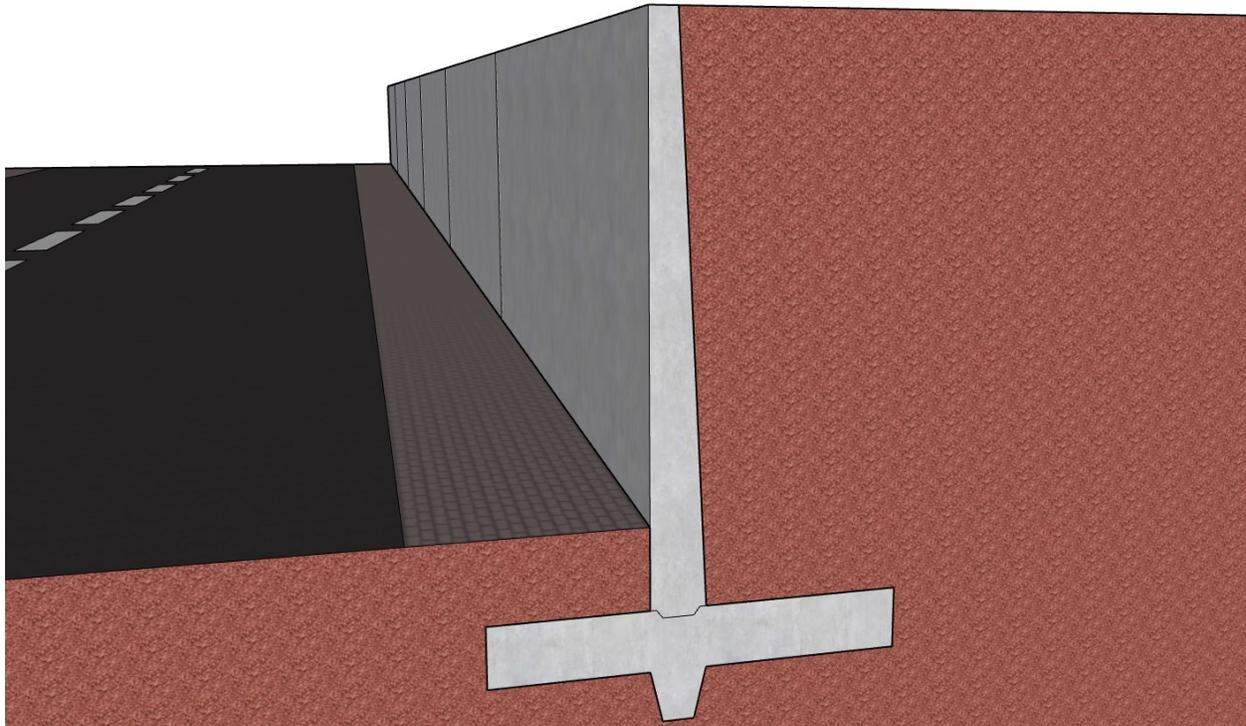
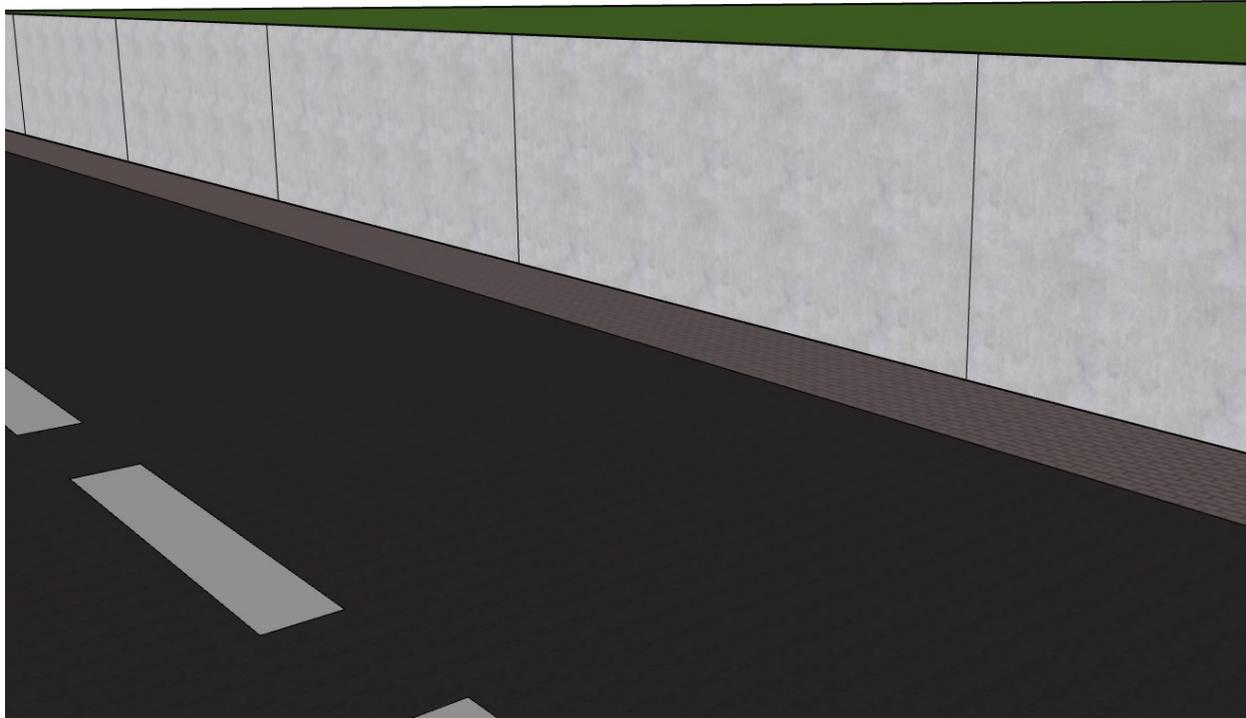


