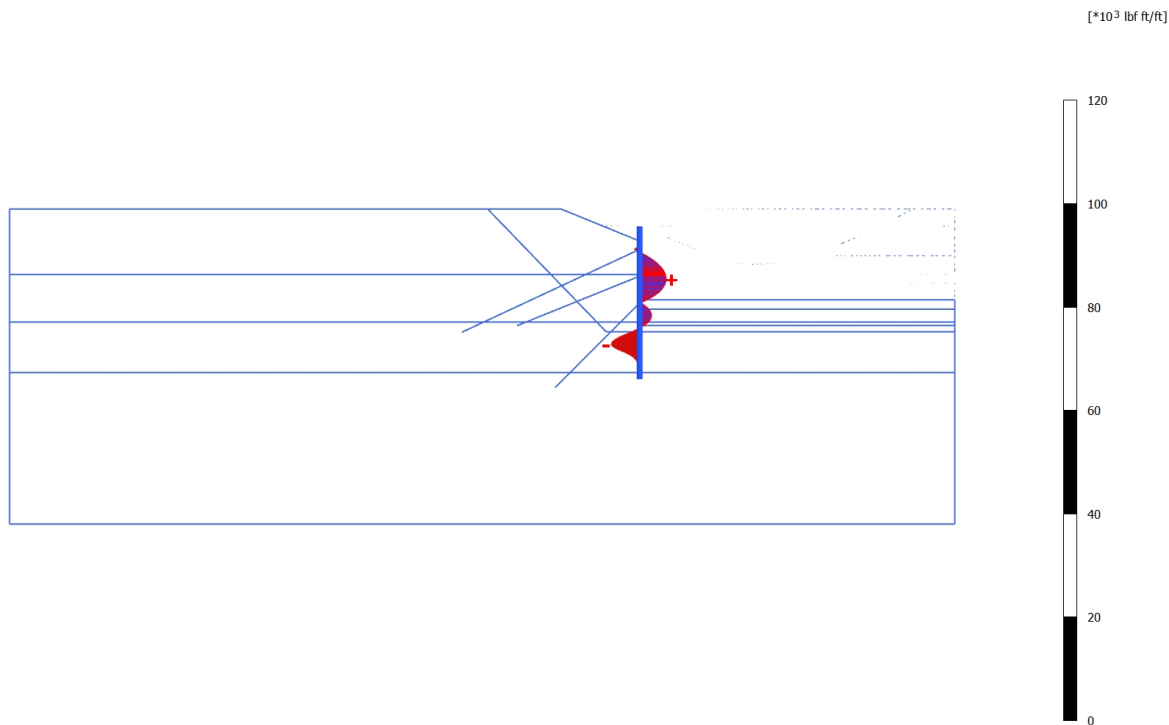


**Bending moments M (scaled up  $0,500 \cdot 10^{-3}$  times)**

Maximum value =  $32,27 \cdot 10^3$  lbf ft/ft (Element 69 at Node 1923)

Minimum value =  $-20,27 \cdot 10^3$  lbf ft/ft (Element 80 at Node 10372)

### 3.1.2.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/296), Bending moments M

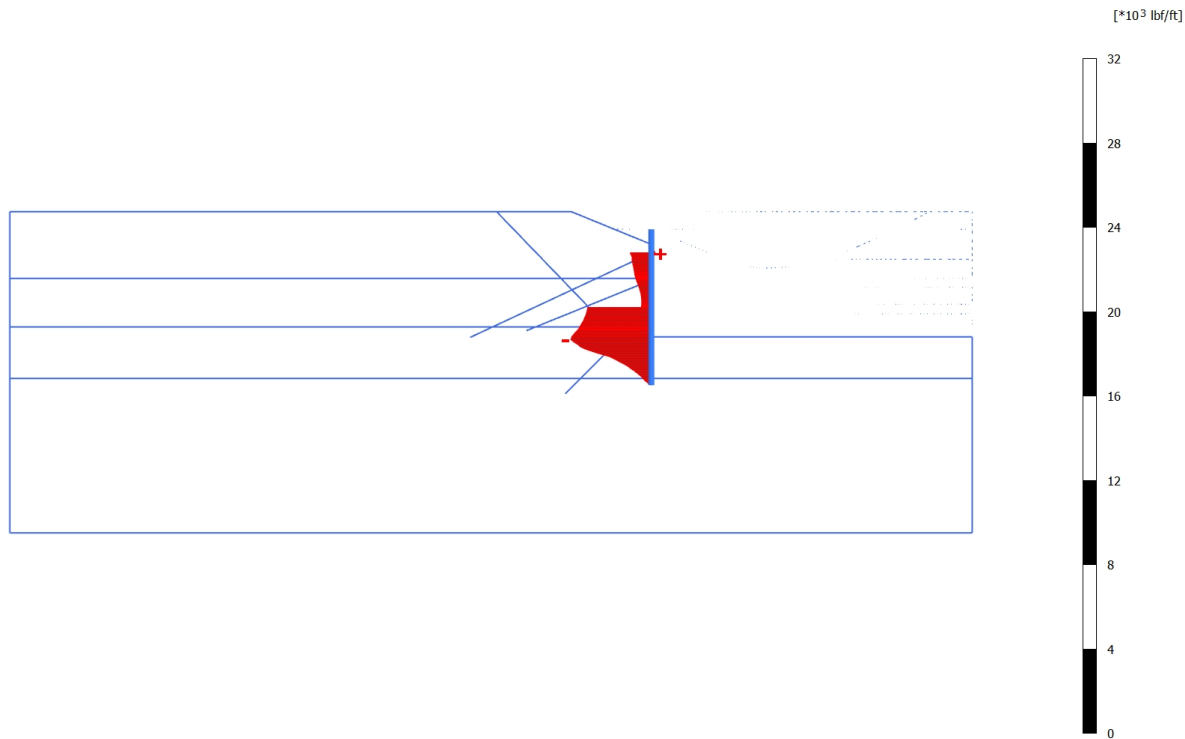


#### **Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 16,82\*10<sup>3</sup> lbf ft/ft (Element 71 at Node 2586)

Minimum value = -18,16\*10<sup>3</sup> lbf ft/ft (Element 82 at Node 11783)

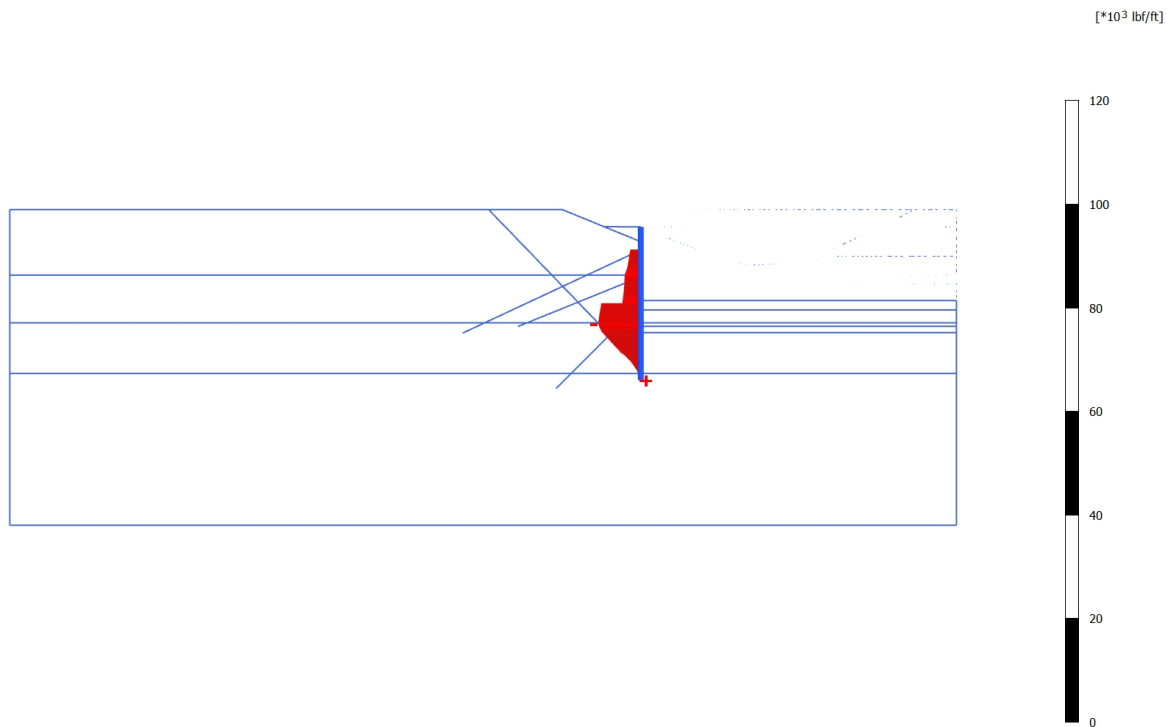
### 3.1.2.3.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/174), Axial forces N



**Axial forces N (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 599,4 lbf/ft (Element 64 at Node 496)  
Minimum value =  $-12,56 \cdot 10^3$  lbf/ft (Element 81 at Node 10373)

### 3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/283), Axial forces N

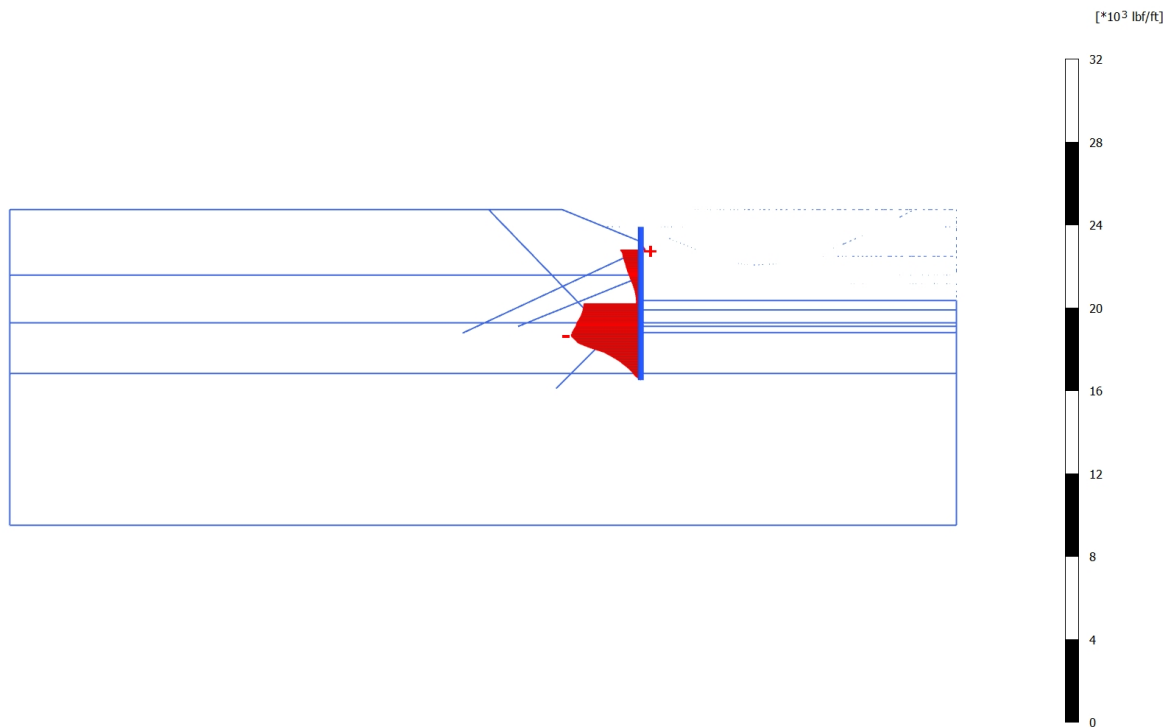


**Axial forces N (scaled up  $0,500*10^{-3}$  times)**

Maximum value = 16,37 lbf/ft (Element 85 at Node 14054)

Minimum value =  $-26,84*10^3$  lbf/ft (Element 78 at Node 8746)

### 3.1.2.3.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/296), Axial forces N



**Axial forces N (scaled up  $2,00 \cdot 10^{-3}$  times)**  
Maximum value = 726,2 lbf/ft (Element 64 at Node 496)  
Minimum value =  $-11,09 \cdot 10^3$  lbf/ft (Element 81 at Node 10373)

3.2.1.1.1 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/174), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	496	1	100,000	87,200	74,296	0,000	75,422
Element 1-1 (Node-to-node anchor)	21016	2	75,246	75,657	74,296	0,000	75,422
NodeToNodeAnchor\_1\_1	6548	1	100,000	70,200	94,576	0,000	94,576
Element 3-3 (Node-to-node anchor)	21106	2	90,800	61,000	94,576	0,000	94,576

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/283), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	496	1	100,000	87,200	101,277	0,000	101,277
Element 1-1 (Node-to-node anchor)	21016	2	75,246	75,657	101,277	0,000	101,277
NodeToNodeAnchor\_1\_1	6548	1	100,000	70,200	149,826	0,000	149,826
Element 3-3 (Node-to-node anchor)	21106	2	90,800	61,000	149,826	0,000	149,826

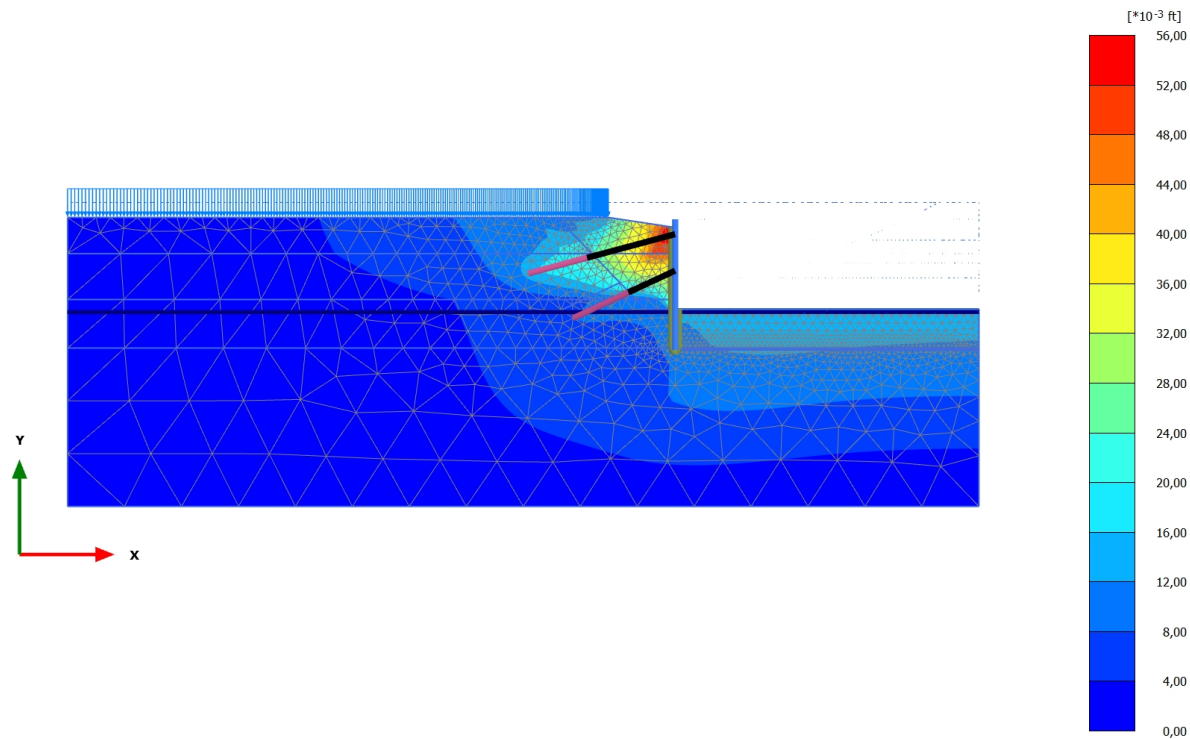
3.2.1.1.3 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/296), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_3\_1	496	1	100,000	87,200	74,869	0,000	75,422
Element 1-1 (Node-to-node anchor)	21016	2	75,246	75,657	74,869	0,000	75,422
NodeToNodeAnchor\_1\_1	6548	1	100,000	70,200	93,724	0,000	94,576
Element 3-3 (Node-to-node anchor)	21106	2	90,800	61,000	93,724	0,000	94,576

# PLAXIS Report

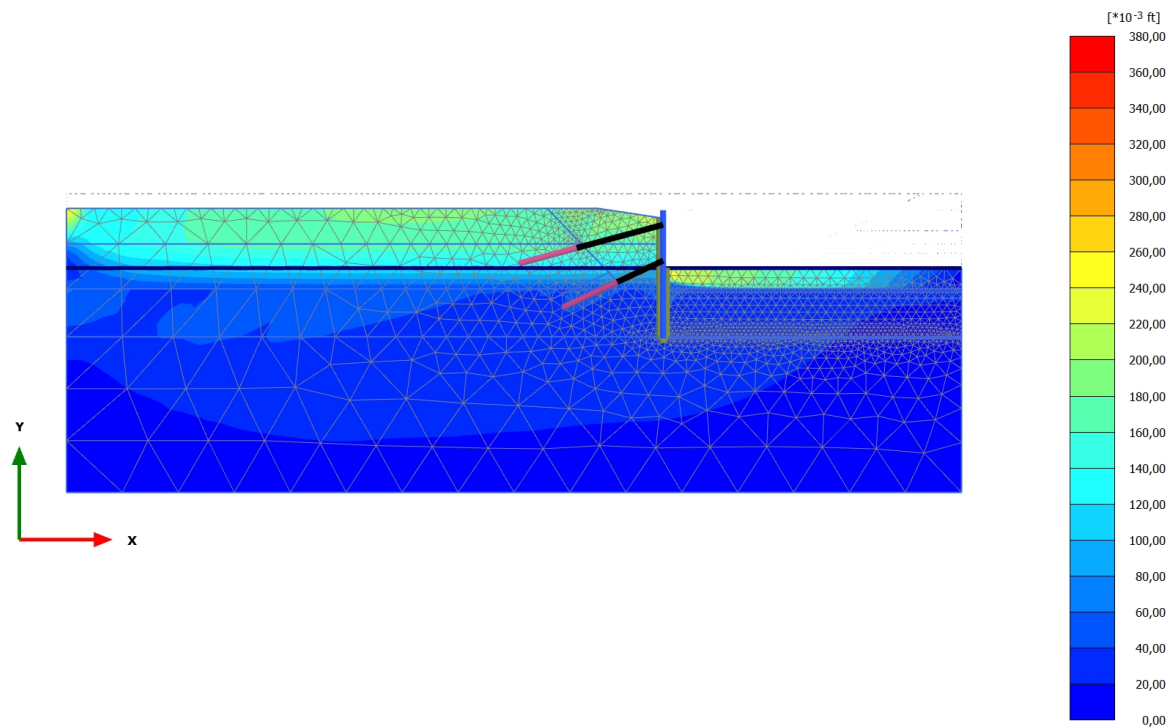
**Plaxis Model Wingwall 4\_Section 4: WW4-5  
STA. 6+56.36 to 6+69.19**

### 2.1.1.1.1 Calculation results, Exc. to bottom [Phase\_10] (10/182), Total displacements $|u|$



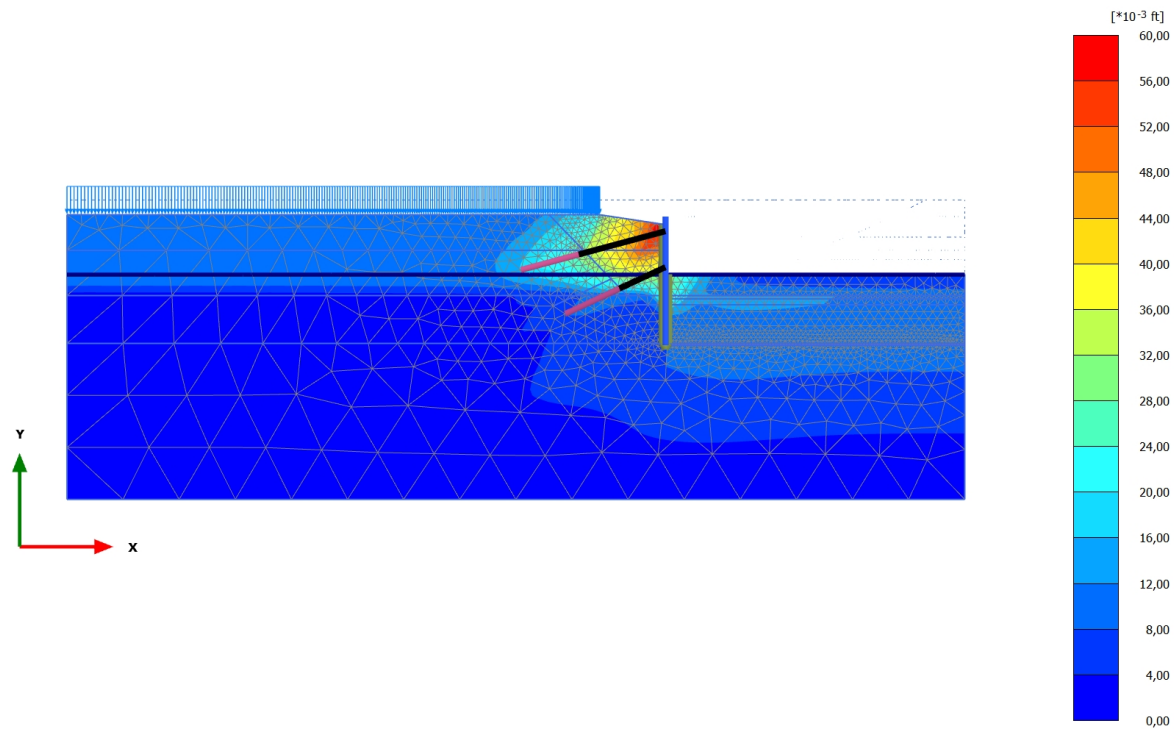
**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,05482 ft (Element 456 at Node 975)