Reinforced Concrete Cantilever Retaining Wall Analysis and Design (ACI 318-14)



Reinforced Concrete Cantilever Retaining Wall Analysis and Design (ACI 318-14)

Reinforced concrete cantilever retaining walls consist of a relatively thin stem and a base slab. The stem may have constant thickness along the length or may be tapered based on economic and construction criteria. The base is divided into two parts, the heel and toe. The heel is the part of the base under the backfill. This system uses much less concrete than monolithic gravity walls, but require more design and careful construction. Cantilever retaining walls can be precast in a factory or formed on site and considered economical up to about 25 ft in height. This design example focuses on the analysis and design of a tapered cantilever retaining wall including a comparison with model results from the engineering software programs [spWall](#) and [spMats](#). The retaining wall is fixed to the reinforced concrete slab foundation with a shear key for sliding resistance. The following figure and design data section will serve as input for detailed analysis and design.

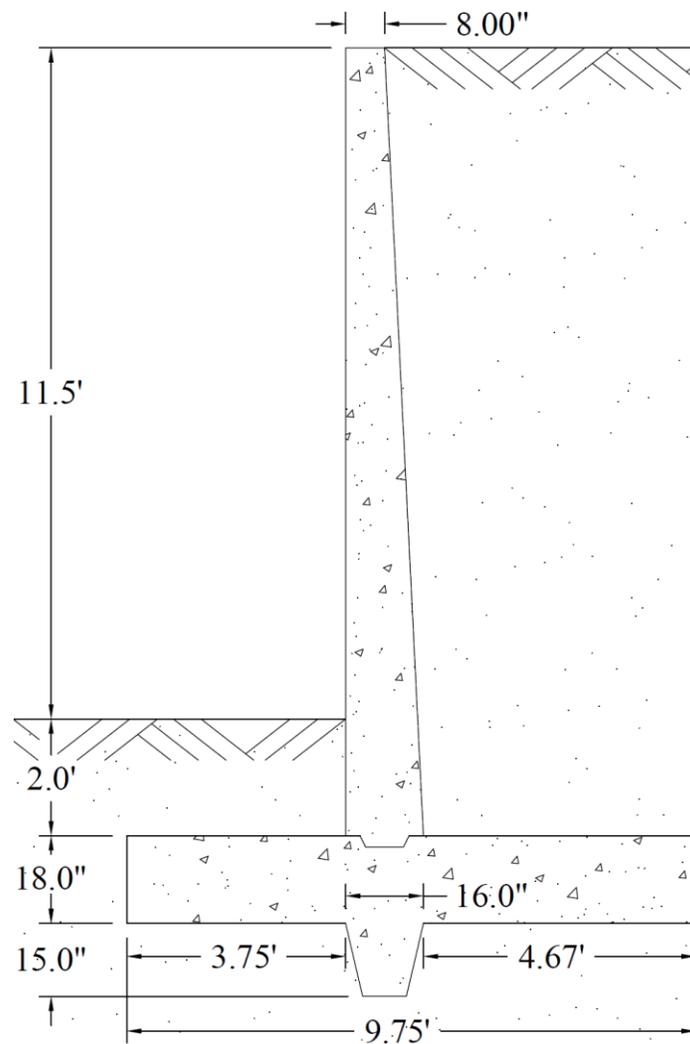


Figure 1 – Cantilever Retaining Wall Dimensions

Code

Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)

Reference

Design of Concrete Structures, 15th Edition, 2016, Darwin et. al., McGraw-Hill Education, Example 16.8

spWall Engineering Software Program Manual v5.01, StructurePoint LLC., 2016

spMats Engineering Software Program Manual v8.50, StructurePoint LLC., 2016

Design Data

Wall Stem Materials

$$f_c' = 4,500 \text{ psi}$$

$$f_y = 60,000 \text{ psi}$$

$$\gamma_c = 150 \text{ pcf}$$

Wall Foundation Materials

$$f_c' = 4,500 \text{ psi}$$

$$f_y = 60,000 \text{ psi}$$

$$\gamma_c = 150 \text{ pcf}$$

Wall Stem Dimensions

$$\text{Width} = 1 \text{ ft strip}$$

$$\text{Height} = 13.5 \text{ ft}$$

$$\text{Thickness} = 8 \text{ in. top}$$
$$= 16 \text{ in. bottom}$$

Wall Foundation Dimensions

$$\text{Width} = 1 \text{ ft strip}$$

$$\text{Length} = 9.75 \text{ ft}$$

$$\text{Thickness} = 18 \text{ in.}$$

Retaining Wall Loads

The following figure shows all the loads applied to the cantilever retaining wall where:

$$W_1 = 0.67 \times 13.5 \times 150 = 1360 \text{ lb}$$

$$W_2 = 0.67 \times 0.5 \times 13.5 \times 150 = 680 \text{ lb}$$

$$W_3 = 9.75 \times 1.5 \times 150 = 2190 \text{ lb}$$

$$W_4 = 1.33 \times 1.25 \times 150 = 250 \text{ lb}$$

$$W_5 = 3.75 \times 2 \times 120 = 900 \text{ lb}$$

$$W_6 = 0.67 \times 0.5 \times 13.5 \times 120 = 540 \text{ lb}$$

$$W_6 = 4.67 \times 13.5 \times 120 = 7570 \text{ lb}$$

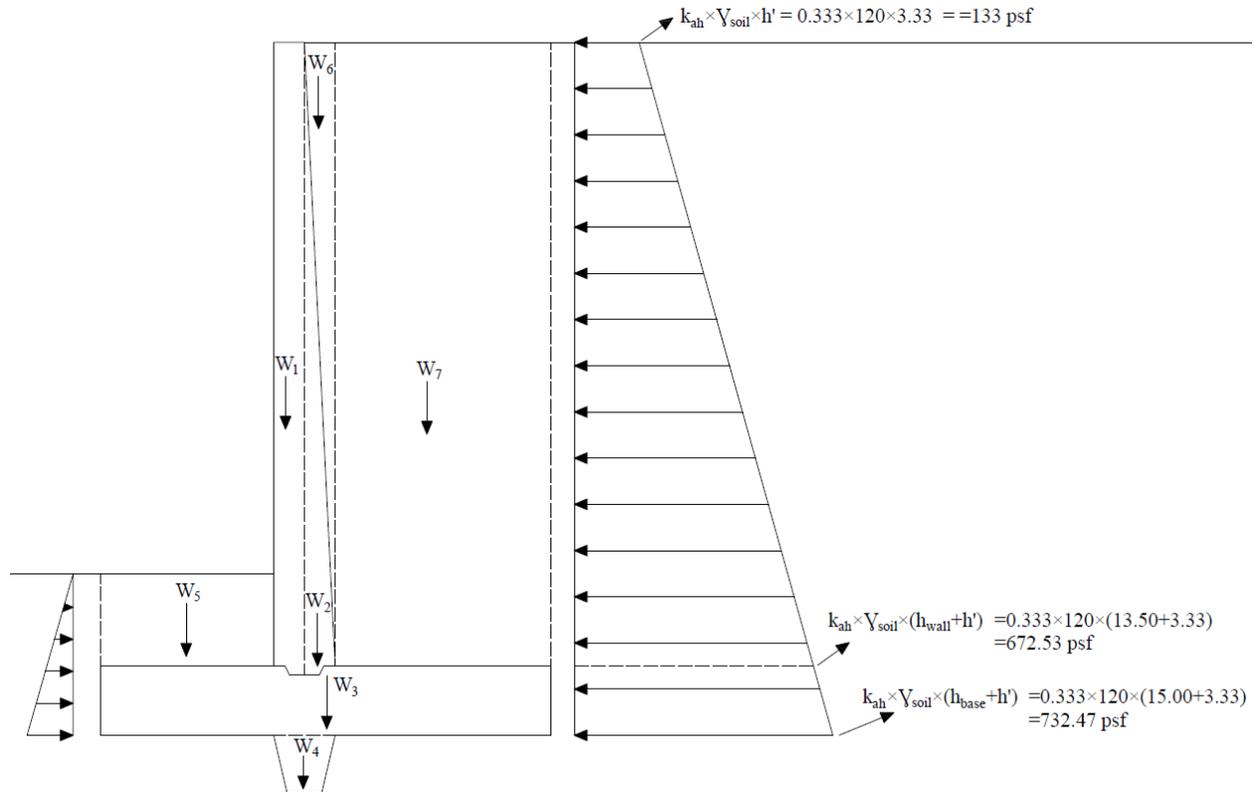


Figure 2 – Applied Loads and Soil Pressure at Critical Sections

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1. Preliminary Design

The thickness of the footing is roughly estimated to calculate the required thickness of the stem at the critical section (stem bottom). With the bottom of the footing at 3.5 ft below grade and an estimated footing thickness of 1.5 ft, the free height of the stem is 13.5 ft. using the information provided in Figures 1 and 2:

$$P = 0.5 \times 0.333 \times 120 \times 13.5 \times (13.5 + 2 \times 3.33) = 5440 \text{ lb (at the stem bottom)}$$

$$y = \frac{13.5^2 + 3 \times 13.5 \times 3.33}{3 \times (13.5 + 2 \times 3.33)} = 5.25 \text{ ft}$$