2.1.1.1.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/439), Total displacements  $|u|$



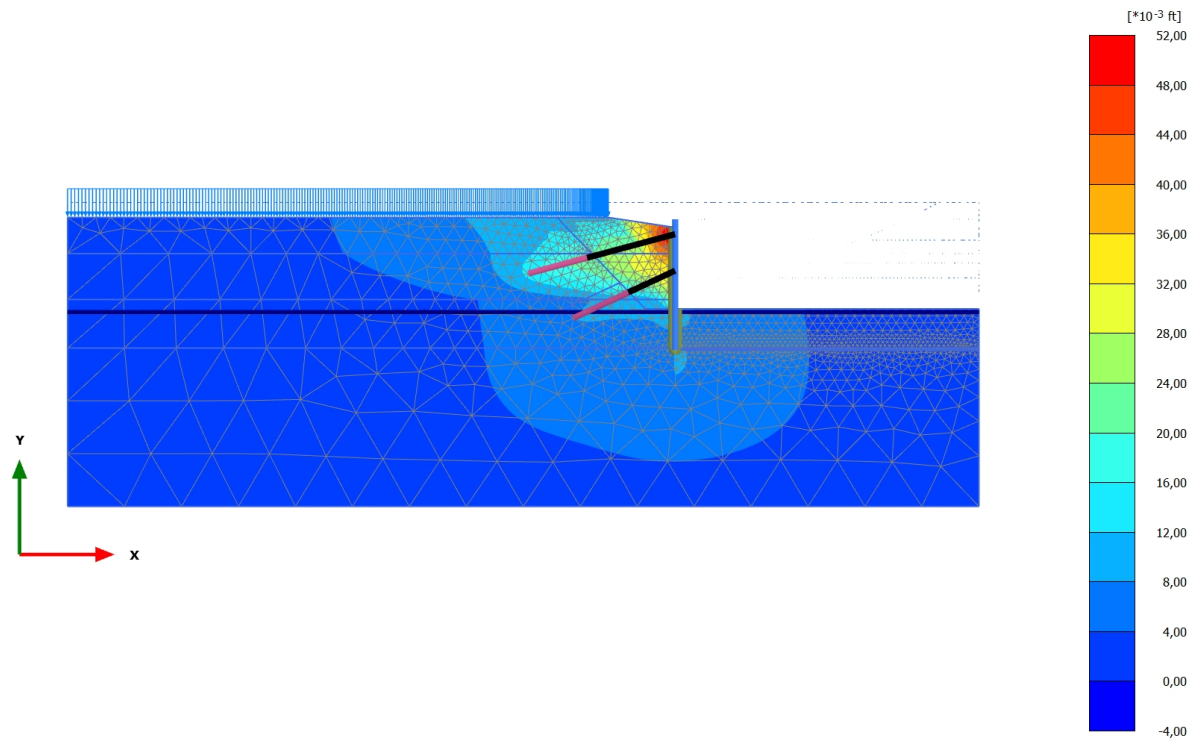
**Total displacements  $|u|$  (scaled up 20,0 times)**  
Maximum value = 0,3666 ft (Element 1476 at Node 7144)

### 2.1.1.1.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/854), Total displacements $|u|$



**Total displacements  $|u|$  (scaled up 200 times)**  
Maximum value = 0,05920 ft (Element 456 at Node 974)

### 2.1.1.2.1 Calculation results, Exc. to bottom [Phase\_10] (10/182), Total displacements $u_x$

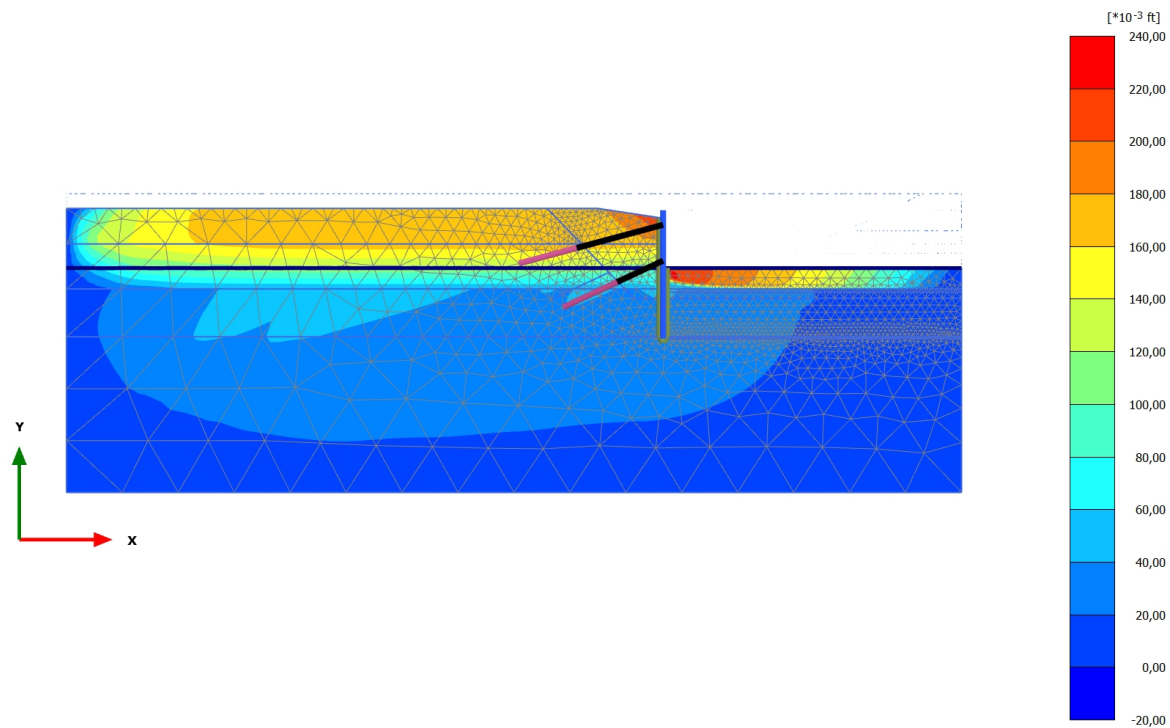


**Total displacements  $u_x$  (scaled up 200 times)**

Maximum value = 0,05013 ft (Element 456 at Node 974)

Minimum value = 0,000 ft (Element 586 at Node 13259)

2.1.1.2.2 Calculation results, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/439), Total displacements  $u_x$

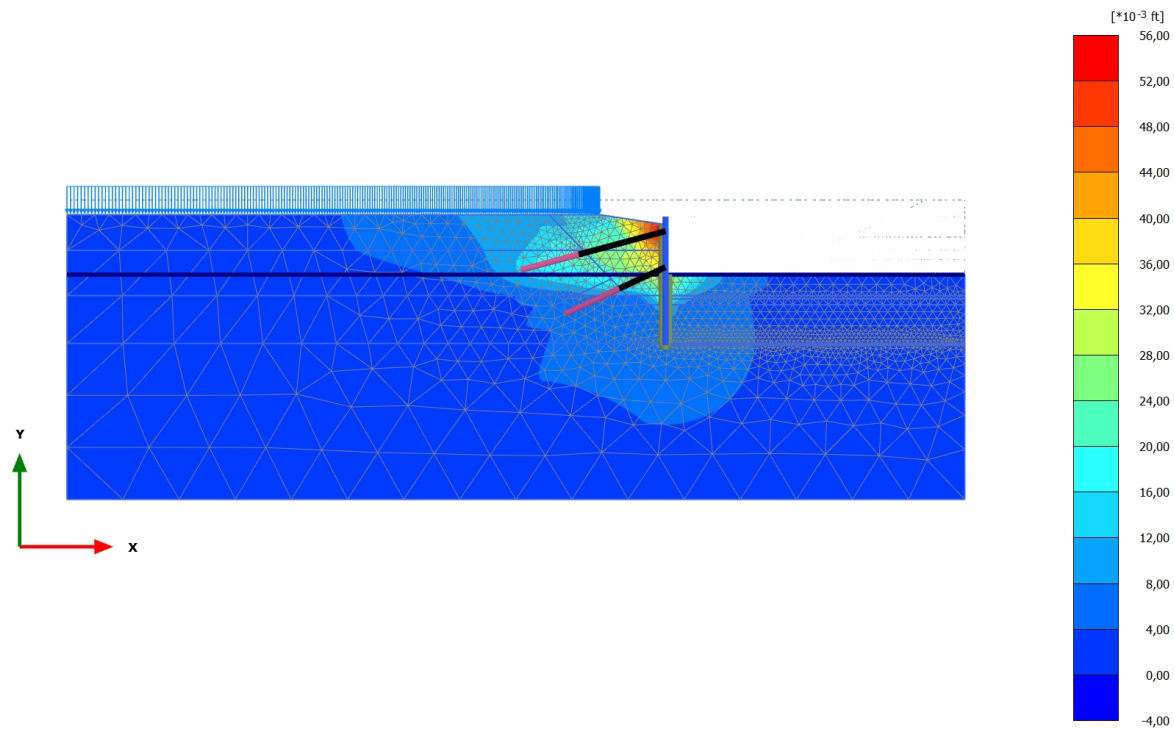


**Total displacements  $u_x$  (scaled up 50,0 times)**

Maximum value = 0,2240 ft (Element 1528 at Node 7152)

Minimum value = 0,000 ft (Element 586 at Node 13259)

### 2.1.1.2.3 Calculation results, Long-term (corroded, final surface level) [Phase\_18] (18/854), Total displacements $u_x$

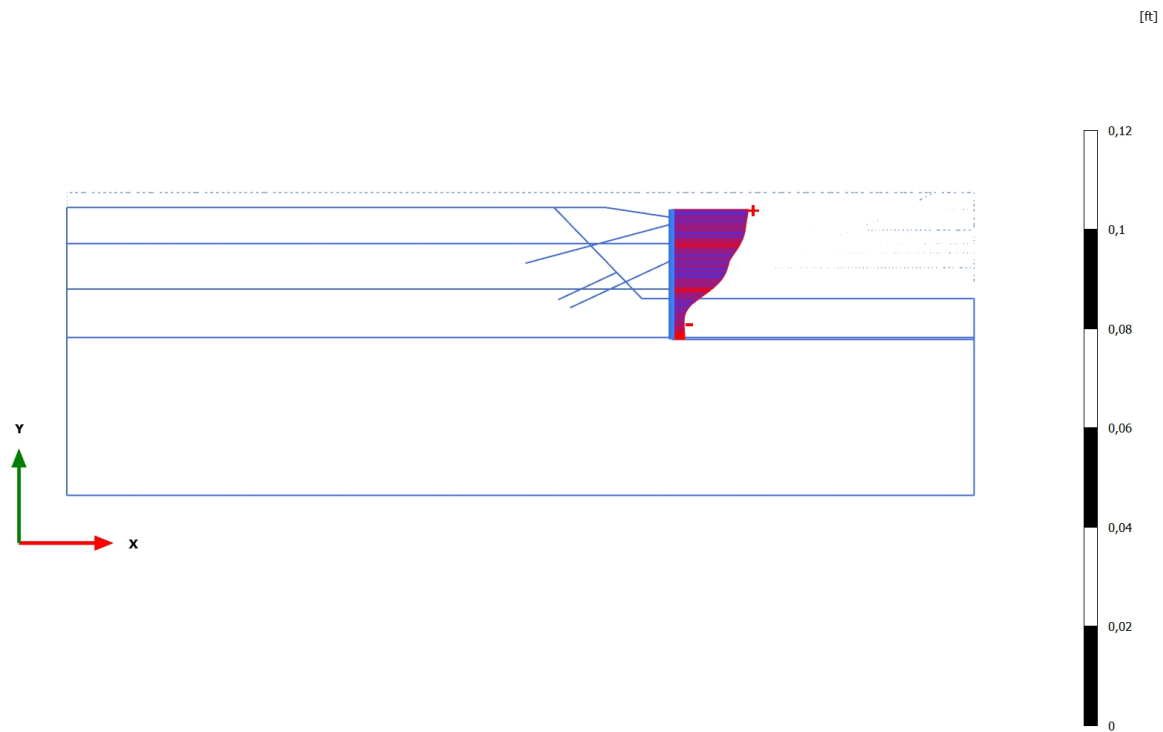


#### Total displacements $u_x$ (scaled up 200 times)

Maximum value = 0,05380 ft (Element 456 at Node 974)

Minimum value = 0,000 ft (Element 586 at Node 13259)

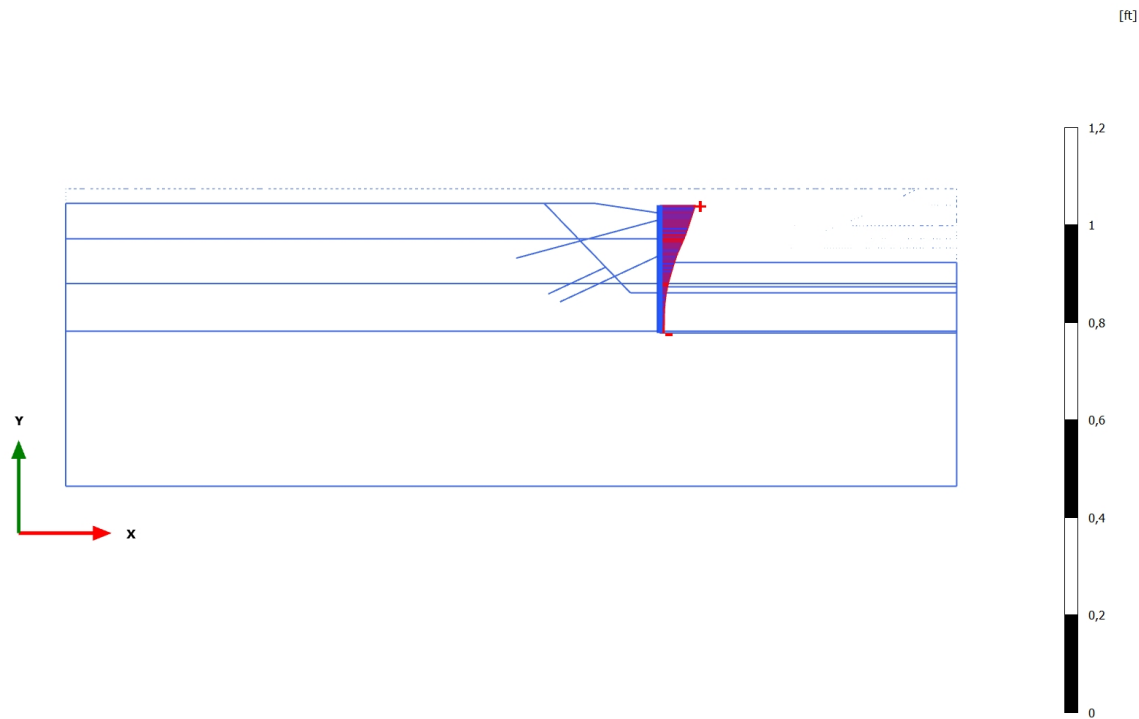
### 3.1.1.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/182), Total displacements $|u|$



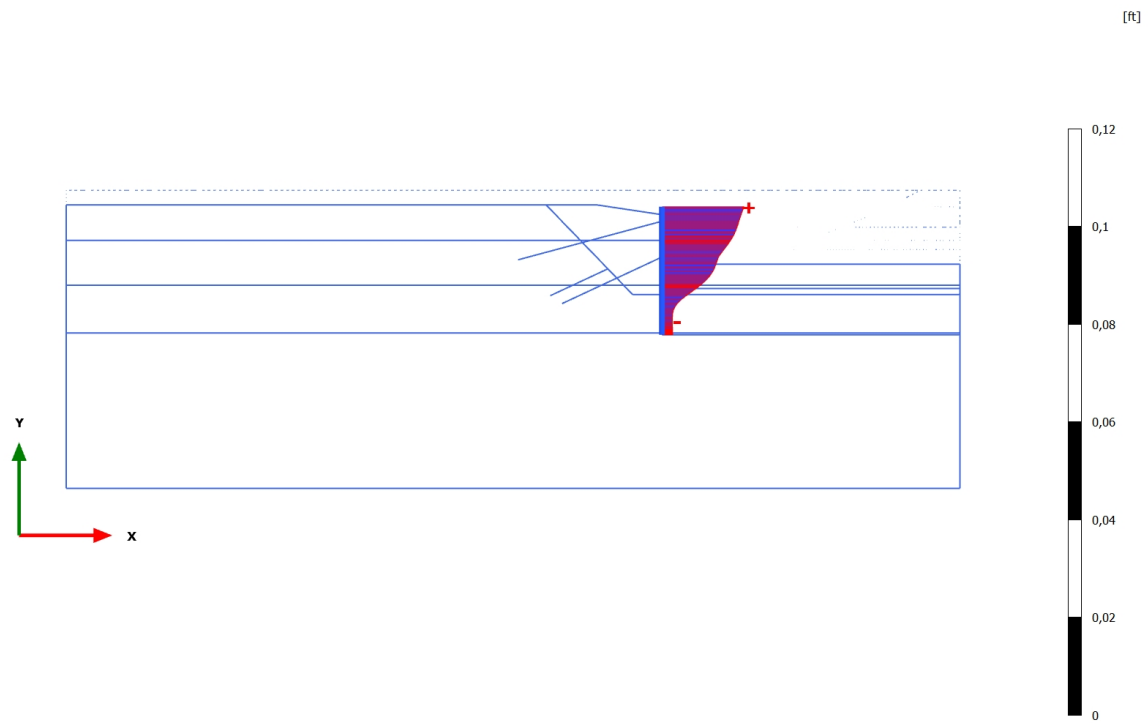
**Total displacements  $|u|$  (scaled up 500 times)**

Maximum value = 0,05082 ft (Element 59 at Node 858)

3.1.1.1.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/439), Total displacements |u|

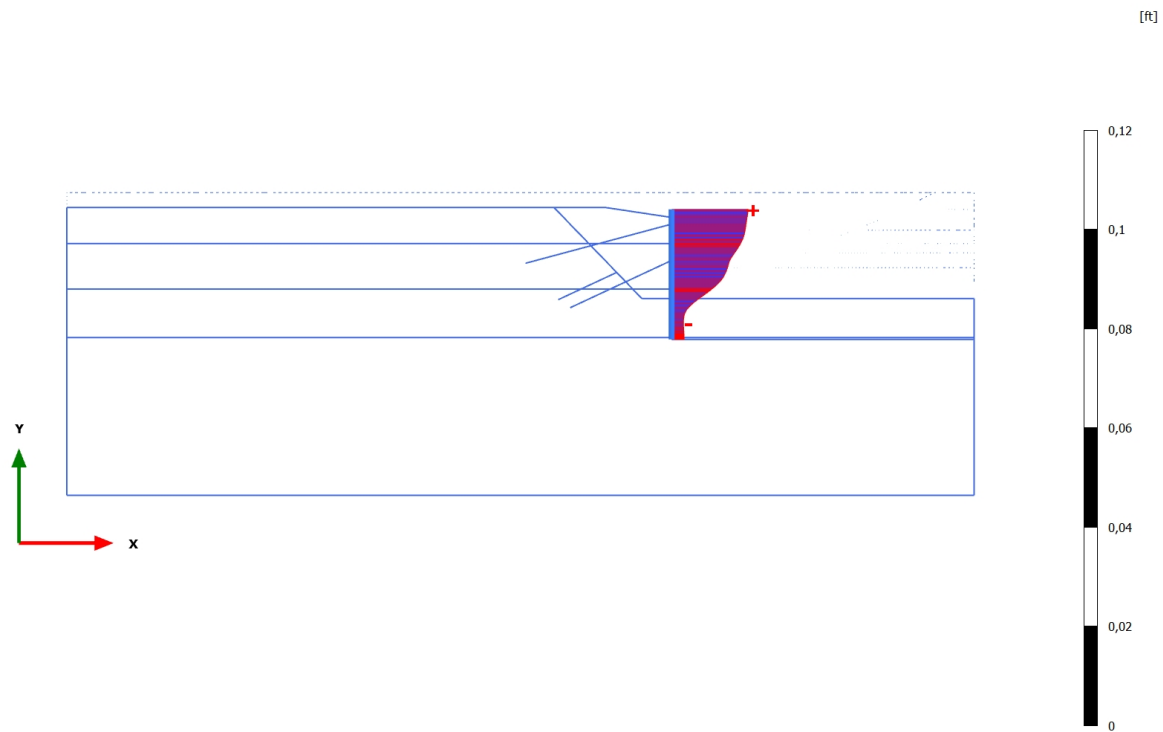


### 3.1.1.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/854), Total displacements |u|



**Total displacements |u| (scaled up 500 times)**  
Maximum value = 0,05504 ft (Element 59 at Node 858)

### 3.1.1.1.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/182), Total displacements $u_x$

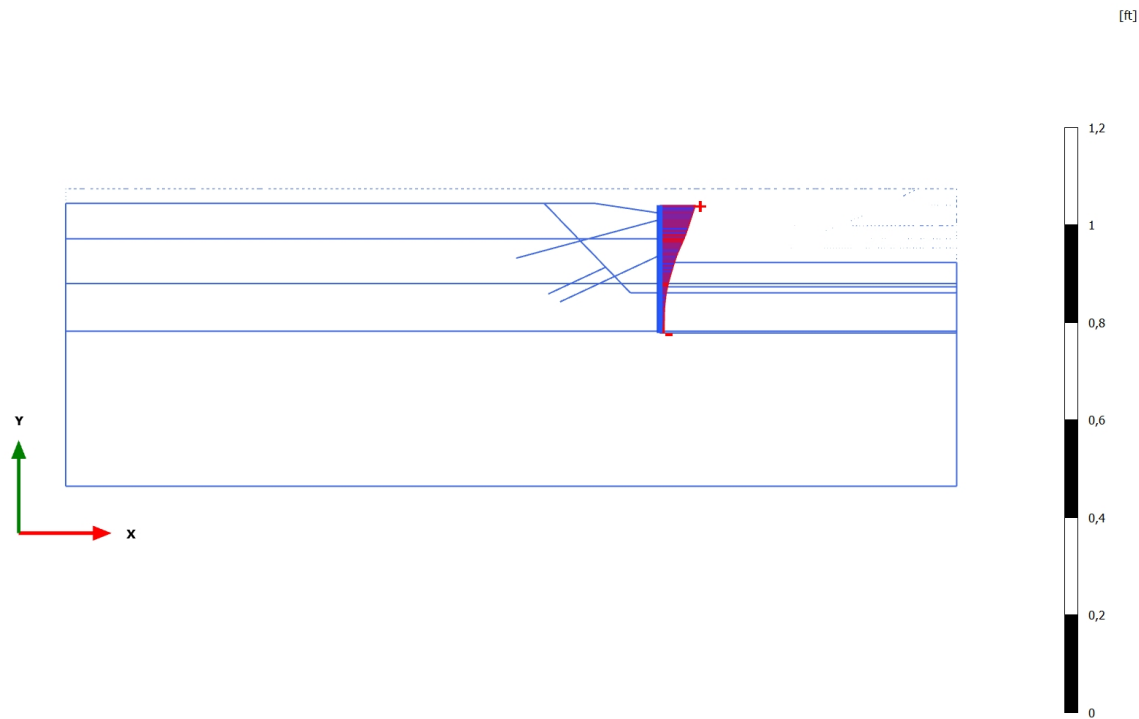


**Total displacements  $u_x$  (scaled up 500 times)**

Maximum value = 0,05079 ft (Element 59 at Node 858)

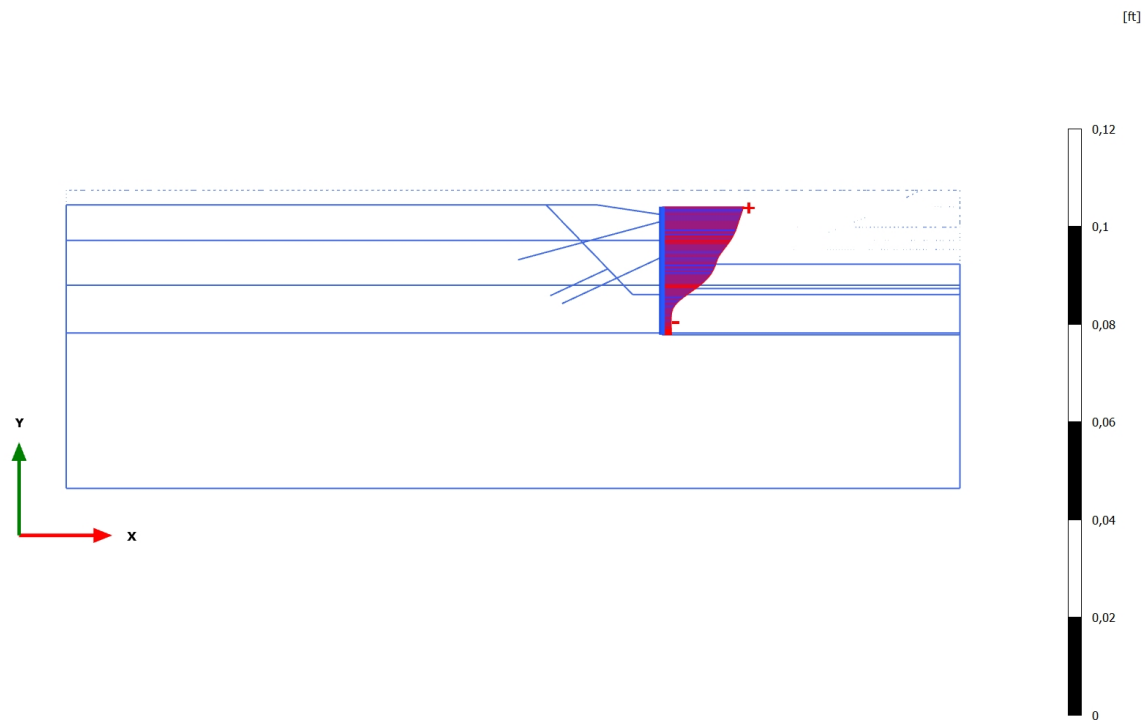
Minimum value =  $7,830 \cdot 10^{-3}$  ft (Element 76 at Node 14761)

3.1.1.1.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/439), Total displacements  $u_x$



**Total displacements  $u_x$  (scaled up 50,0 times)**  
Maximum value = 0,2425 ft (Element 59 at Node 858)  
Minimum value = 0,03186 ft (Element 80 at Node 21160)

### 3.1.1.1.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/854), Total displacements $u_x$

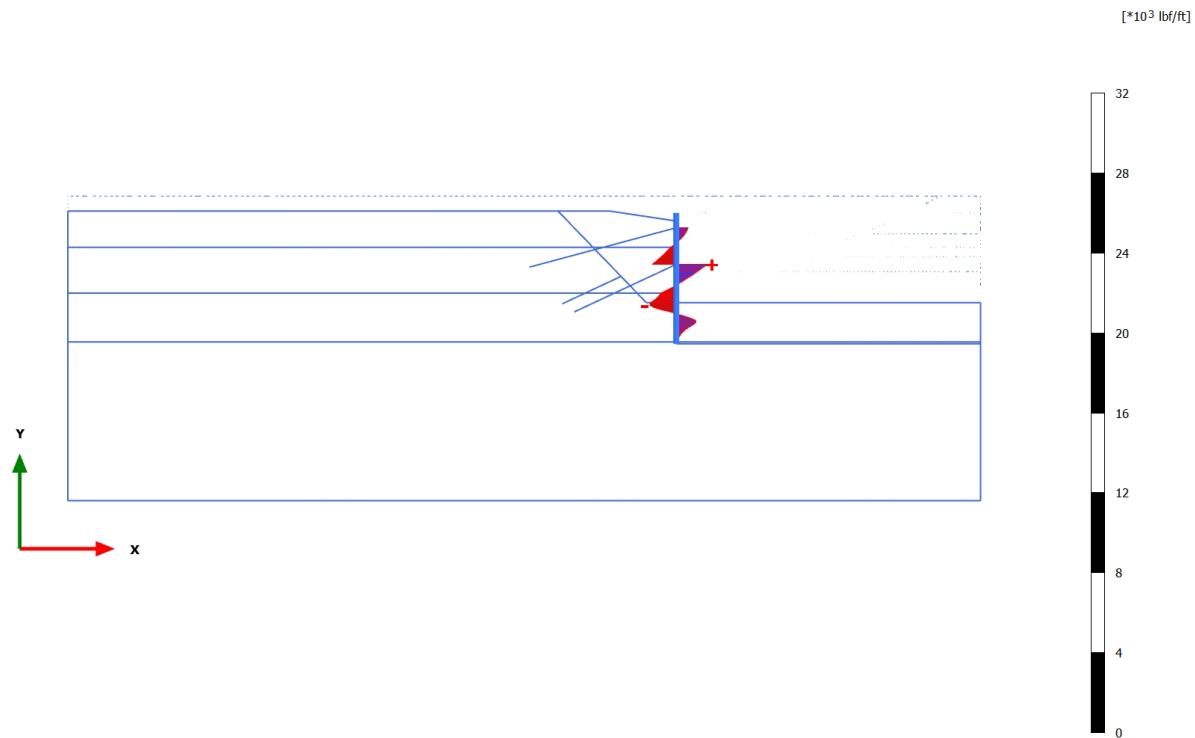


**Total displacements  $u_x$  (scaled up 500 times)**

Maximum value = 0,05498 ft (Element 59 at Node 858)

Minimum value =  $6,217 \cdot 10^{-3}$  ft (Element 76 at Node 14759)

### 3.1.2.1.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/182), Shear forces Q

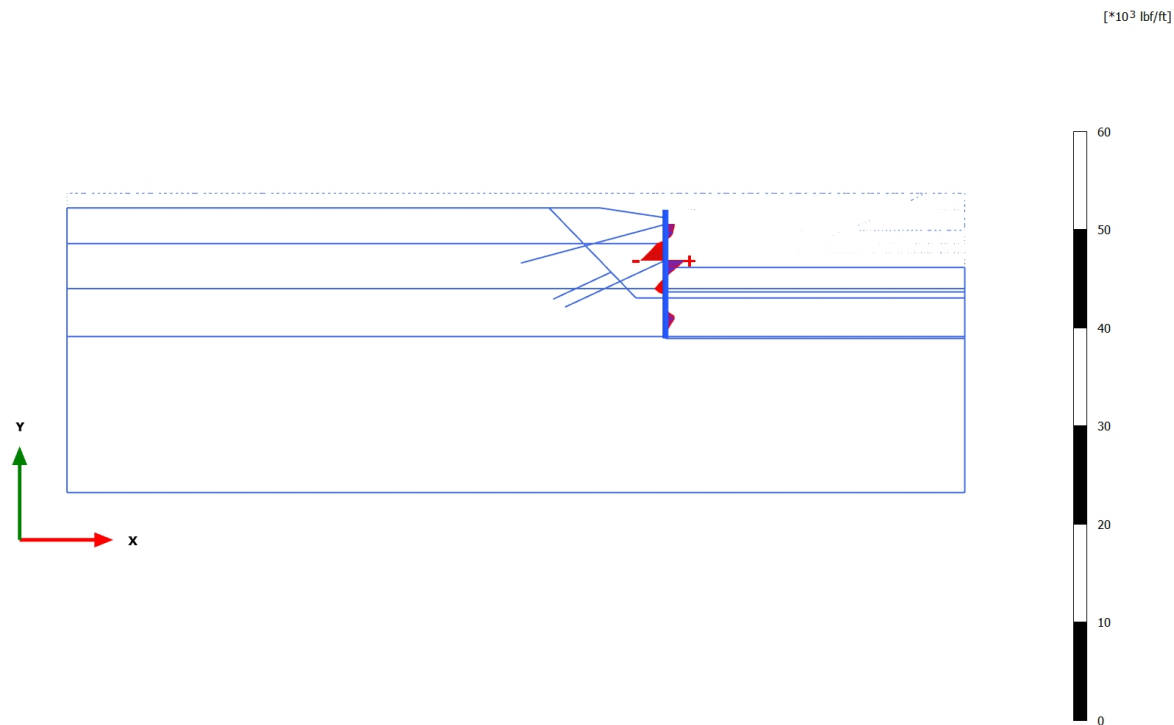


**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**

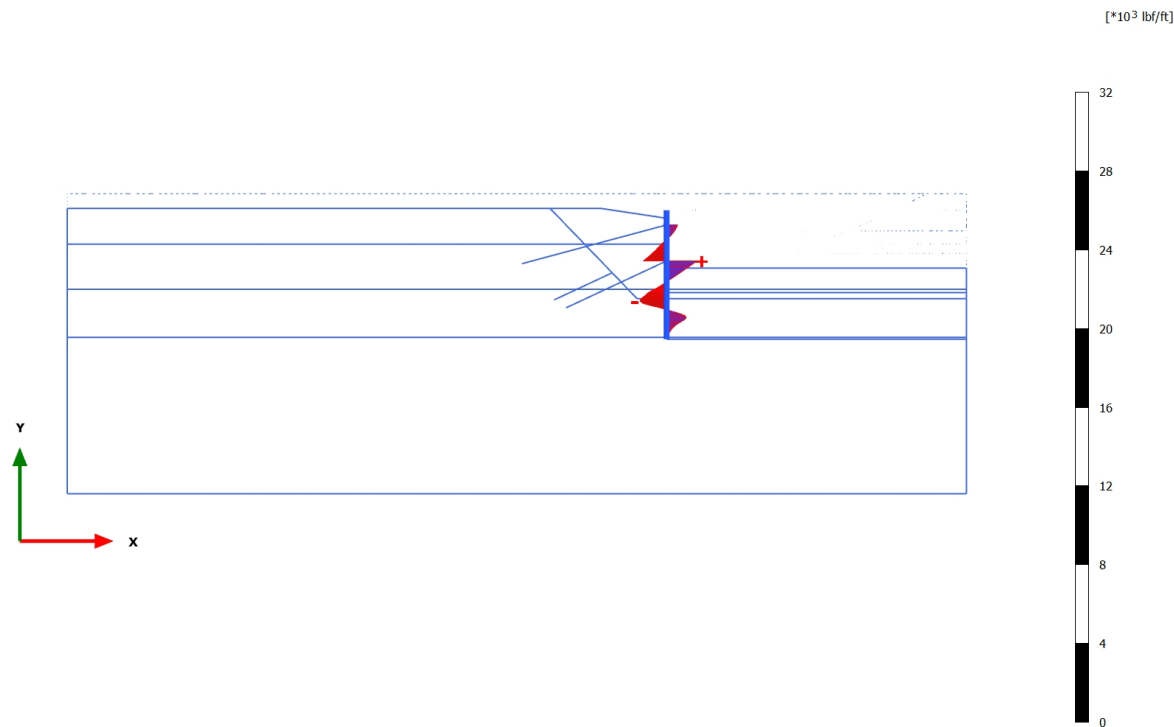
Maximum value = 5084 lbf/ft (Element 67 at Node 6602)

Minimum value = -4378 lbf/ft (Element 73 at Node 11251)

### 3.1.2.1.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/439), Shear forces Q



### 3.1.2.1.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/854), Shear forces Q

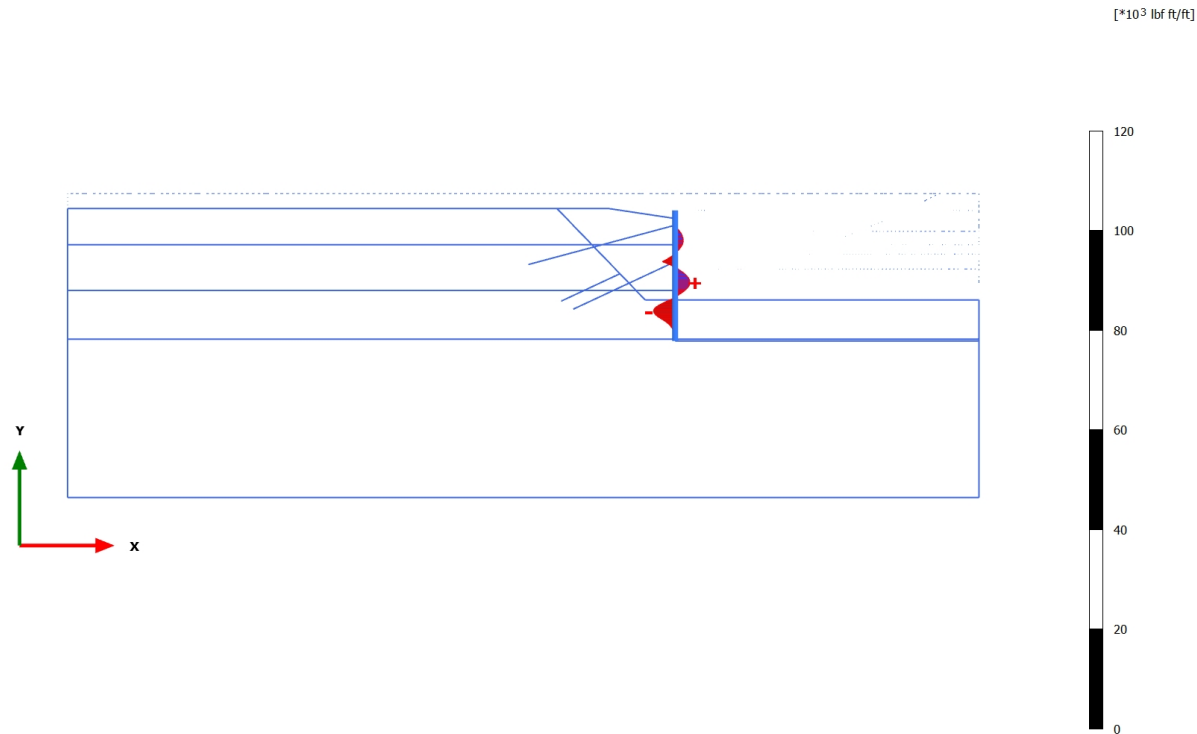


**Shear forces Q (scaled up  $2,00 \cdot 10^{-3}$  times)**

Maximum value = 5037 lbf/ft (Element 67 at Node 6602)

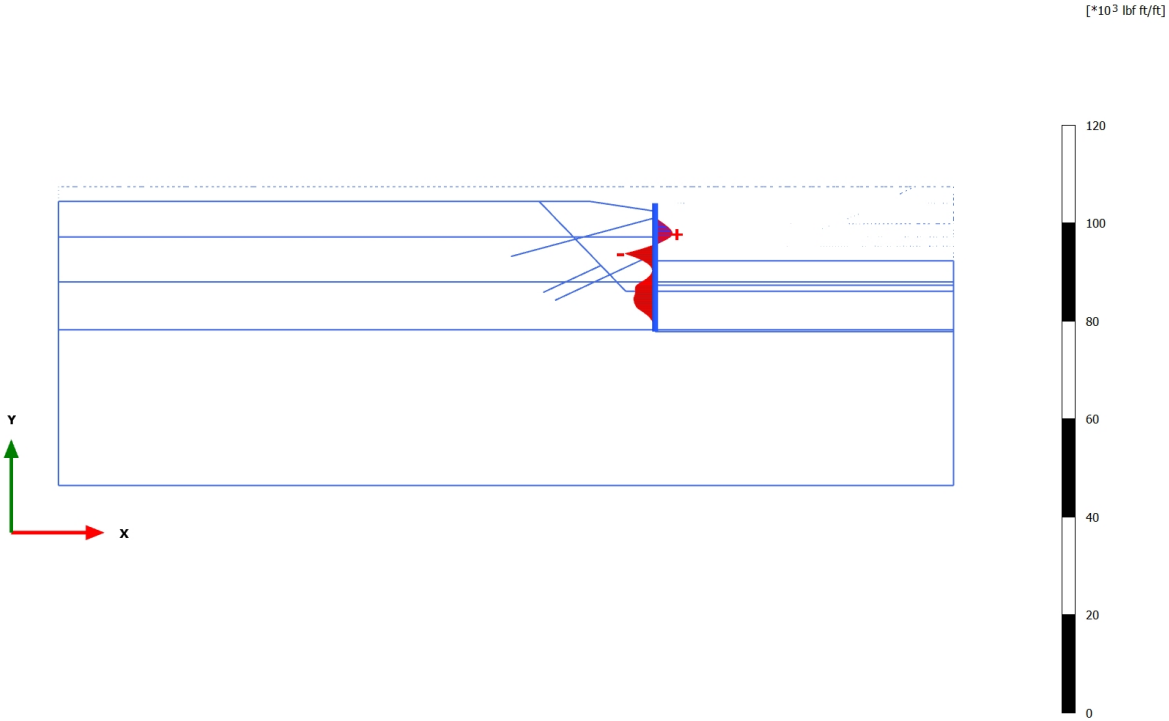
Minimum value = -4482 lbf/ft (Element 73 at Node 11251)

### 3.1.2.2.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/182), Bending moments M



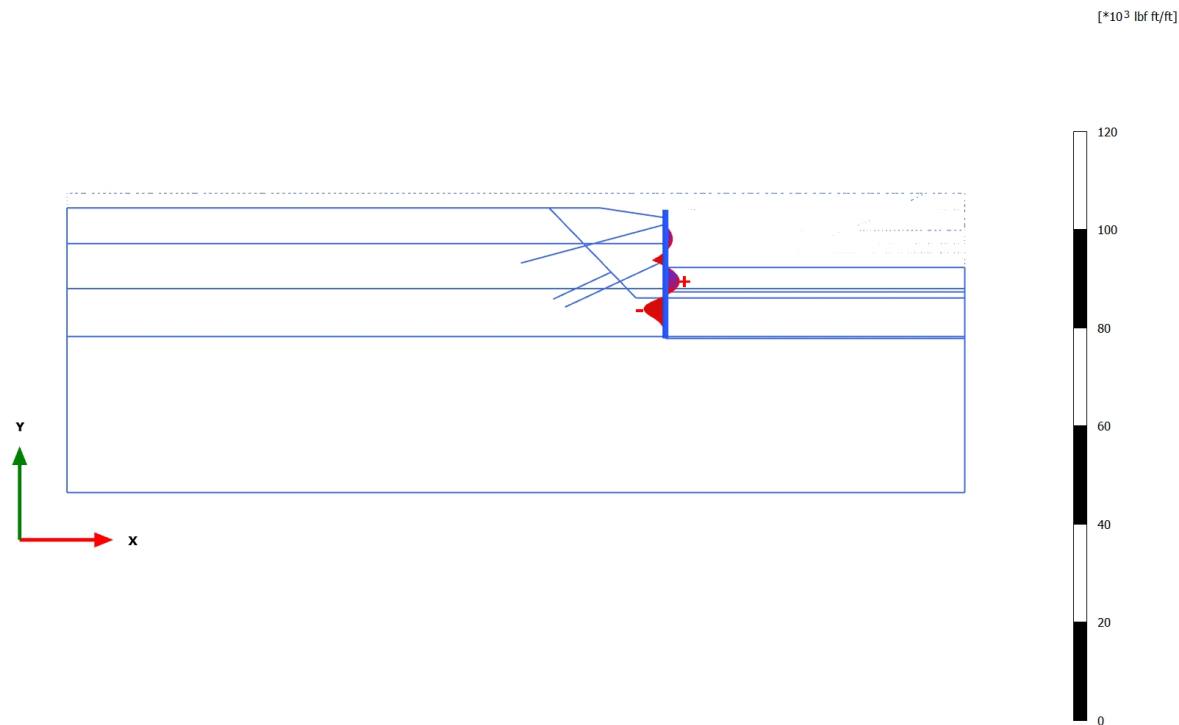
**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 9728 lbf ft/ft (Element 69 at Node 8064)  
Minimum value = -14,29\*10<sup>3</sup> lbf ft/ft (Element 74 at Node 11425)