$$M_u = P_u \times y = 1.6 \times 5440 \times 5.25 = 45.7 \text{ ft-kip}$$

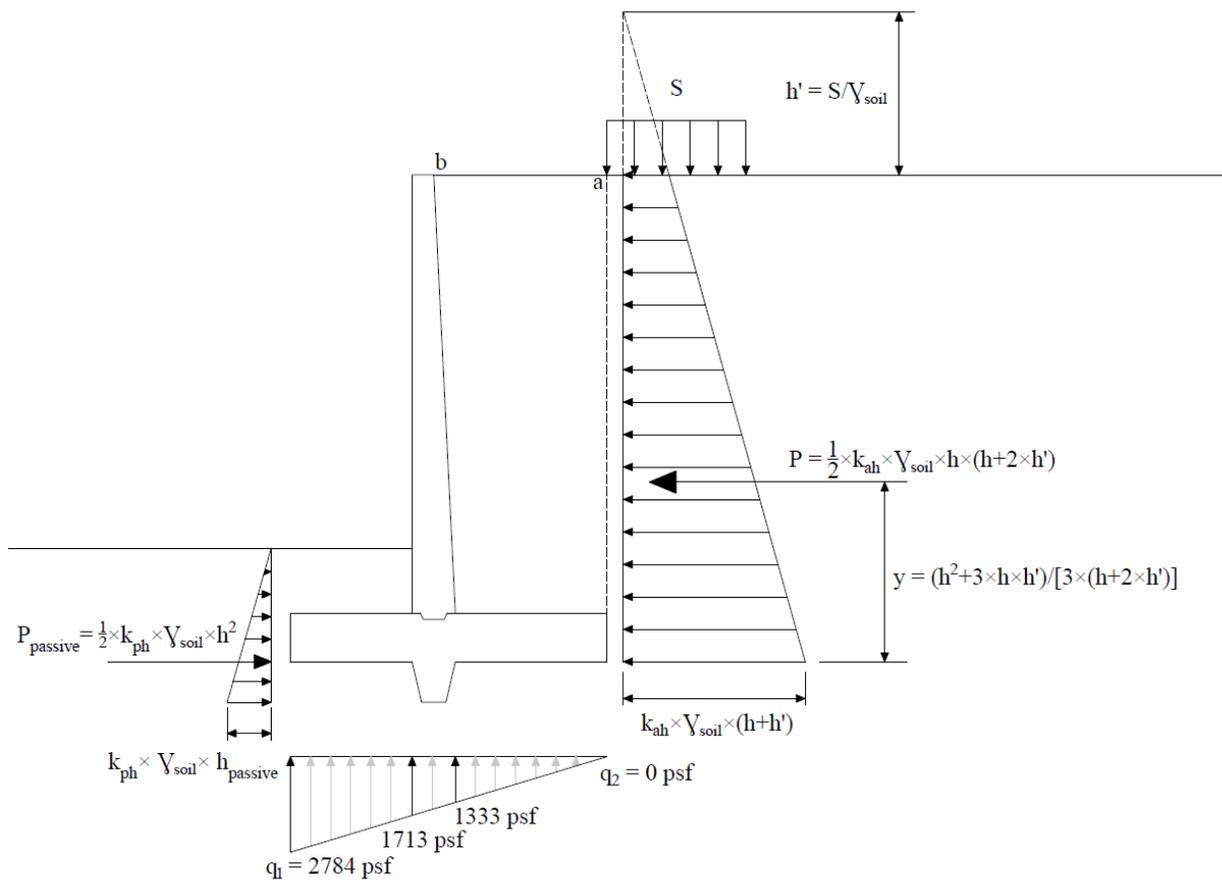


Figure 3 – Bearing Pressure, Overturning and Sliding Loads

The preliminary dimensions are selected using design aids from the reference Appendix A.

$$\rho_{0.005} = 0.85 \times \beta_1 \times \frac{f'_c}{f_y} \times \frac{0.003}{0.003 + 0.005}$$

Reference 1 (Table A.4)

$$\rho_{0.005} = 0.85 \times 0.825 \times \frac{4500}{60000} \times \frac{0.003}{0.003 + 0.005} = 0.0197$$

The reference recommends the use of a ratio of about 40% of the maximum ($\rho = 0.008$) for economy and ease of bar placement.

$$\frac{M_u}{\phi \times b \times d^2} = 430$$

Reference 1 (Graph A.1b)

$$d = \sqrt{\frac{45700 \times 12}{0.9 \times 12 \times 430}} = 10.9 \text{ in.}$$

Using cover of 2 in. for members exposed to weather or in contact with ground. **ACI 318-14 (Table 20.6.1.3.1)**

And #8 bars ($d_b = 1$ in.), the minimum required thickness of the stem at the base equals:

$$\text{minimum } t_{\text{stem,base}} = d_{\text{min}} + \text{cover} + \frac{d_b}{2} = 10.9 + 2 + \frac{1}{2} = 13.4 \text{ in.}$$

Use $t_{\text{stem,base}} = 16$ in.

For Shear Check (at distance d above the base):

$$P = 0.5 \times 0.333 \times 120 \times 12.5 \times (12.5 + 2 \times 3.33) = 4800 \text{ lb}$$

$$V_u = 1.6 \times P = 1.6 \times 4800 = 7680 \text{ lb}$$

$$\phi V_c = \phi \times 2 \times \lambda \times \sqrt{f'_c} \times b \times d^2$$

ACI 318-14 (22.5.5.1)

$$\phi V_c = 0.75 \times 2 \times 1 \times \sqrt{4500} \times 12 \times 13.5^2 = 16300 \text{ lb} > V_u$$

Stem thickness of 16 in. is adequate to resist the factored shear force.