3.1.2.2.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/439), Bending moments M



**Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**  
Maximum value = 11,45\*10<sup>3</sup> lbf ft/ft (Element 63 at Node 3277)  
Minimum value = -20,06\*10<sup>3</sup> lbf ft/ft (Element 67 at Node 6602)

### 3.1.2.2.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/854), Bending moments M

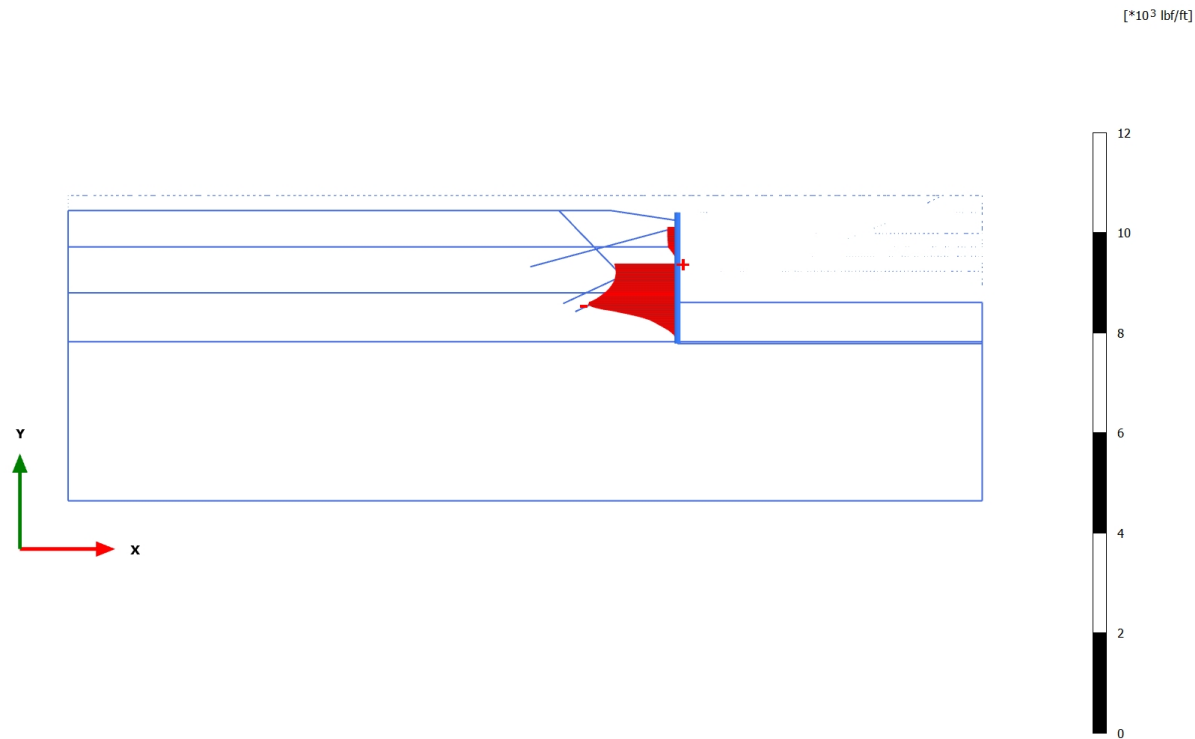


#### **Bending moments M (scaled up 0,500\*10<sup>-3</sup> times)**

Maximum value = 9263 lbf ft/ft (Element 69 at Node 8064)

Minimum value = -14,33\*10<sup>3</sup> lbf ft/ft (Element 74 at Node 11425)

### 3.1.2.3.1 Calculation results, Plate, Exc. to bottom [Phase\_10] (10/182), Axial forces N

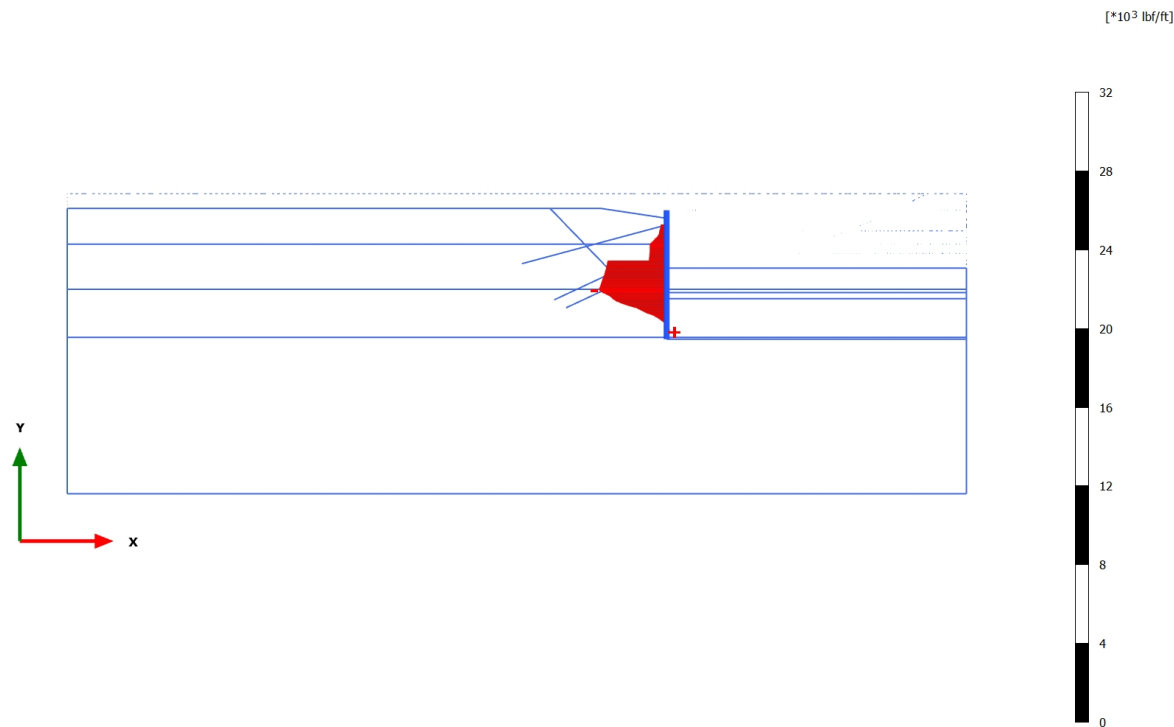


**Axial forces N (scaled up  $5,00 \cdot 10^{-3}$  times)**

Maximum value = 84,17 lbf/ft (Element 66 at Node 6602)

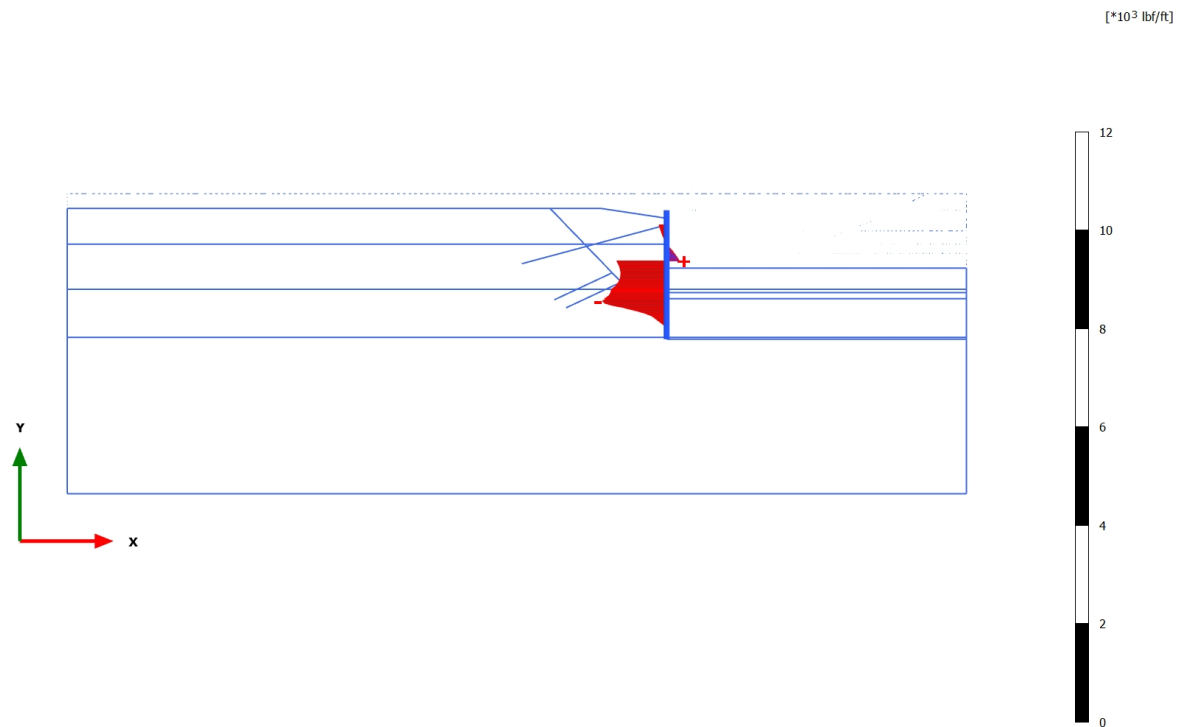
Minimum value = -5858 lbf/ft (Element 73 at Node 11251)

3.1.2.3.2 Calculation results, Plate, Eq- (flood, Kh, corroded, final surface level)  
[Phase\_15] (15/439), Axial forces N



**Axial forces N (scaled up  $2,00*10^{-3}$  times)**  
Maximum value = 517,2 lbf/ft (Element 77 at Node 18128)  
Minimum value =  $-11,27*10^3$  lbf/ft (Element 70 at Node 10434)

### 3.1.2.3.3 Calculation results, Plate, Long-term (corroded, final surface level) [Phase\_18] (18/854), Axial forces N



**Axial forces N (scaled up  $5,00 \cdot 10^{-3}$  times)**

Maximum value = 841,6 lbf/ft (Element 66 at Node 6602)

Minimum value = -4288 lbf/ft (Element 73 at Node 11251)

3.2.1.1.1 Calculation results, Node-to-node anchor, Exc. to bottom [Phase\_10]  
(10/182), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	2018	1	100,000	89,600	14,730	0,000	16,073
Element 1-1 (Node-to-node anchor)	32306	2	71,022	81,835	14,730	0,000	16,073
NodeToNodeAnchor\_1\_1	6602	1	100,000	77,600	59,832	0,000	59,832
Element 3-3 (Node-to-node anchor)	32364	2	84,593	70,415	59,832	0,000	59,832

3.2.1.1.2 Calculation results, Node-to-node anchor, Eq- (flood, Kh, corroded, final surface level) [Phase\_15] (15/439), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	2018	1	100,000	89,600	19,667	0,000	19,667
Element 1-1 (Node-to-node anchor)	32306	2	71,022	81,835	19,667	0,000	19,667
NodeToNodeAnchor\_1\_1	6602	1	100,000	77,600	97,564	0,000	97,564
Element 3-3 (Node-to-node anchor)	32364	2	84,593	70,415	97,564	0,000	97,564

3.2.1.1.3 Calculation results, Node-to-node anchor, Long-term (corroded, final surface level) [Phase\_18] (18/854), Table of node-to-node anchors

Structural element	Node [ $10^3$ ]	Local number	X [ft]	Y [ft]	N [ $10^3$ lbf]	N <sub>min</sub> [lbf]	N <sub>max</sub> [ $10^3$ lbf]
NodeToNodeAnchor\_4\_1	2018	1	100,000	89,600	14,677	0,000	16,073
Element 1-1 (Node-to-node anchor)	32306	2	71,022	81,835	14,677	0,000	16,073
NodeToNodeAnchor\_1\_1	6602	1	100,000	77,600	59,130	0,000	59,832
Element 3-3 (Node-to-node anchor)	32364	2	84,593	70,415	59,130	0,000	59,832

## **APPENDIX C: PYWALL model calculations**

# Wingwall 3 (design section WW3-1) results

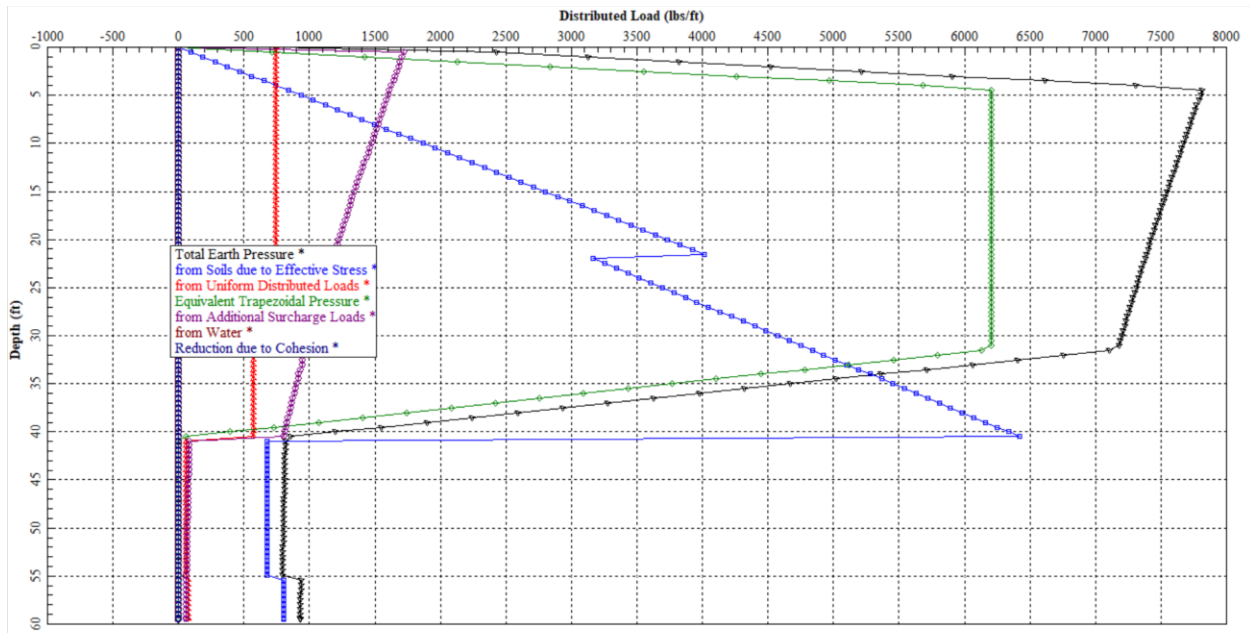


Figure 1 Pressure diagrams following trapezoidal pressure for anchored walls

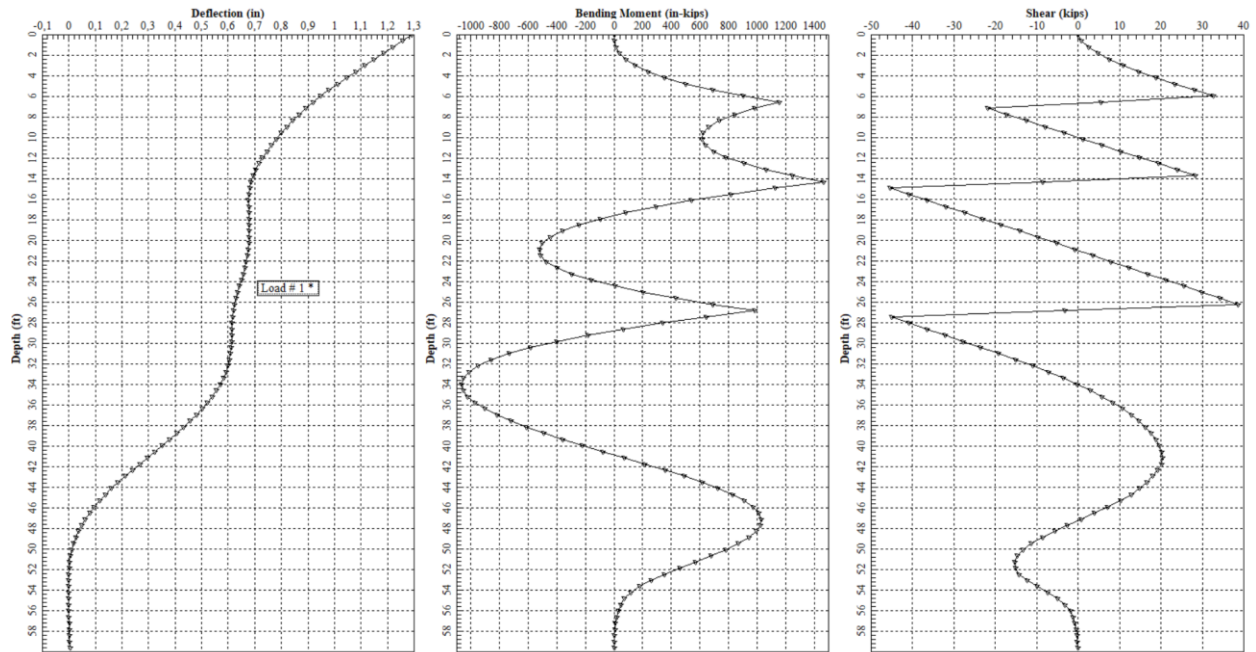


Figure 2 Deflection, bending moment and shear diagrams

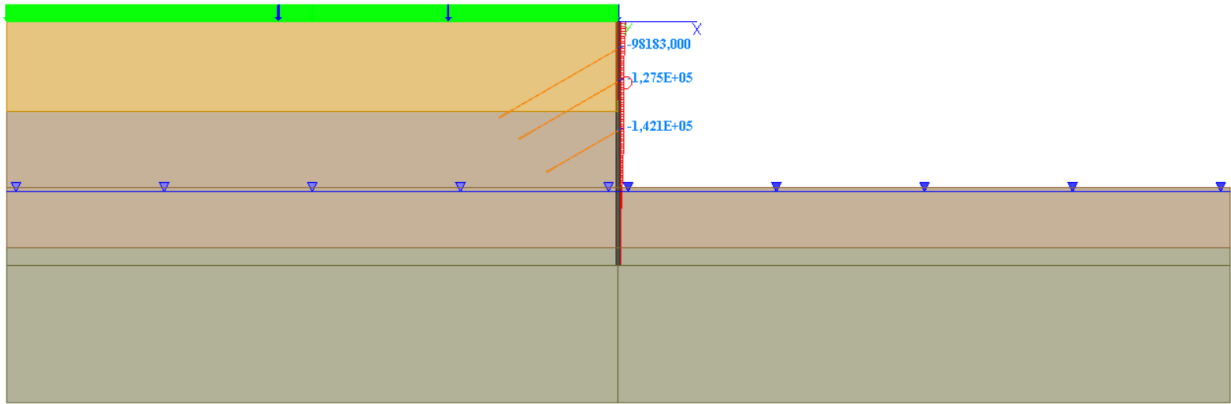


Figure 3 Model cross section with tie-back loads (in lb)

## Wingwall 4 (design section WW4-1) results

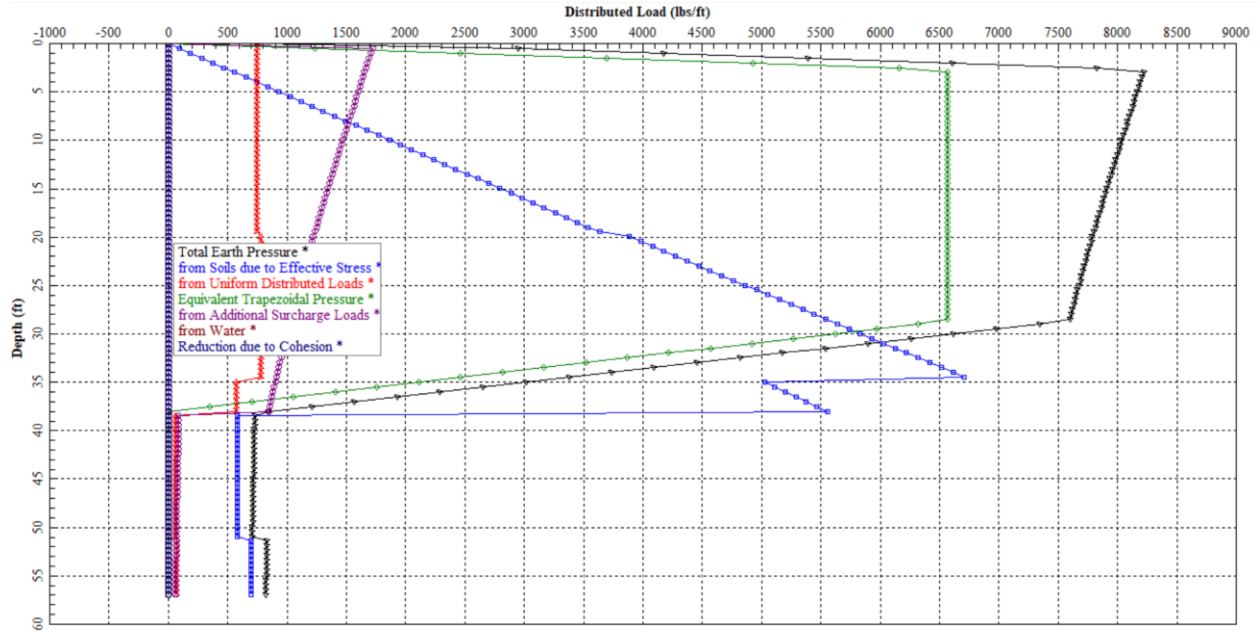


Figure 4 Pressure diagrams following trapezoidal pressure for anchored walls

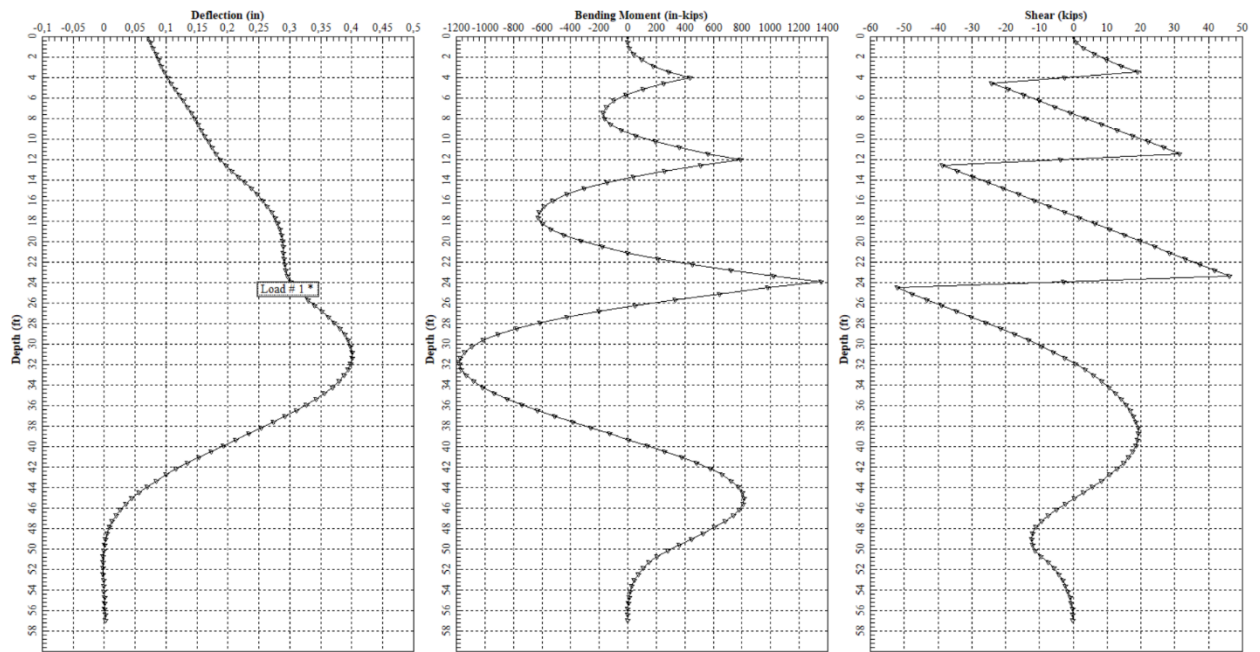


Figure 5 Deflection, bending moment and shear diagrams

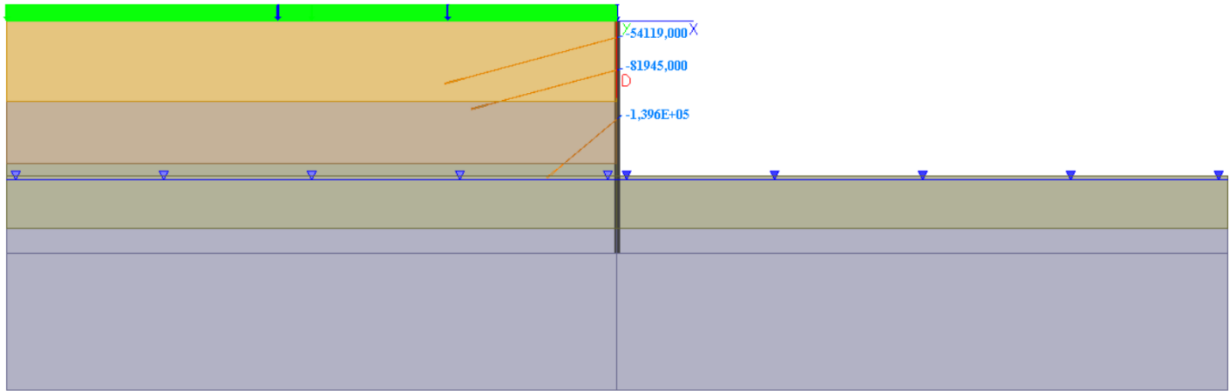


Figure 6 Model cross section with tie-back loads (in lb)

## **APPENDIX D: Fascia structural calculations**

## Technical summary

This appendix addresses the structural design of the permanent structures of the East Portal, including the following:

- East portal northern wingwall

- East portal southern wingwall

- East portal headwall fascia

The design considers permanent and extreme loads during the design life of the structure, as per the AASHTO limit states. It also includes consideration of corrosion according to the structure's exposure class.

## Calculation inputs

### Concrete

Calculation considers a compressive strength ( $f_c'$ ) of 4.00 ksi for the concrete, complying with the requirements of the WSDOT BDM. For that concrete class and according to AASHTO LRFD Section 5 the following properties are derived:

- Modulus of elasticity = 3 605 000 psi
- Unit-weight = 145 pcf.
- Poisson's ratio = 0.2.

### Reinforcement

Reinforcement steel bars will be uncoated, grade 60, compliant with ASTM A706 and with a modulus of elasticity of 29 000 ksi. The reinforcement bars considered available for the design are #3, #4, #5, #6, #8 and #10 (ASTM standard).

The minimum reinforcement requirement of #4 spaced at 12" centers is considered in the design process.

### Cover

The cover considered in the calculation is set as 2 inches clear.

### Loads

The loads used for the concrete fascia design are the apparent earth pressures, earth surcharge, water (if applicable) and live load at surface in static condition. While in seismic condition, the earth pressure accounting for dynamic effects is also considered (plus the static condition loads).

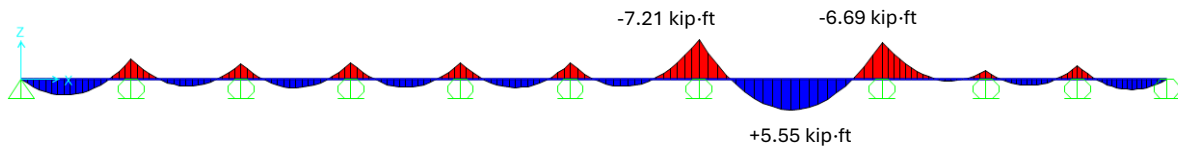
The load factors considered in the design are as presented in Section 4.3 of the report. Loads are combined accordingly using the factors presented.

## East portal fascia wingwalls

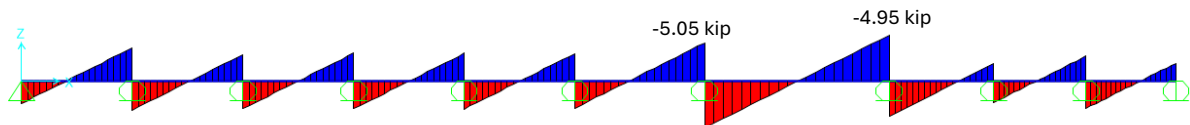
The fascia of the east portal structures has been assessed using a standard based spreadsheet, where the nominal loads and the properties of the structure are introduced. This spreadsheet performs the structural verifications needed according to AASHTO at Strength I, Extreme Event I and Service I states. It considers horizontal bending (between soldier piles) as continuous spans (allowing negative flexural bending at supports; soldier piles).

The southern wingwall (Wingwall 3) concrete fascia has been designed with an 8.00 ft span (panel length), 14-inch thickness with a flexural reinforcement of #4 at 8" spacing on both faces without shear reinforcement.

The northern wingwall (Wingwall 4) concrete fascia considers an irregular span distribution. To evaluate the maximum positive and negative bending moment and shear, the structure was modelled in SAP2000, so the magnitude of both maximum bending and shear forces can be checked. This model has used a distributed load of 1 kip/ft, from which the results (maximum shear and moments) will be proportional to the ones acting on the fascia. To obtain the relevant structural forces, the maximum bending moments and shear forces of the model will be multiplied by the acting pressures to obtain the final design forces.



Unit load (1kip/ft) moment distribution. Wingwall 4



Unit load (1kip/ft) shear distribution. Wingwall 4

The Wingwall 4 concrete fascia has been designed with a maximum 10.00 ft span (panel length), 14-inch thickness with a flexural reinforcement of #4 at 8" spacing on both faces without shear reinforcement.

Calculation results are presented in the next calculation sheets.

### Input Data:

#### Material properties

Unit weight of concrete, $\gamma_{concrete}$	155	[pcf]
Yield strength of steel, $f_y$	60	[ksi]
Compressive strength of concrete, $f_c$	4.0	[ksi]
Cover, $c$	2.00	[in]

#### Geometrical properties

Length of panel, $L_{panel}$	8.00	[ft]
Thickness of wall, $D_{panel}$	14.00	[in]
Height of wall, $H_1$	10.00	[ft]
Base of calculation, $b$	12	[in]
Soldier pile width, $w_{sp}$	7.53	[in]

#### Proposed reinforcement

Bar	# 4	
Diameter of bar, $d_{bar}$	0.50	[in]
Area of bar	0.20	[in <sup>2</sup> ]
Spacing of vertical crack control reinforcement, $s$	8	[in]
Reinforcement (per length, $b$ ), $A_s$	0.295	[in <sup>2</sup> ]
Reinforcement	#4 @ 8"	



#### Calculation parameters

Material resistant factor, $\phi$ [5.5.4.2]	0.90	
Effective shear depth, $d_v = \max[d_s - a/2; 0.9 \cdot d_s; 0.72 \cdot D_{panel}]$ , [5.7.2.8]	11.53	[in]
Compression depth, $a = A_s \cdot f_y / (0.85 \cdot f_c \cdot b)$	0.43	[in]
Distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement, $d_s = D_{panel} - c - d_{bar}/2$ , [5.6.2.1]	11.75	[in]

#### Loads and load factors and forces, Strength I

Earth horizontal pressure	1034.81	[psf]	Load modifier ductility, [1.3.3]	1.05
Earth surcharge pressure	227.70	[psf]	Load modifier redundancy, [1.3.4]	1.00
Water pressure	0.00	[psf]	Load modifier operational importance, [1.3.5]	1.05
Live load pressure	75.00	[psf]	Load factor for earth horizontal pressure, [3.4.1]	1.50
Factored load pressure, Strength I	2194.92	[psf]	Load factor for earth pressure, [3.4.1]	1.35
Unfactored Bending moment, $M_i$	8.56	[kip-ft]	Load factor for Water pressure, [3.4.1]	1.00
Factored Bending moment, $M_d$	14.05	[kip-ft]	Load factor for Live load pressure, [3.4.1]	1.75
Case	2		Factored Shear force, $V_d$	7.74 [kip-ft]

#### Cases of analysis

Case 1. Simply spans	Case 2. Continuous spans	Case 3. Custom
		Asimetric continuous spans, other cases
$M_d = \frac{pl^2}{8}$ $V_d = 1 \cdot p \cdot l$	$M_d = \frac{pl^2}{10}$ $V_d = 1 \cdot p \cdot l$	$M_d = \frac{pl^2}{10.00}$ $V_d = 0.5 \cdot p \cdot l$

#### Loads and load factors and forces, Seismic

Earth horizontal pressure	1709.53	[psf]	Load factor for earth horizontal pressure, [3.4.1]	1.00
Earth surcharge pressure	227.70	[psf]	Load factor for earth pressure, [3.4.1]	1.00
Water pressure	0.00	[psf]	Load factor for Water pressure, [3.4.1]	1.00
Live load pressure	75.00	[psf]	Load factor for Live load pressure, [3.4.1]	1.00
Factored load pressure, Seismic	2012.23	[psf]		
Factored Bending moment, $M_{d, seismic}$	12.88	[kip-ft]	Factored Shear forces, $V_{d, seismic}$	7.09 [kip-ft]



Spreadsheet

Job No.

Sheet No.

CONCRETE FASCIA

Created by:

CAD

2 of 2

Date:

17/12/2024

Job Title:

Brickyard I-405. Juanita Creek

Verified by:

PGB

Rev.

Subject:

East Portal. South Fascia

Date:

17/12/2024

V.01

### Flexural design

$$M_r = \phi \cdot A_s \cdot f_y \cdot (d - a/2) \quad [5.6.3.2.2]$$

15.29 [kip-ft]

OK,  $M_r > M_d$

$$M_{r, \text{extreme}} = M_r / \phi \quad [11.5.7]$$

16.98 [kip-ft]

OK,  $M_{r, \text{extreme}} > M_{d, \text{seismic}}$

### Shear Design

$$\phi_c \quad [5.5.4.2]$$

0.90

$$b \quad [5.7.3.4.1]$$

2.00

$$V_c = 0.0316 \cdot \beta \cdot (fc)^{1/2} \cdot d_v \cdot b \quad [5.7.3.3]$$

17.49 [kip]

$$0.5 \cdot \phi_s \cdot V_c \quad [5.7.2.3]$$

7.87

$$0.5 \cdot \phi_s \cdot V_c > V_d \rightarrow \text{No transversal reinf.}$$

No transv. Reinforcement

$$0.5 \cdot V_c$$

8.75

$$0.5 \cdot V_c > V_{d, \text{seismic}} \rightarrow \text{No transversal reinf.}$$

No transv. Reinforcement

### Temperature and Shrinkage

$$A_s, \text{temp.o} = (1.3 \cdot b \cdot D_{\text{panel}}) / (2(b + D_{\text{panel}})) \cdot f_y \quad [5.10.6-1]$$

0.070 [in<sup>2</sup>/ft]

$$0.11 \leq A_s \leq 0.60 \rightarrow A_s$$

[5.10.6-2] 0.110 [in<sup>2</sup>/ft]

### Minimum reinforcement

$$M_u (\max(M_d, M_{d, \text{seismic}}))$$

14.05 [kip-ft]

$$\text{Flexural cracking variability factor, } \gamma_1, \quad [5.6.3.3]$$

1.60

$$\text{Ratio of specified minimum yield strength to ultimate tensile strength, } \gamma_3, \quad [5.6.3.3]$$

0.75

$$\text{Section modulus, } S_c, \quad [5.6.3.3]$$

392.00 [in<sup>3</sup>]

$$M_{cr} = \gamma_3 [(\gamma_1 f_r) S_c]$$

18.82 [kip-ft]

$$M_{\text{min.reinf}} = \min(M_u; M_{cr})$$

14.05

$$M_r > M_{\text{min.reinf}}$$

OK

### Control of Cracking by Distribution of Reinforcement

$$d_c = c_{\text{cover}} + d_{\text{bar}} / 2$$

2.250 [in]

$$k_1, \quad [5.4.2.4]$$

1.00

$$E_c = 120000 \cdot k_1 \cdot (\gamma_{\text{conc}})^2 \cdot f_c^{0.33}, \quad [5.4.2.4]$$

4555.38 [ksi]

$$E_s, \quad [5.4.3.2]$$

29000 [ksi]

$$n = E_s / E_c$$

6.37

$$\beta_s = 1 + d_c / (0.70 \cdot (h - d_c)), \quad [5.6.7]$$

1.27

$$\gamma_{cr}, \quad [5.6.7]$$

0.75

$$\rho_s = A_s / (b \cdot d)$$

0.002089

$$k = (\rho_s \cdot n)^2 + 2 \cdot \rho_s \cdot n^{0.50} - \rho_s \cdot n$$

0.150

$$j = 1 - k/3$$

0.950

$$f_{ss} < [M/A_s \cdot j \cdot d; 0.6 \cdot f_y], \quad [5.6.7]$$

31.25 [ksi]

$$s = 700 \cdot \gamma_{cr} / (\beta_s \cdot f_{ss}) - 2 \cdot d_c, \quad [5.6.7]$$

8.69 [in]

$$s \geq s_v$$

OK

### Summary

Main Reinforcement:

Retained Side #4 @8"

Opposite Side #4 @8"

### Input Data:

#### Material properties

Unit weight of concrete, $\gamma_{concrete}$	155	[pcf]
Yield strength of steel, $f_y$	60	[ksi]
Compressive strength of concrete, $f_c$	4.0	[ksi]
Cover, $c$	2.00	[in]

#### Geometrical properties

Length of panel, $L_{panel}$	10.00	[ft]
Thickness of wall, $D_{panel}$	14.00	[in]
Height of wall, $H_1$	10.00	[ft]
Base of calculation, $b$	12	[in]
Soldier pile width, $w_{sp}$	7.53	[in]

#### Proposed reinforcement

Bar	# 4	
Diameter of bar, $d_{bar}$	0.50	[in]
Area of bar	0.20	[in <sup>2</sup> ]
Spacing of vertical crack control reinforcement, $s$	8	[in]
Reinforcement (per length, $b$ ), $A_s$	0.29	[in <sup>2</sup> ]
Reinforcement	#4 @ 8"	



#### Calculation parameters

Material resistant factor, $\phi$ [5.5.4.2]	0.90	
Effective shear depth, $d_v = \max[d_s - a/2; 0.9 \cdot d_s; 0.72 \cdot D_{panel}]$ , [5.7.2.8]	11.53	[in]
Compression depth, $a = A_s \cdot f_y / (0.85 \cdot f_c \cdot b)$	0.43	[in]
Distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement, $d_s = D_{panel} - c - d_{bar}/2$ , [5.6.2.1]	11.75	[in]

#### Loads and load factors and forces, Strength I

Earth horizontal pressure	959.07	[psf]	Load modifier ductility, [1.3.3]	1.05
Earth surcharge pressure	132.00	[psf]	Load modifier redundancy, [1.3.4]	1.00
Water pressure	0.00	[psf]	Load modifier operational importance, [1.3.5]	1.05
Live load pressure	75.00	[psf]	Load factor for earth horizontal pressure, [3.4.1]	1.50
Factored load pressure, Strength I	1927.23	[psf]	Load factor for earth pressure, [3.4.1]	1.35
Unfactored Bending moment, $M_i$	8.41	[kip-ft]	Load factor for Water pressure, [3.4.1]	1.00
Factored Bending moment, $M_d$	13.90	[kip-ft]	Load factor for Live load pressure, [3.4.1]	1.75
Case	3		Factored Shear force, $V_d$	7.28 [kip-ft]

#### Cases of analysis

Case 1. Simply spans	Case 2. Continuous spans	Case 3. Custom
 $M_d = \frac{pl^2}{8}$ $V_d = 1 \cdot p \cdot l$	 $M_d = \frac{pl^2}{10}$ $V_d = 1 \cdot p \cdot l$	<p>Asimetric continuous spans, other cases</p> $M_d = \frac{pl^2}{13.86}$ $k_1 = (1/7.2147 \cdot l^2)$ $V_d = 0.51 \cdot p \cdot l$ $k_2 = (5.02/l)$

#### Loads and load factors and forces, Seismic

Earth horizontal pressure	1650.93	[psf]	Load factor for earth horizontal pressure, [3.4.1]	1.00
Earth surcharge pressure	132.00	[psf]	Load factor for earth pressure, [3.4.1]	1.00
Water pressure	0.00	[psf]	Load factor for Water pressure, [3.4.1]	1.00
Live load pressure	75.00	[psf]	Load factor for Live load pressure, [3.4.1]	1.00
Factored load pressure, Seismic	1857.93	[psf]		
Factored Bending moment, $M_{d, seismic}$	13.40	[kip-ft]	Factored Shear forces, $V_{d, seismic}$	7.02 [kip-ft]

### Flexural design

$$M_r = \phi \cdot A_s \cdot f_y \cdot (d - a/2) \quad [5.6.3.2.2]$$

**15.29** [kip-ft]

OK,  $M_r > M_d$

$$M_{r, \text{extreme}} = M_r / \phi \quad [11.5.7]$$

**16.98** [kip-ft]

OK,  $M_{r, \text{extreme}} > M_{d, \text{seismic}}$

### Shear Design

$$\phi_c \quad [5.5.4.2]$$

**0.90**

$$b \quad [5.7.3.4.1]$$

**2.00**

$$V_c = 0.0316 \cdot \beta \cdot (fc)^{1/2} \cdot d_v \cdot b \quad [5.7.3.3]$$

**17.49** [kip]

$$0.5 \cdot \phi_s \cdot V_c \quad [5.7.2.3]$$

**7.87**

$$0.5 \cdot \phi_s \cdot V_c > V_d \rightarrow \text{No transversal reinf.}$$

No transv. Reinforcement

$$0.5 \cdot V_c$$

**8.75**

$$0.5 \cdot V_c > V_{d, \text{seismic}} \rightarrow \text{No transversal reinf.}$$