The thickness of the foundation (base) is the same as or slightly larger than that at the bottom of the stem. Thus, the 18 in. selected earlier need not be revised. The stem thickness can be reduced by tapering one side only up to 8 in. at the top since the bending moment decreases with increasing distance from the wall base to zero at the top of the wall.

2. Wall Stability Checks

The wall has two failure modes: 1) Wall parts may not be strong enough to resist the acting forces, 2) the wall as a rigid body may be displaced or overturned by the earth pressure acting on it. The latter will be discussed in this section to ensure that the retaining wall is stable by checking stability against overturning, sliding, and allowable soil bearing pressure.

Note: two cases are being examined. Case 1 where surcharge load is applied to point a (see Figure 3), and Case 2 where surcharge load is applied to point b.

2.1. Wall Overturning Check

Case 1 governs for wall overturning since it generated the highest overturning with the least resistance.

Weights and moments about the front edge of the wall are shown in the following table (See figure 2 and design data section):

Table 1 - Weights and Moments about the Front Edge			
component Weights	W, kips	x, ft	M _r , ft-kip
W ₁	1.36	4.08	5.55
W ₂	0.68	4.67	3.18
W ₃	2.19	4.88	10.69
W ₄	0.25	4.42	1.11
W ₅	0.90	1.88	1.69
W ₆	0.54	4.86	2.62
W ₇	7.57	7.42	56.17
Total	13.49		81.00

$$P = 0.5 \times 0.333 \times 120 \times 15 \times (15 + 2 \times 3.33) = 6.49 \text{ kips}$$

$$y = \frac{15^2 + 3 \times 15 \times 3.33}{3 \times (15 + 2 \times 3.33)} = 5.77 \text{ ft}$$