No transv. Reinforcement

### Temperature and Shrinkage

$$A_{s, \text{temp.o}} = (1.3 \cdot b \cdot D_{\text{panel}}) / (2(b + D_{\text{panel}})) \cdot f_y$$

[5.10.6-1]

**0.070** [in<sup>2</sup>/ft]

$$0.11 \leq A_s \leq 0.60 \rightarrow A_s$$

[5.10.6-2]

**0.110** [in<sup>2</sup>/ft]

### Minimum reinforcement

$$M_u (\max(M_d, M_{d, \text{seismic}}))$$

**13.90** [kip-ft]

$$\text{Flexural cracking variability factor, } \gamma_1, \quad [5.6.3.3]$$

**1.60**

$$\text{Ratio of specified minimum yield strength to ultimate tensile strength, } \gamma_3, \quad [5.6.3.3]$$

**0.75**

$$\text{Section modulus, } S_c, \quad [5.6.3.3]$$

**392.00** [in<sup>3</sup>]

$$M_{cr} = \gamma_3 [(\gamma_1 f_t) S_c]$$

**18.82** [kip-ft]

$$M_{\text{min.reinf}} = \min(M_u; M_{cr})$$

**13.90**

$$M_r > M_{\text{min.reinf}}$$

OK

### Control of Cracking by Distribution of Reinforcement

$$d_c = c_{\text{cover}} + d_{\text{bar}} / 2$$

**2.250** [in]

$$k_1, \quad [5.4.2.4]$$

**1.00**

$$E_c = 120000 \cdot k_1 \cdot (\gamma_{\text{conc}})^2 \cdot f_c^{0.33}, \quad [5.4.2.4]$$

**4555.38** [ksi]

$$E_s, \quad [5.4.3.2]$$

**29000** [ksi]

$$n = E_s / E_c$$

**6.37**

$$\beta_s = 1 + d_c / (0.70 \cdot (h - d_c)), \quad [5.6.7]$$

**1.27**

$$\gamma_{cr}, \quad [5.6.7]$$

**0.75**

$$\rho_s = A_s / (b \cdot d)$$

**0.002089**

$$k = (\rho_s \cdot n)^2 + 2 \cdot \rho_s \cdot n^{0.50} - \rho_s \cdot n$$

**0.150**

$$j = 1 - k/3$$

**0.950**

$$f_{ss} < [M/A_s \cdot j \cdot d; 0.6 \cdot f_y], \quad [5.6.7]$$

**30.71** [ksi]

$$s = 700 \cdot \gamma_{cr} / (\beta_s \cdot f_{ss}) - 2 \cdot d_c, \quad [5.6.7]$$

**8.92** [in]

$$s \geq s_v$$

OK

### Summary

Main Reinforcement:

Retained Side **#4 @8"**

Opposite Side **#4 @8"**

## East portal headwall

The permanent long-term structure is designed to consist of a 14-inch-thick concrete fascia, simply supported (with no rotation constraint) at the contact points with the wingwalls and the tunnel lining. Permanent anchors are also included as part of the structural support.

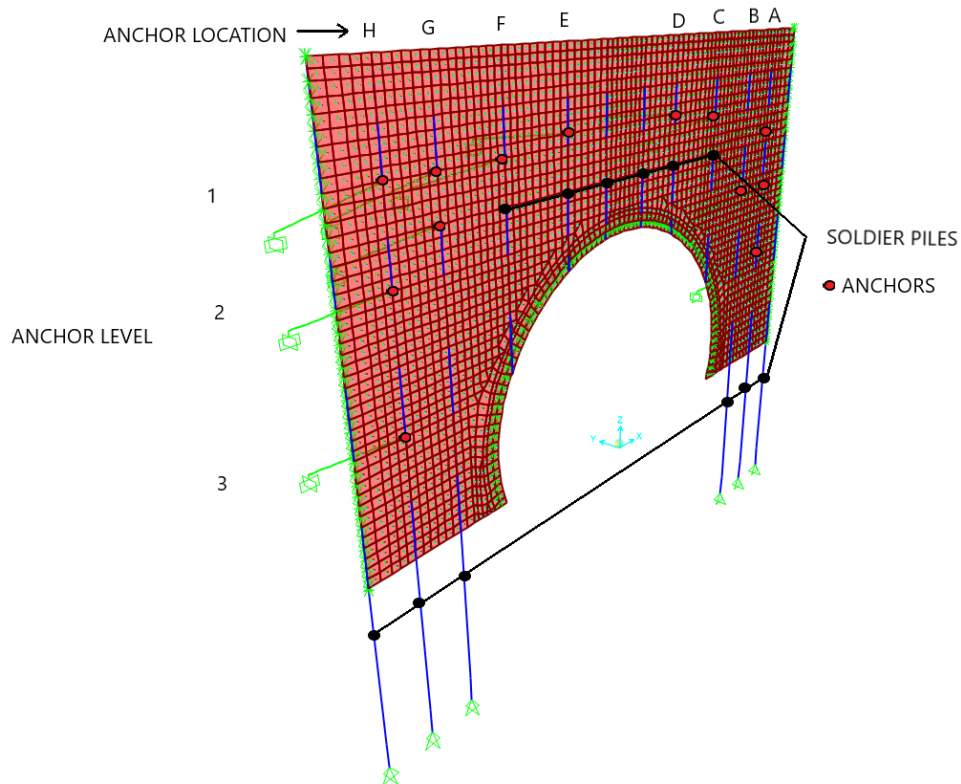
The structure has been evaluated against Strength I, Extreme Event I, and Service I load combinations. The fascia thickness has been sized to ensure that a maximum displacement of 1 inch under Service I conditions is satisfied.

For this analysis, a SAP2000 non-linear model was used to perform the calculations.

The calculations made do not consider staging or intermediate construction phases, being a wish-in place verification, where all the loads are applied directly to the structure in its permanent configuration and dimensions. Refer to Section 6 in the main document for the apparent earth pressure derived in the permanent configuration.

### SAP 2000 model inputs

In the following figure the three-dimensional SAP2000 model is shown:



Headwall-2 SAP2000 model geometry.

The fascia wall is modeled with a 14" thickness using 4000 psi concrete.

**S** Shell Section Data X

**Section Name** FASCIA Display Color ■

**Section Notes** Modify/Show...

---

**Type**

Shell - Thin  
 Shell - Thick  
 Plate - Thin  
 Plate Thick  
 Membrane  
 Shell - Layered/Nonlinear

Modify/Show Layer Definition...

---

**Thickness**

Membrane   
 Bending

---

**Material**

Material Name  ▼  
 Material Angle

---

**Time Dependent Properties**

Set Time Dependent Properties...

---

**Concrete Shell Section Design Parameters**

Modify/Show Shell Design Parameters...

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**Stiffness Modifiers** Temp Dependent Properties

OK Cancel

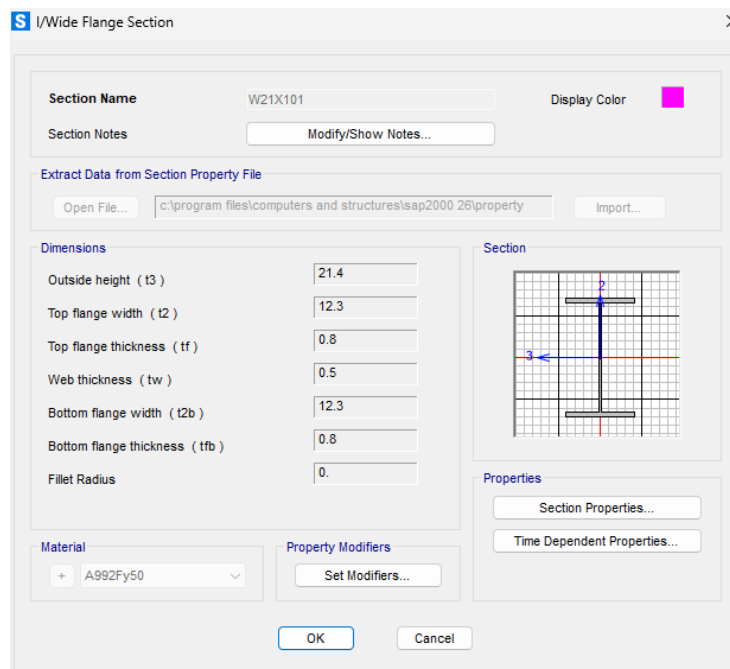
Headwall-2 SAP2000 fascia definition (inches)

The tie-backs have been simulated with cable type structures with a virtual length. Due to this virtual length, equivalent properties have been used. In the following tables a summary of the properties of the tie-backs is shown:

Real lengths (to mid-point of bulb) ( $l_0$ [ft])								
Level	Tie-back							
	A	B	C	D	E	F	G	H
1	65	56	69	75	75	69	67	67
2	60						63	59
3	46							46
Calculation length ( $l$ [ft])								
Level	Tie-back							
	A	B	C	D	E	F	G	H
1	11.35	11.85	10.97	10.2	10.2	10.97	11.35	11.35
2	11.35						11.35	11.35
3	11.85							11.85

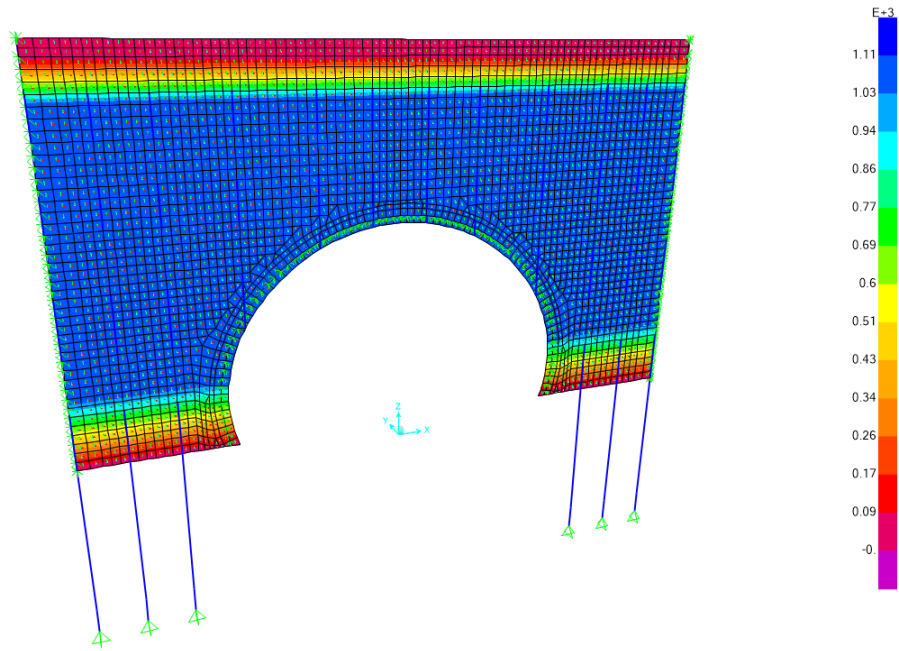
Equivalent Stiffness (E [psf])								
Level	Tie-back							
	A	B	C	D	E	F	G	H
1	7.12E+08	8.63E+08	6.48E+08	5.54E+08	5.54E+08	6.48E+08	6.91E+08	6.91E+08
2	7.71E+08						7.34E+08	7.84E+08
3	1.05E+09							1.05E+09

The soldier piles section used does not account for the concrete around the steel beam, being the calculation on the safe side:

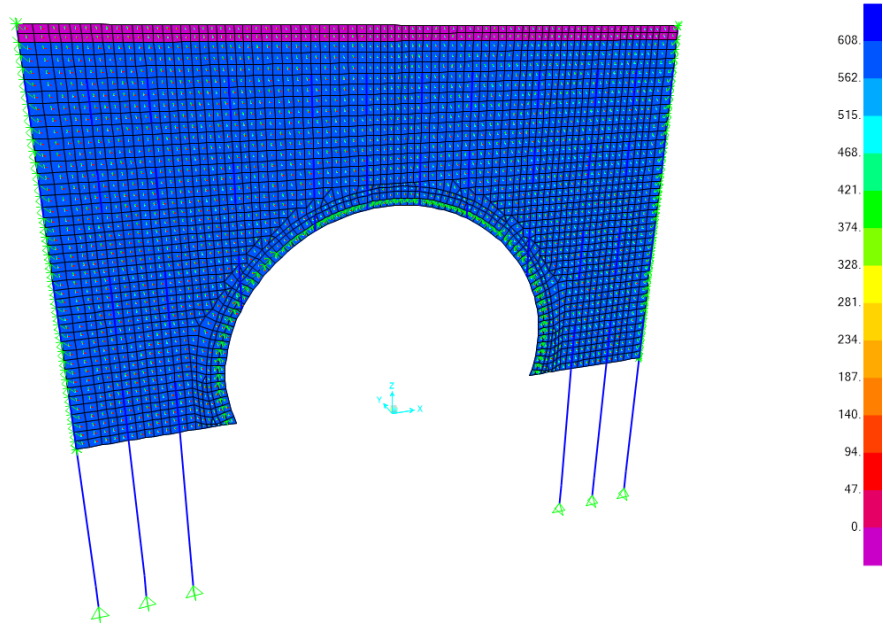


Headwall-2 SAP2000 soldier pile definition (inches)

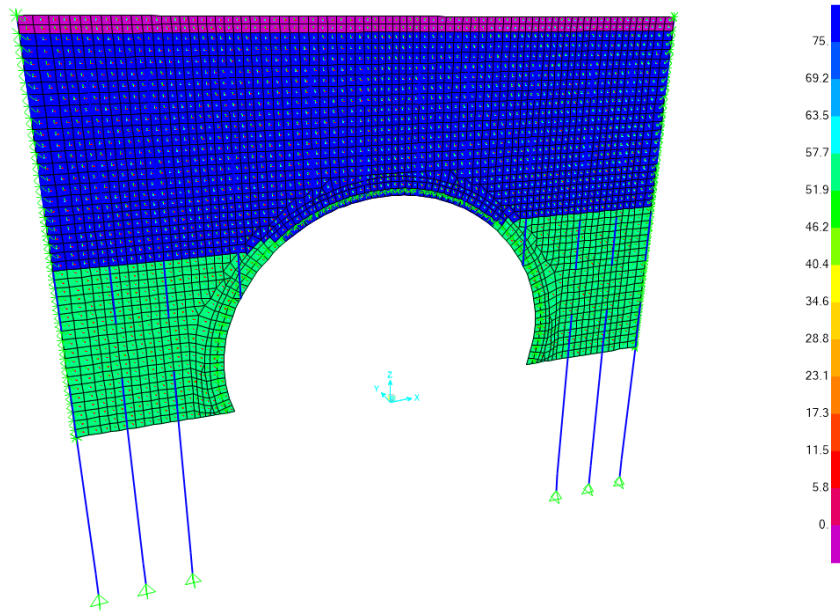
The loads applied to the model are the Apparent Earth Pressure, Earth Pressure due to Surcharges, Prestress, Self-weight and Apparent Dynamic Earth Pressure (due to seismic effects).



Headwall-2 SAP2000 Apparent Earth Pressure (psf)



Headwall-2 SAP2000 Dynamic Apparent Earth Pressure (psf)



Headwall-2 SAP2000 Surcharge Apparent Earth Pressure (psf)

Tie-backs pre-stress forces have been introduced applying and equivalent temperature variation (decrease) computed based on the cable's thermal coefficient. The initial value of the pre-stress force is based on the lock-off load (refer to section 7 in main document). The pre-stress has been adjusted locally to allow the fascia meet the Serviceability criteria.

## SAP 2000 model outputs

The structure must be verified against the following situations:

Serviceability:

Maximum 1 inch displacement at Service 1 load combination

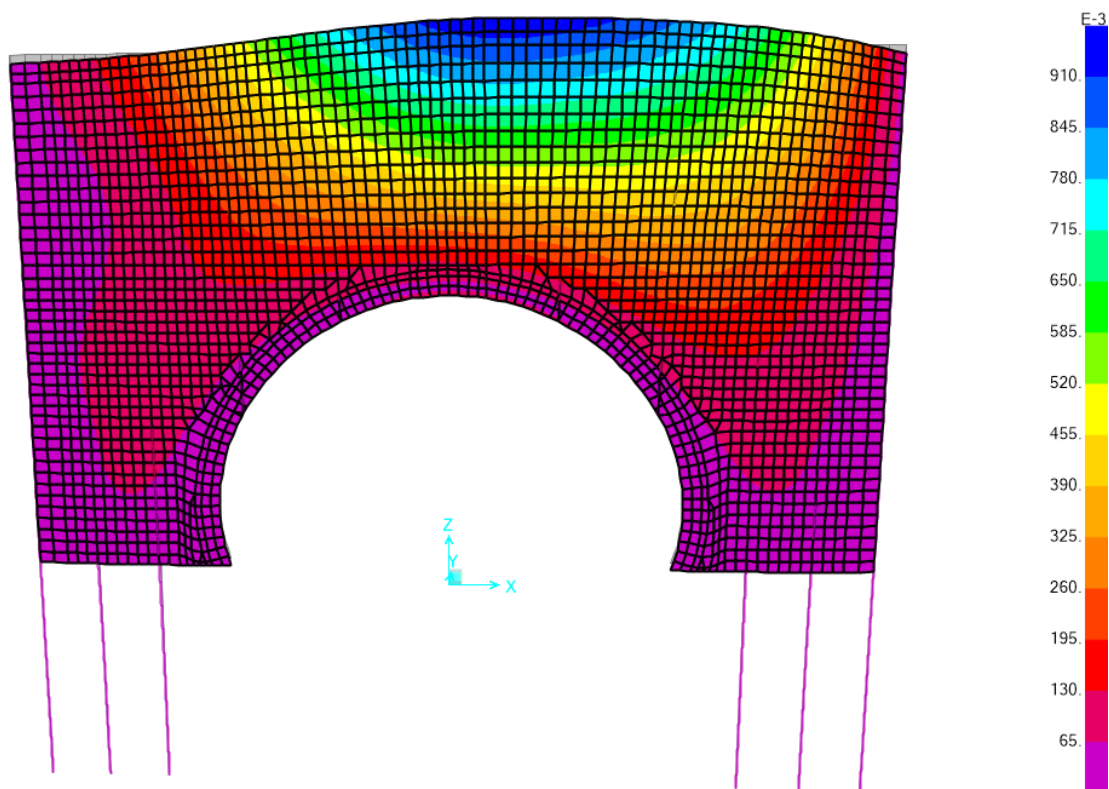
Cracking verification

Strength (structural verification):

Determination of the reinforcement against Strength 1 load combination.

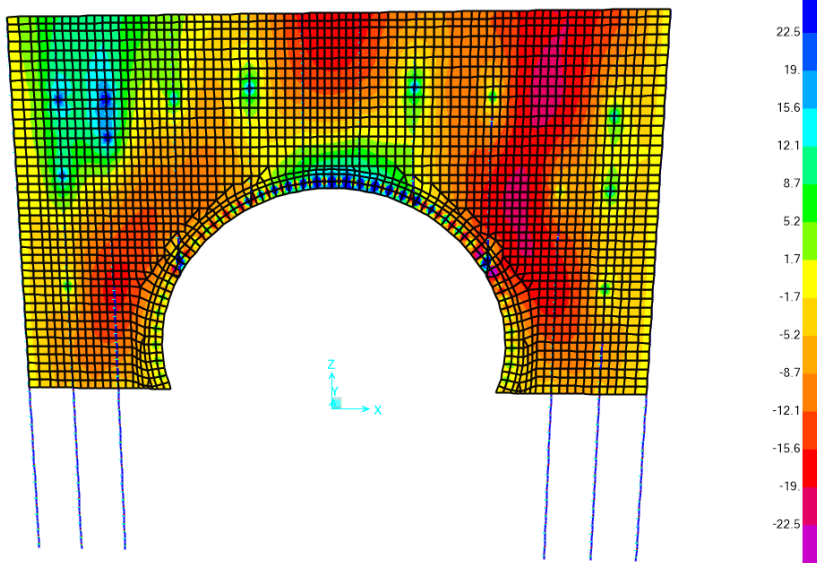
Determination of the reinforcement against Extreme Event 1 load combination.