The overturning moment is equal to:

$$M_o = P \times y = 6.49 \times 5.77 = 37.46 \text{ ft-kip}$$

Factor of Safety against overturning:

$$FOS_{\text{overturning}} = \frac{81.00}{37.46} = 2.16 > 1.5 \text{ (o.k.)}$$

2.2. Soil Bearing Pressure

The distance of the resultant force from the base slab front edge is:

$$a = \frac{81.00 - 37.46}{13.49} = 3.23 \text{ ft} \approx \frac{9.75}{3} = 3.25 \text{ ft}$$

The resultant is barely outside the middle third of the foundation (it is assumed that the bearing pressure becomes zero exactly at the edge of the heel as shown in Figure 2). The maximum soil pressure at the toe is calculated as follows:

$$q_1 = \frac{2 \times R_v}{3 \times a} \quad \text{Reference 1 (Figure 16.5c)}$$

$$q_1 = \frac{2 \times 13.49 \times 1000}{3 \times 3.23} = 2784 \text{ psf} < q_{allowable} = 8000 \text{ psf (o.k.)}$$

$$q_2 = 0 \quad \text{Reference 1 (Figure 16.5c)}$$

The soil pressure values calculated for Case 1. The soil pressure values for Case 2 do not govern for overturning and sliding. However, values calculated from Case 2 are needed for foundation flexural design as follows:

$$q_1 = (4 \times l - 6 \times a) \frac{R_v}{l^2} \quad \text{Reference 1 (Figure 16.5a)}$$

$$q_1 = 2710 \text{ psf} < q_{allowable} = 8000 \text{ psf (o.k.)}$$

$$q_2 = (6 \times a - 2 \times l) \frac{R_v}{l^2} \quad \text{Reference 1 (Figure 16.5a)}$$

$$q_2 = 492 \text{ psf} < q_{allowable} = 8000 \text{ psf (o.k.)}$$

2.3. Wall Sliding Check

Case 1 also governs for sliding since it produces the least pressure and corresponding friction resistance.

The coefficient of friction that applies for the length along the heel and key is 0.5, while the coefficient of friction for the length in front of the key is equal to the internal soil friction, that is, $\tan 30^\circ = 0.577$. More information about selecting the friction coefficient can be found in the reference in chapter 16 section 4. (for case where surcharge load is applied to point a):

Friction, toe:

$$F_{toe} = 0.5 \times (2784 + 1713) \times 3.75 \times 0.577 = 4.87 \text{ kips}$$

Friction, heel and key:

$$F_{heel \text{ and key}} = 0.5 \times 1713 \times 6 \times 0.5 = 2.57 \text{ kips}$$

Passive earth pressure:

$$P_{passive} = 0.5 \times 3.0 \times 120 \times (4.75 - 1.5)^2 = 1.90 \text{ kips}$$

Note that the top 1.5 ft layer of soil is discounted in this check as unreliable.

Total:

$$F_{total} = 4.87 + 2.57 + 1.90 = 9.34 \text{ kips}$$

Factor of Safety against sliding:

$$FOS_{sliding} = \frac{9.34}{6.49} = 1.44 \approx 1.5 \text{ (can be regarded as adequate)}$$

Thus, the retaining wall with the selected geometry is externally stable.

3. Flexural Reinforcement Requirements

The required flexural reinforcement is traditionally calculated at three critical sections: at the stem base, the toe and heel at the face of the stem.

Calculate the required reinforcement to resist the moment at the stem base:

$$M_u = 45.7 \text{ kip-ft}$$

Use #8 bars with 2.0 in. concrete cover per ACI 318-14 (Table 20.6.1.3.1). The distance from extreme compression fiber to the centroid of longitudinal tension reinforcement, d , is calculated below:

$$d = 16 - (2 + 0.5 \times 1) = 13.5 \text{ in.}$$

To determine the area of steel, assumptions have to be made whether the section is tension or compression controlled, and regarding the distance between the resultant compression and tension forces along the beam section (jd). In this example, tension-controlled section will be assumed so the reduction factor ϕ is equal to 0.9, and jd will be taken equal to $0.95d$. The assumptions will be verified once the area of steel is finalized.

$$jd = 0.95 \times d = 0.95 \times 13.5 = 12.83 \text{ in.}$$

$$b = 12 \text{ in.}$$

The required reinforcement at initial trial is calculated as follows:

$$A_s = \frac{M_u}{\phi \times f_y \times jd} = \frac{45.7 \times 12,000}{0.9 \times 60,000 \times 12.83} = 0.79 \text{ in.}^2$$

$$\text{Recalculate 'a' for the actual } A_s = 0.79 \text{ in.}^2: a = \frac{A_s \times f_y}{0.85 \times f'_c \times b} = \frac{0.79 \times 60,000}{0.85 \times 4500 \times 12} = 1.04 \text{ in.}$$

$$c = \frac{a}{\beta_1} = \frac{1.04}{0.83} = 1.25 \text{ in.}$$

$$\varepsilon_t = \left(\frac{0.003}{c} \right) \times d_t - 0.003 = \left(\frac{0.003}{1.25} \right) \times 13.5 - 0.003 = 0.0293 > 0.005$$