For this reason, the results of the model have been extracted. Next, the maximum displacements of the Service 1 combination load are shown:

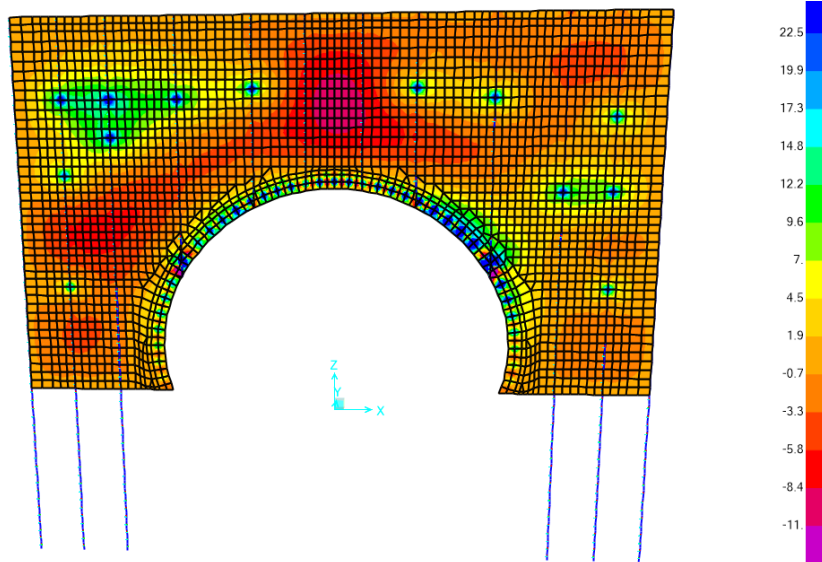


Headwall-2 SAP2000 Service 1 maximum displacements (inches)

The maximum bending moments at Service 1 load combination are shown:

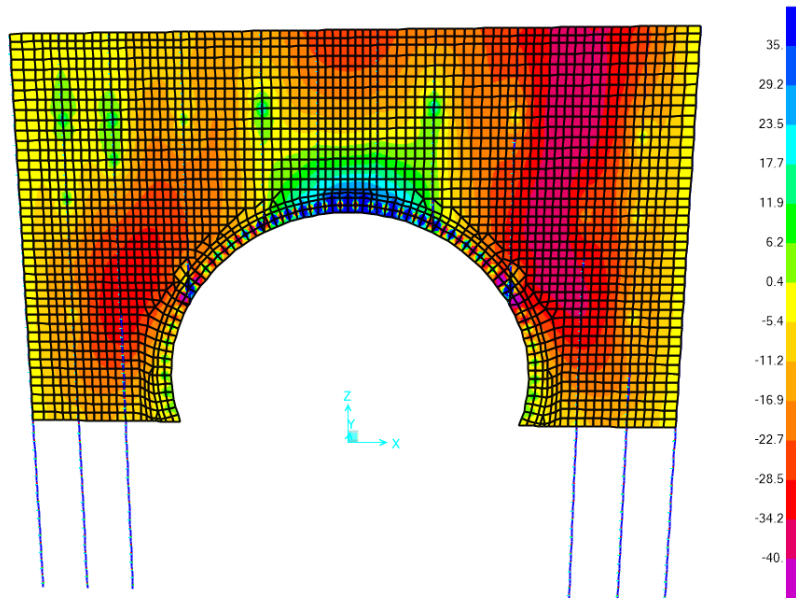


Headwall-2 SAP2000 Service 1 Bending moments (horizontal direction) (kip-ft/ft)

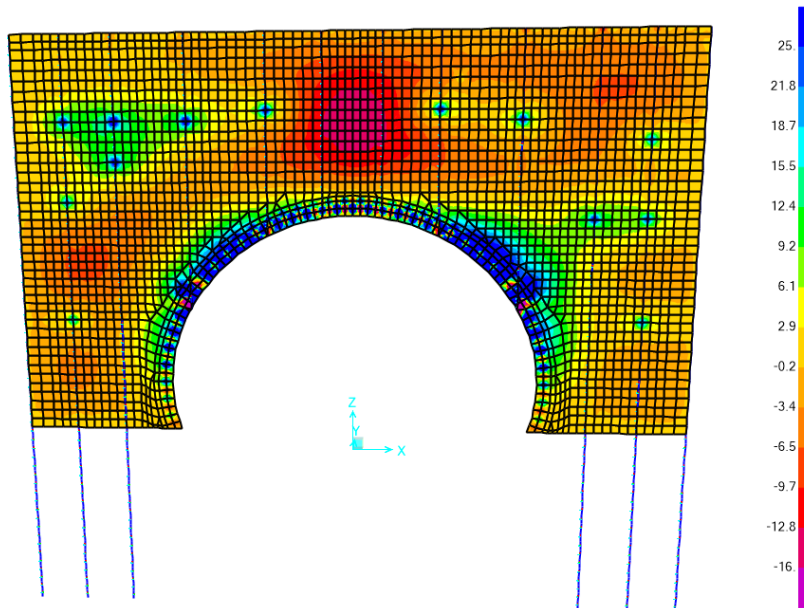


Headwall-2 SAP2000 Service 1 Bending moments (vertical direction) (kip-ft/ft)

The relevant results for structural checking against Strength 1 load combination are next shown:



Headwall-2 SAP2000 Strength 1 Bending moments (horizontal direction) (kip-ft/ft)

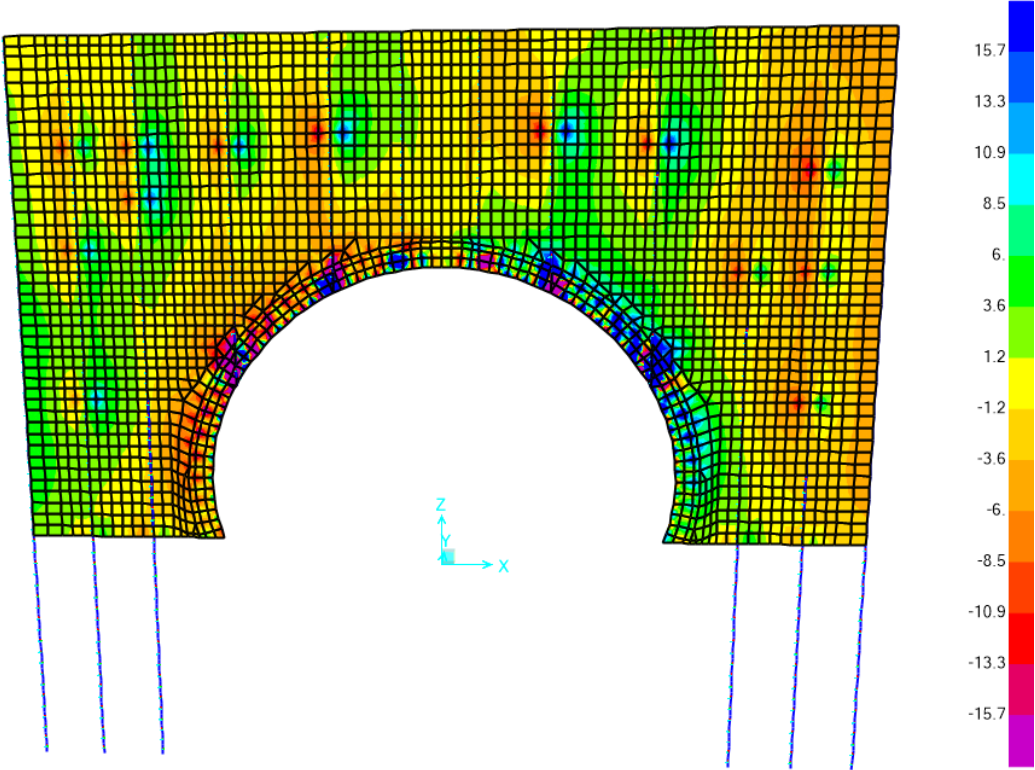


Headwall-2 SAP2000 Strength 1 Bending moments (vertical direction) (kip-ft/ft)

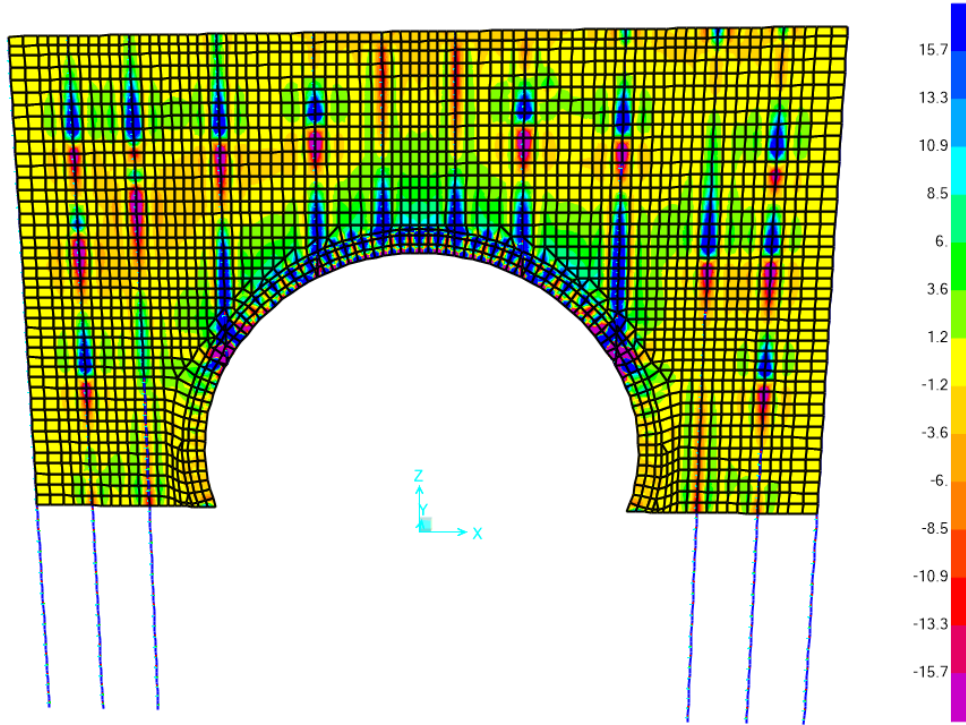
According to AASHTO (5.7.3.2), the location of the critical sections for shear shall be taken at a distance of  $d_v$  from the internal face of the support. So, all the areas which are within this distance from tie-back locations, supports and/or soldier piles, do not require of a shear verification. Next, the maximum allowable shear force determination is shown:

Shear Design	
$\phi_c$ , [5.5.4.2]	<b>0.90</b>
$\beta$ , [5.7.3.4.1]	<b>2.00</b>
$V_n=V_c = 0.0316 \cdot \beta \cdot (f_c)^{1/2} \cdot d_v \cdot b$ , [5.7.3.3]	<b>17.39</b> [kip/ft]
$V_r = \phi_s \cdot (V_c = V_n)$ 5.7.2.3]	<b>15.65</b>
$\phi_s \cdot V_c > V_d \rightarrow$ No transversal reinf.	<b>No transv. Reinforcement</b>
$V_c$	<b>17.39</b>
$V_c > V_{d, seismic} \rightarrow$ No transversal reinf.	<b>No transv. Reinforcement</b>

In the next two figures, the shear stresses, limited to the maximum and minimum allowable shear stress, are shown. In both cases, the shear forces which exceed the maximum allowable shear resistance, are located within the critical sections.

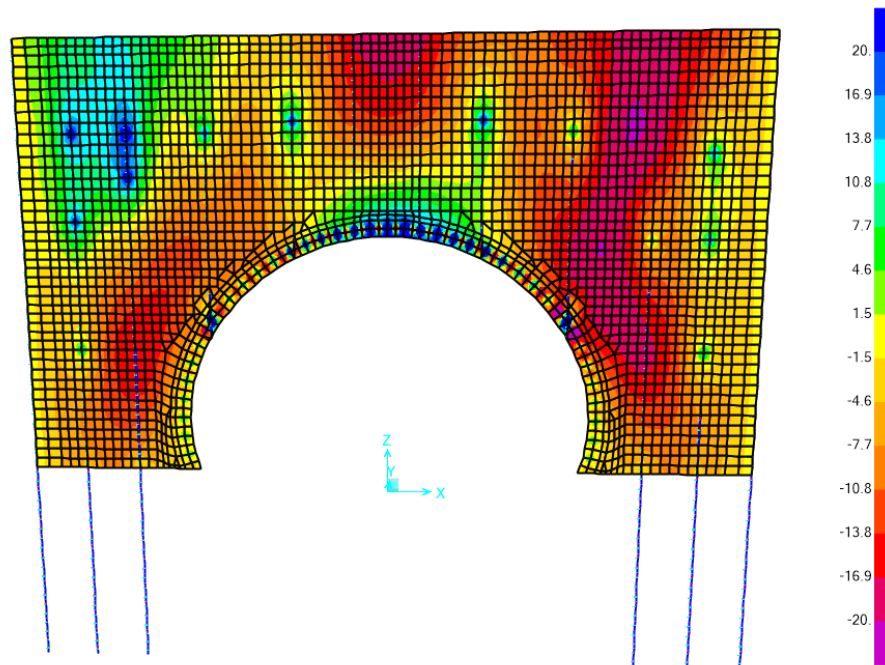


Headwall-2 SAP2000 Strength 1 Shear forces (horizontal direction) (kip/ft)

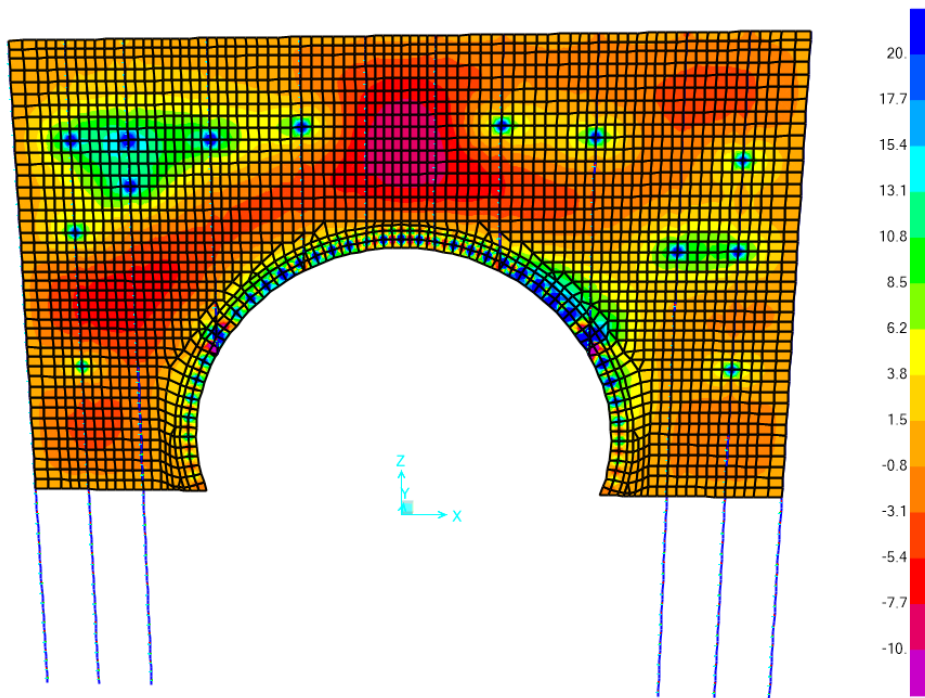


Headwall-2 SAP2000 Strength 1 Shear forces (vertical direction) (kip/ft)

The relevant results for structural checking against Extreme Event 1 load combination are next shown:

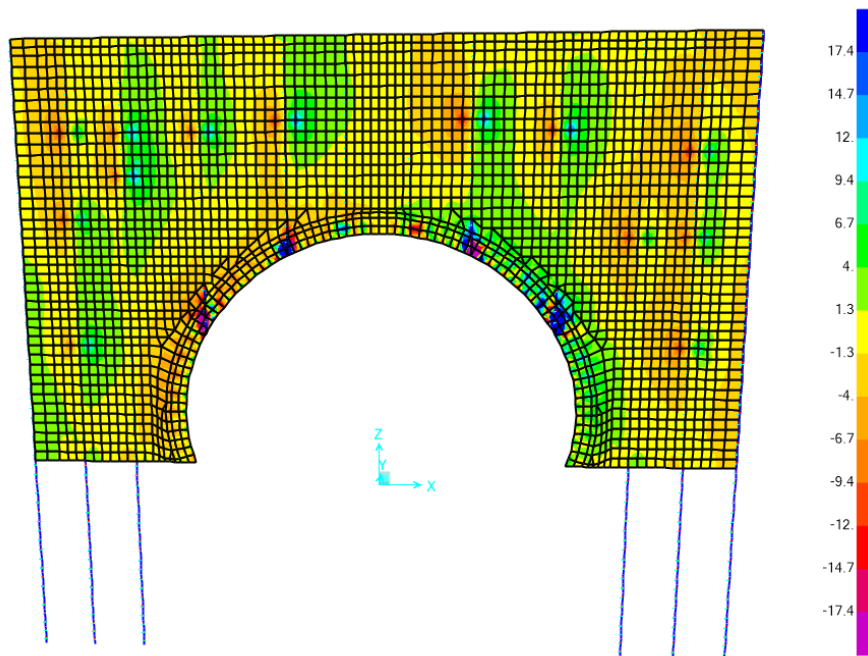


Headwall-2 SAP2000 Extreme Event 1 Bending moments (horizontal direction) (kip-ft/ft)

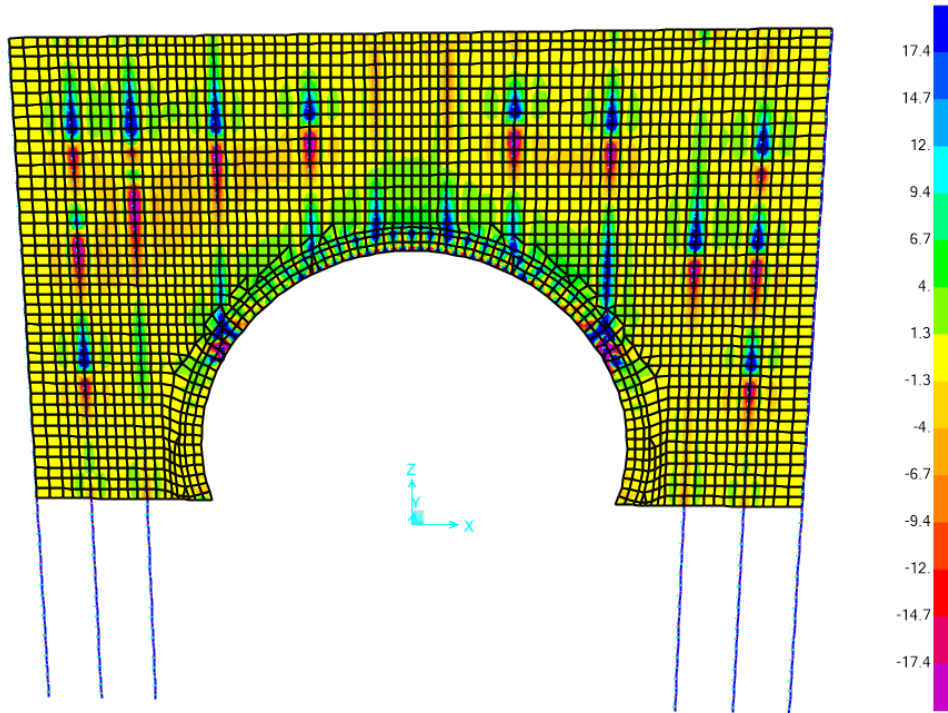


Headwall-2 SAP2000 Extreme Event 1 Bending moments (vertical direction) (kip-ft/ft)

As for Strength 1, the shear forces displayed have been limited to the maximum allowable in Extreme Event 1 case.



Headwall-2 SAP2000 Extreme Event 1 Shear forces (horizontal direction) (kip/ft)



Headwall-2 SAP2000 Extreme Event 1 Shear forces (vertical direction) (kip/ft)

Both vertical and horizontal shear stresses meet the structural requirements of AASHTO beyond the critical sections.

### Structural checks

The fascia has been verified against shear (which has been done graphically in the previous section), bending moment (Strength 1 and Extreme Event 1) and cracking (by analyzing the reinforcement distribution).

First, the analysis of the horizontal stresses has been made considering a base reinforcement of #5@6inches, which maximum bending resistance is next assessed:

### Flexural design

$$M_r = \phi \cdot A_s \cdot f_y \cdot (d - a/2),$$

[5.6.3.2.2]

$$15.34 \quad [\text{kip}\cdot\text{ft}]$$

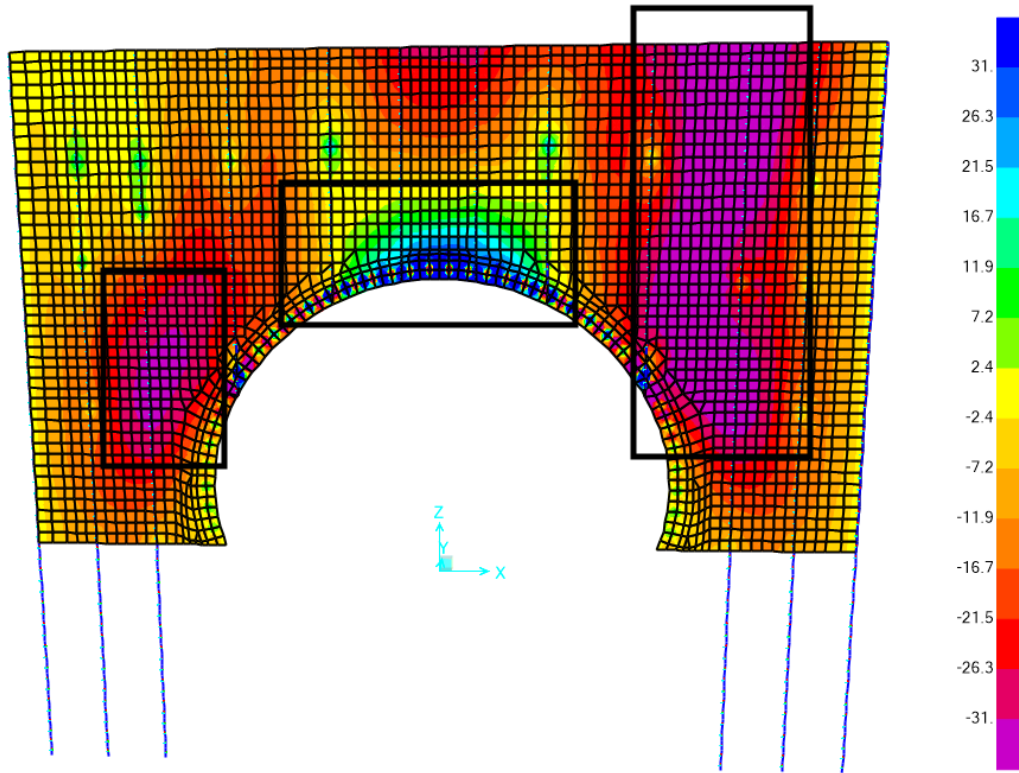
OK,  $M_r > M_d$

$$M_{r, \text{extreme}} = M_r / \phi, [11.5.7]$$

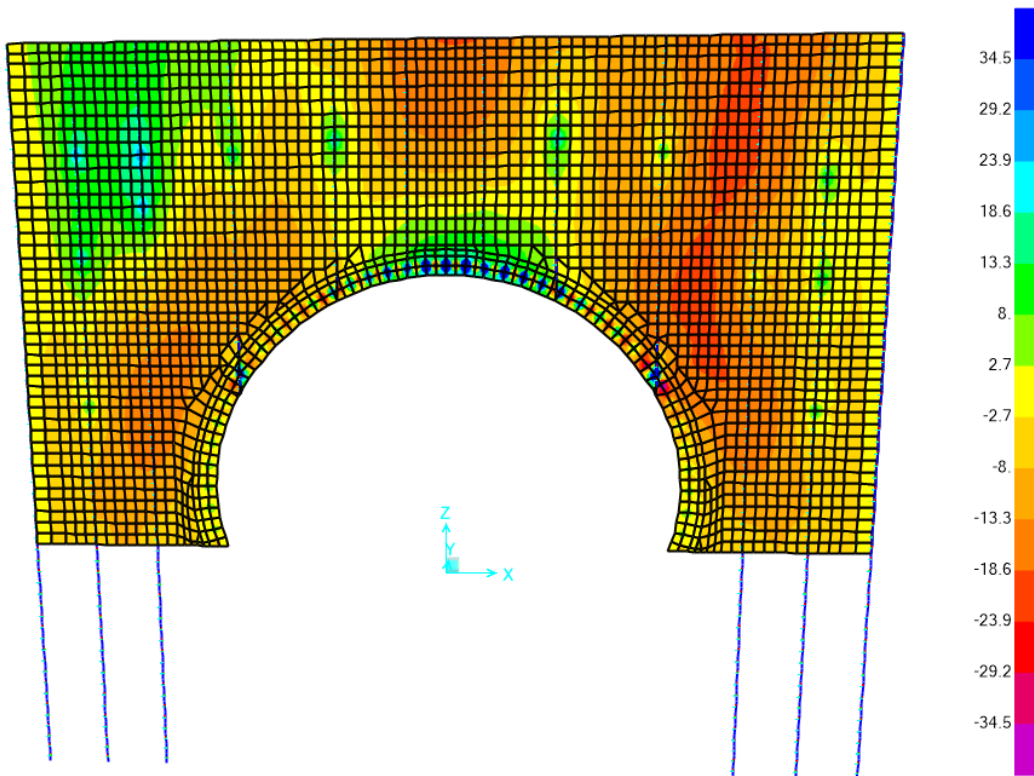
$$17.05 \quad [\text{kip}\cdot\text{ft}]$$

OK,  $M_{r, \text{extreme}} > M_{d, \text{seismic}}$

In the next figures, the stresses associated to bending moments are plotted by limiting the maximum stress to the maximum allowable in each case (either Strength or Extreme):



Headwall-2 SAP2000 Strength 1 Bending moments (horizontal direction) #5@6" (kip-ft/ft)



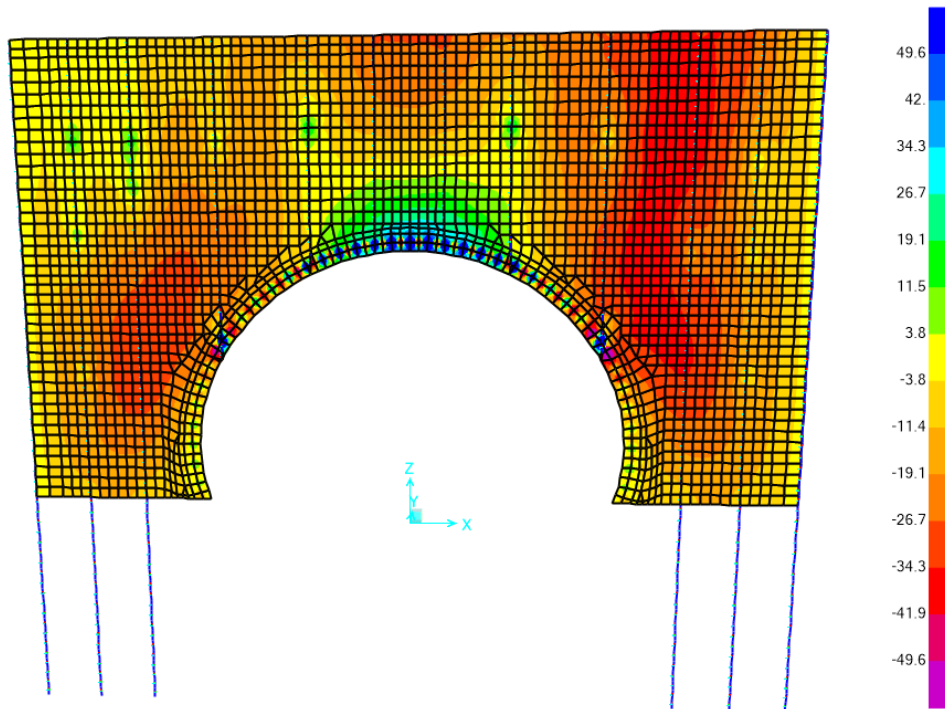
Headwall-2 SAP2000 Extreme Event 1 Bending moments (horizontal direction) #5@6" (kip·ft/ft)

The highlighted areas (in magenta) will require additional horizontal reinforcements in the outer face of the fascia. The ones in blue will need additional horizontal reinforcements in the inner face of the fascia.

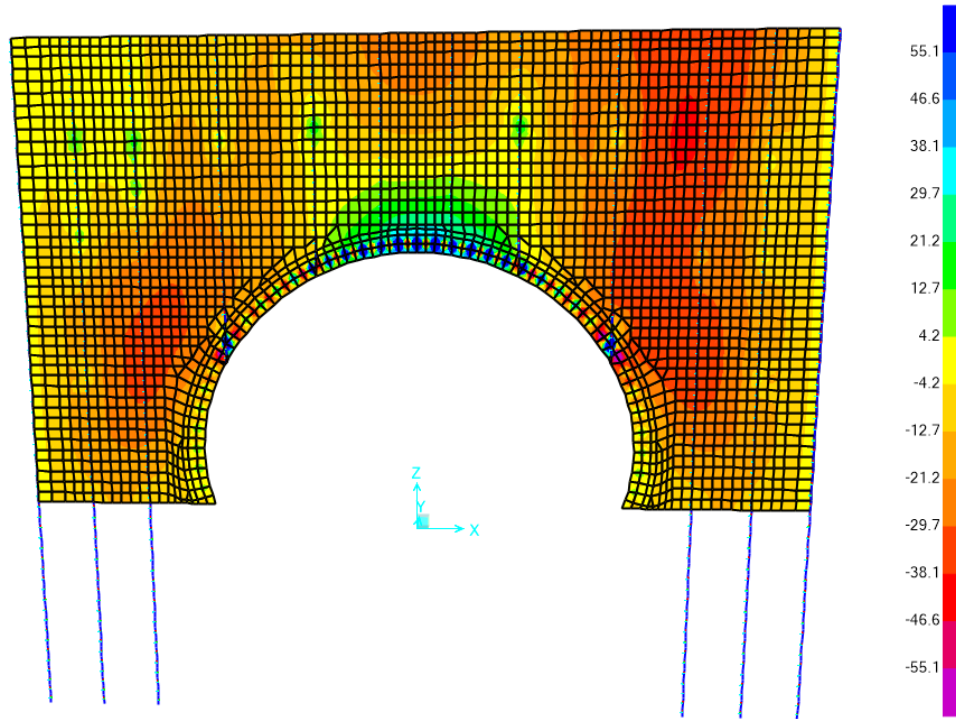
This additional reinforcement will be #4@6", with a maximum allowable stress of:

Flexural design	
$M_r = \phi \cdot A_s \cdot f_y \cdot (d-a/2)$ [5.6.3.2.2]	<b>49.57</b> [kip·ft]
	<b>OK, <math>M_r &gt; M_d</math></b>
$M_{r, \text{extreme}} = M_r / \phi$ , [11.5.7]	<b>55.08</b> [kip·ft]
	<i>OK, <math>M_{r, \text{extreme}} &gt; M_{d, \text{seismic}}</math></i>

In the following figures, the maximum stresses are now covered in the previously highlighted areas:



Headwall-2 SAP2000 Strength 1 Bending moments (horizontal direction) #5@6" + #4@6" (kip·ft/ft)

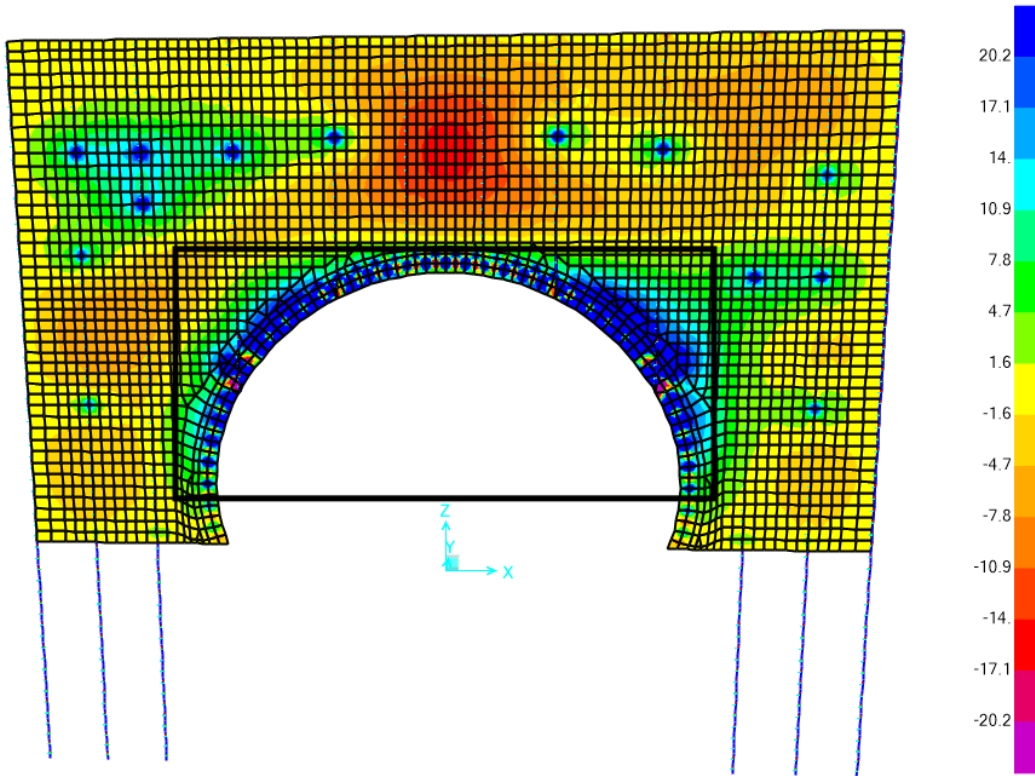


Headwall-2 SAP2000 Extreme Event 1 Bending moments (horizontal direction) #5@6''+  
#4@6''(kip-ft/ft)

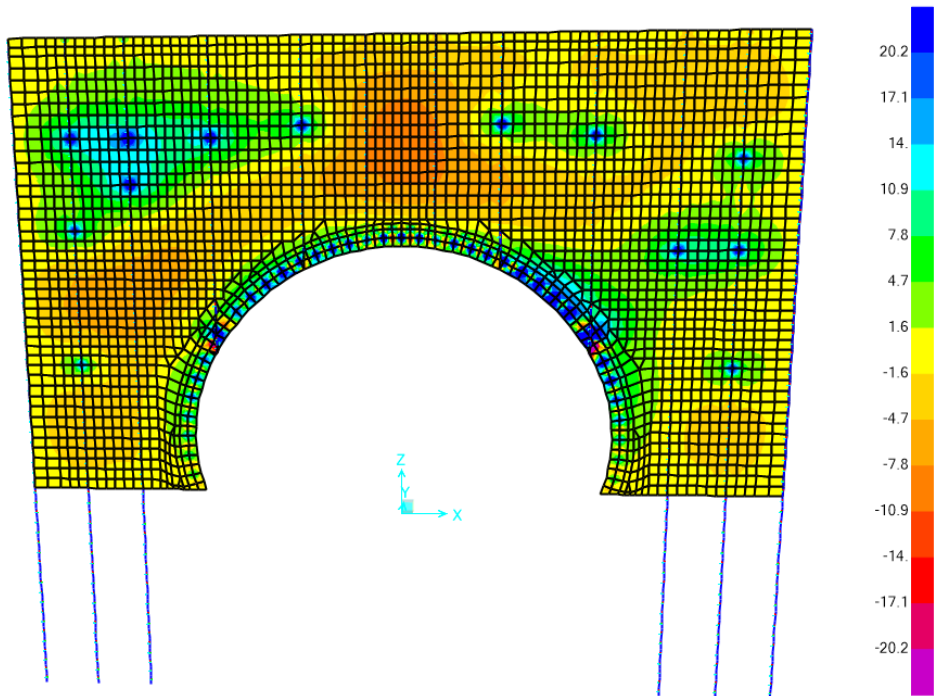
Secondly, the analysis of the vertical stresses has been made considering a base reinforcement of #4@6inches, which maximum bending resistance is next assessed:

Flexural design	
$M_r = \phi \cdot A_s \cdot f_y \cdot (d-a/2)$ , [5.6.3.2.2]	<b>20.25</b> [kip-ft]
	<b>OK, <math>M_r &gt; M_d</math></b>
$M_{r, \text{extreme}} = M_r / \phi$ , [11.5.7]	<b>22.50</b> [kip-ft]
	<b>OK, <math>M_{r, \text{extreme}} &gt; M_{d, \text{seismic}}</math></b>

In the next figures, the stresses associated to bending moments are plotted by limiting the maximum stress to the maximum allowable in each case (Strength or Extreme):



Headwall-2 SAP2000 Strength 1 Bending moments (horizontal direction) #4@6" (kip·ft/ft)



Headwall-2 SAP2000 Extreme Event 1 Bending moments (horizontal direction) #4@6" (kip·ft/ft)

Only the area around the tunnel permanent lining will require additional reinforcement in the vertical direction in the inner face.

The areas with additional vertical reinforcement will comprise an extra layer with #4@6", with a maximum allowable bending moment of:

<b>Flexural design</b>	
$M_r = \phi \cdot A_s \cdot f_y \cdot (d - a/2)$ , [5.6.3.2.2]	<b>39.49</b> [kip·ft]
	<b>OK, <math>M_r &gt; M_d</math></b>
$M_{r, \text{extreme}} = M_r / \phi$ , [11.5.7]	<b>43.87</b> [kip·ft]
	<b>OK, <math>M_{\text{extreme}} &gt; M_{\text{seismic}}</math></b>

The cracking verification for the maximum vertical Service 1 bending moment is next shown:

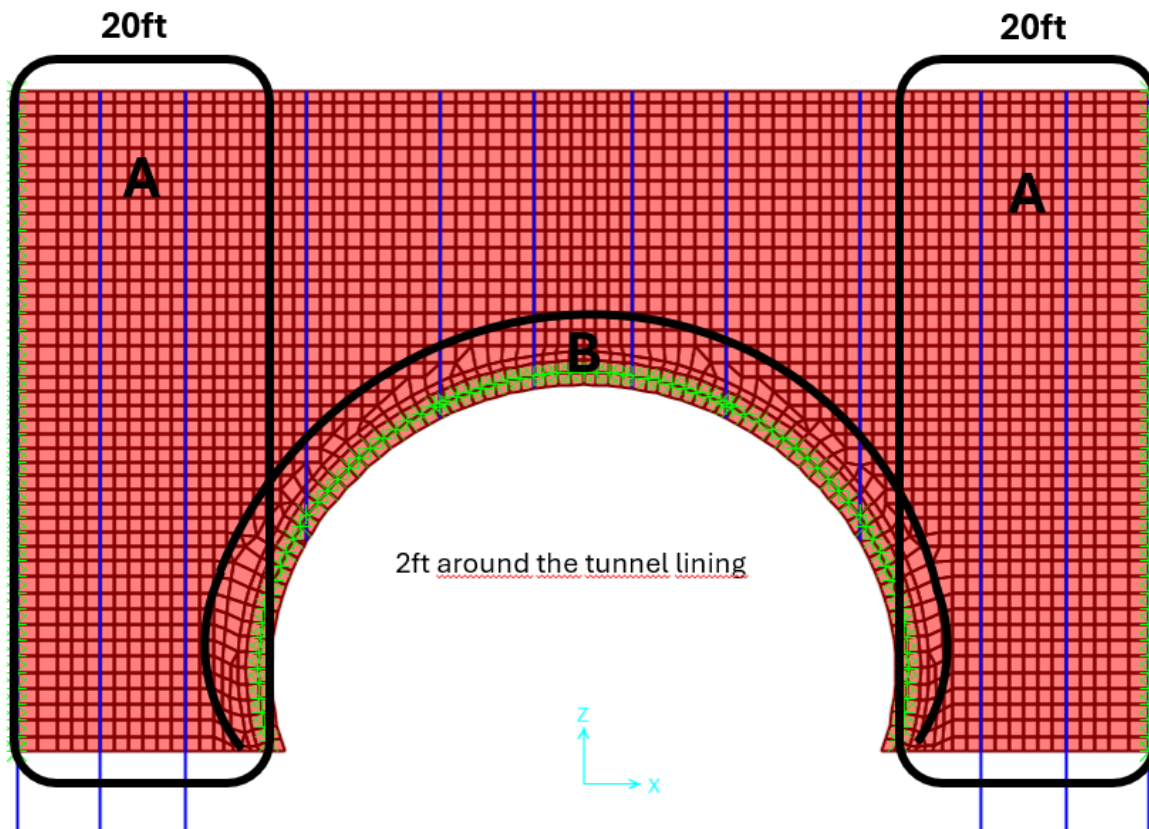
Control of Cracking by Distribution of Reinforcement			
$d_c = c_{cover} + d_{bar}/2$	2.250 [in]	$\rho_s = A_s / (b \cdot d)$	0.002785
$k_1$ , [5.4.2.4]	1.00	$k = (\rho_s \cdot n)^2 + 2 \cdot \rho_s \cdot n^{0.50} - \rho_s \cdot n$	0.171
$E_c = 120000 \cdot k_1 \cdot (\gamma_{conc})^2 \cdot f_c^{0.33}$ , [5.4.2.4]	4555.38 [ksi]	$j = 1 - k/3$	0.943
$E_s$ , [5.4.3.2]	29000 [ksi]	$f_{ss} < [M/A_s \cdot j \cdot d ; 0.6 \cdot f_t]$ , [5.6.7]	36.00 [ksi]
$n = E_s / E_c$	6.37	$s = 700 \cdot \gamma_w / (\beta_s \cdot f_{ss}) - 2 \cdot d_c$ , [5.6.7]	6.95 [in]
$\beta_s = 1 + d_c / (0.70 \cdot (h - d_c))$ , [5.6.7]	1.27	$s \geq s_w$	OK
$\gamma_w$ , [5.6.7]	0.75		

The cracking verification for the maximum horizontal Service 1 bending moment is next shown:

Control of Cracking by Distribution of Reinforcement			
$d_c = c_{cover} + d_{bar}/2$	2.375 [in]	$\rho_s = A_s / (b \cdot d)$	0.006334
$k_1$ , [5.4.2.4]	1.00	$k = (\rho_s \cdot n)^2 + 2 \cdot \rho_s \cdot n^{0.50} - \rho_s \cdot n$	0.247
$E_c = 120000 \cdot k_1 \cdot (\gamma_{conc})^2 \cdot f_c^{0.33}$ , [5.4.2.4]	4555.38 [ksi]	$j = 1 - k/3$	0.918
$E_s$ , [5.4.3.2]	29000 [ksi]	$f_{ss} < [M/A_s \cdot j \cdot d ; 0.6 \cdot f_t]$ , [5.6.7]	28.64 [ksi]
$n = E_s / E_c$	6.37	$s = 700 \cdot \gamma_w / (\beta_s \cdot f_{ss}) - 2 \cdot d_c$ , [5.6.7]	9.44 [in]
$\beta_s = 1 + d_c / (0.70 \cdot (h - d_c))$ , [5.6.7]	1.29	$s \geq s_w$	OK
$\gamma_w$ , [5.6.7]	0.75		

## Summary

In the following sketch, a summary of the reinforcement needed is shown:



Reinforcement sketch.

The headwall's fascia reinforcement comprises:

- #5@6" horizontal direction in both outer and inner faces.
- Additional #5@6" in horizontal direction in areas A in outer face.
- #4@6" in vertical direction in both outer and inner faces.
- Additional #4@6" in both vertical and horizontal directions in area B.
- Additional located reinforcements will be needed at tie-back locations (to be provided in final design submission).