Therefore, the assumption that section is tension-controlled is valid.

$$A_s = \frac{M_u}{\phi \times f_y \times (d - a/2)} = \frac{45.7 \times 12,000}{0.9 \times 60,000 \times (13.5 - 1.04/2)} = 0.78 \text{ in.}^2$$

The minimum reinforcement shall not be less than

$$A_{s,\min} = \frac{3 \times \sqrt{f'_c}}{f_y} \times b \times d = \frac{3\sqrt{4,500}}{60,000} \times 12 \times 13.5 = 0.54 \text{ in.}^2 \quad \text{ACI 318-14 (9.6.1.2(a))}$$

And not less than

$$A_{s,\min} = \frac{200}{f_y} \times b \times d = \frac{200}{60,000} \times 12 \times 13.5 = 0.54 \text{ in.}^2 \quad \text{ACI 318-14 (9.6.1.2(b))}$$

$$\therefore A_{s,\min} = 0.54 \text{ in.}^2$$

Maximum spacing allowed:

Check the requirement for distribution of flexural reinforcement to control flexural cracking:

$$s = 15 \left(\frac{40000}{f_s} \right) - 2.5c_c \leq 12 \left(\frac{40000}{f_s} \right) \quad \text{ACI 318-14 (Table 24.3.2)}$$

$$c_c = 2.0 \text{ in.}$$

$$\text{Use } f_s = \frac{2}{3} f_y = 40,000 \text{ psi} \quad \text{ACI 318-14 (24.3.2.1)}$$

$$s = 15 \times \left(\frac{40,000}{40,000} \right) - 2.5 \times 2.0 = 10 \text{ in. (Governs)}$$

$$s = 12 \times \left(\frac{40,000}{40,000} \right) = 12 \text{ in.}$$

Provide #8 bars at 9 in. on centers.

Note that the stem bending moment decreases rapidly with increasing distance from the bottom. For this reason, only part of the main reinforcement is needed at higher elevations and alternate bars can be discontinued where no longer needed. More information about cutting bars in the stem are provided in the reference. All the values in the following table are calculated based on the procedure outlined above for the stem.

Table 2 – Reinforcing Design Summary			
Critical Section	Stem Base	Toe	Heel
Design Moment, M_u (ft-kips)	45.7	24.3	29.9
Effective depth, d (in.)	13.5	14.5	14.5
$A_{s,\text{req}}$ (in. ²)	0.78	0.38	0.47
$A_{s,\text{min}}$ (in. ²)	0.54	0.58	0.58
Reinforcement	#8 @ 9 in.	#7 @ 12 in.	#7 @ 12 in.

4. Cantilever Retaining Wall Analysis and Design – spWall Software

[spWall](#) is a program for the analysis and design of reinforced concrete shear walls, tilt-up walls, precast walls, retaining walls, tank walls and Insulated Concrete Form (ICF) walls. It uses a graphical interface that enables the user to easily generate complex wall models. Graphical user interface is provided for:

- Wall geometry (including any number of openings and stiffeners)
- Material properties including cracking coefficients
- Wall loads (point, line, and area),
- Support conditions (including translational and rotational spring supports)

[spWall](#) uses the Finite Element Method for the structural modeling, analysis, and design of slender and non-slender reinforced concrete walls subject to static loading conditions. The wall is idealized as a mesh of rectangular plate elements and straight line stiffener elements. Walls of irregular geometry are idealized to conform to geometry with rectangular boundaries. Plate and stiffener properties can vary from one element to another but are assumed by the program to be uniform within each element.

Six degrees of freedom exist at each node: three translations and three rotations relating to the three Cartesian axes. An external load can exist in the direction of each of the degrees of freedom. Sufficient number of nodal degrees of freedom should be restrained in order to achieve stability of the model. The program assembles the global stiffness matrix and load vectors for the finite element model. Then, it solves the equilibrium equations to obtain deflections and rotations at each node. Finally, the program calculates the internal forces and internal moments in each element. At the user's option, the program can perform second order analysis. In this case, the program takes into account the effect of in-plane forces on the out-of-plane deflection with any number of openings and stiffeners.

In [spWall](#), the required flexural reinforcement is computed based on the selected design standard (ACI 318-14 is used in this case study), and the user can specify one or two layers of wall reinforcement. In stiffeners and boundary elements, [spWall](#) calculates the required shear and torsion steel reinforcement. Wall concrete strength (in-plane and out-of-plane) is calculated for the applied loads and compared with the code permissible shear capacity.

For illustration purposes, the following figures provide a sample of the input modules and results obtained from an [spWall](#) model created for the cantilever retaining wall in this design example.

4.1. Cantilever Retaining Wall Model Input

Linear Area Loads

Label: Soil Pressure Load Case: Case F Y1 (ft): 13.5 Y2 (ft): 0

Forces at Y1 (psf):
 Wx: 0 Wy: 0 Wz: 133.067

Forces at Y2 (psf):
 Wx: 0 Wy: 0 Wz: 672.527

Label	Case	Y1	Y2	Wx_Y1	Wy_Y1	Wz_Y1	Wx_Y2	Wy_Y2	Wz_Y2
Soil Pressure	F	13.500	0.000	0.000	0.000	133.067	0.000	0.000	672.527

Buttons: Add, Delete, Modify, Import...

Ultimate Load Combinations

Load Cases: Include self-weight with load case A for all combinations

Label: DEAD Case A: LIVE Case B: SNOW Case C: WIND Case D: EQ Case E: SOIL Case F: SOIL

Load Combinations:

Label: U1 Case A: 1.2 Case B: 1.6 Case C: 0.5 Case D: 0 Case E: 0 Case F: 1.6

Label	Case A	Case B	Case C	Case D	Case E	Case F
U1	1.200	1.600	0.500	0.000	0.000	1.600
U2	0.900	0.000	0.000	0.000	0.000	1.600

Buttons: Add, Delete, Modify, Import...

Figure 4 – Cantilever Retaining Wall Loads and Load Combinations

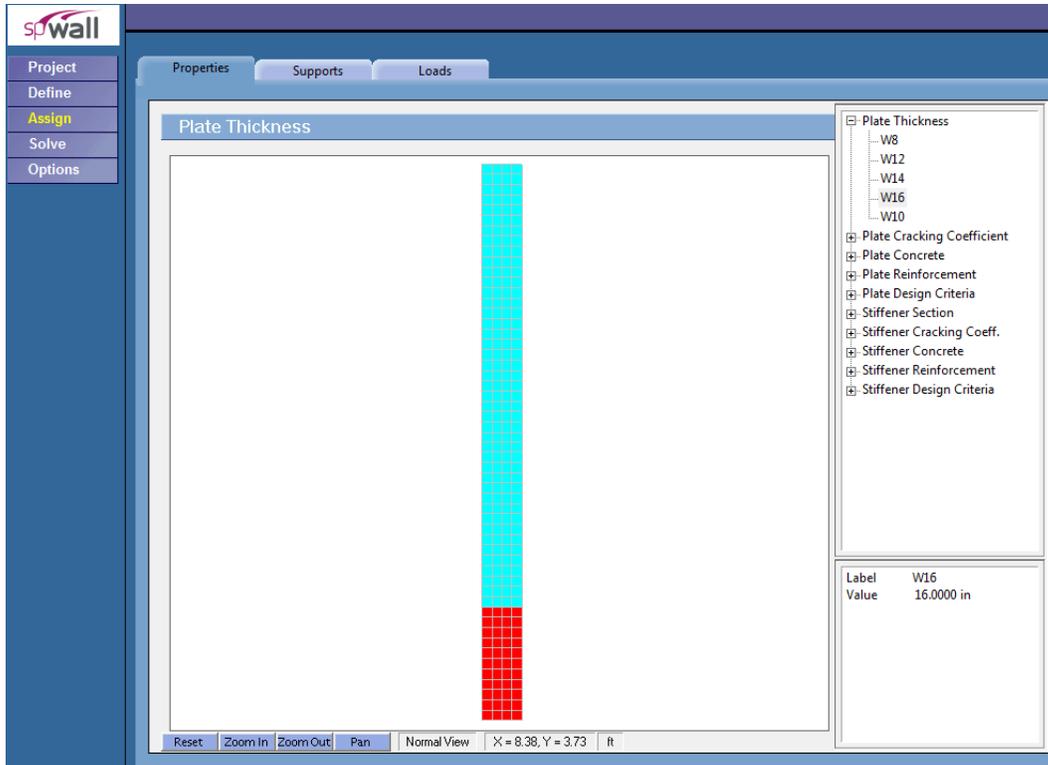


Figure 5 – Assigning Wall Stem Thicknesses

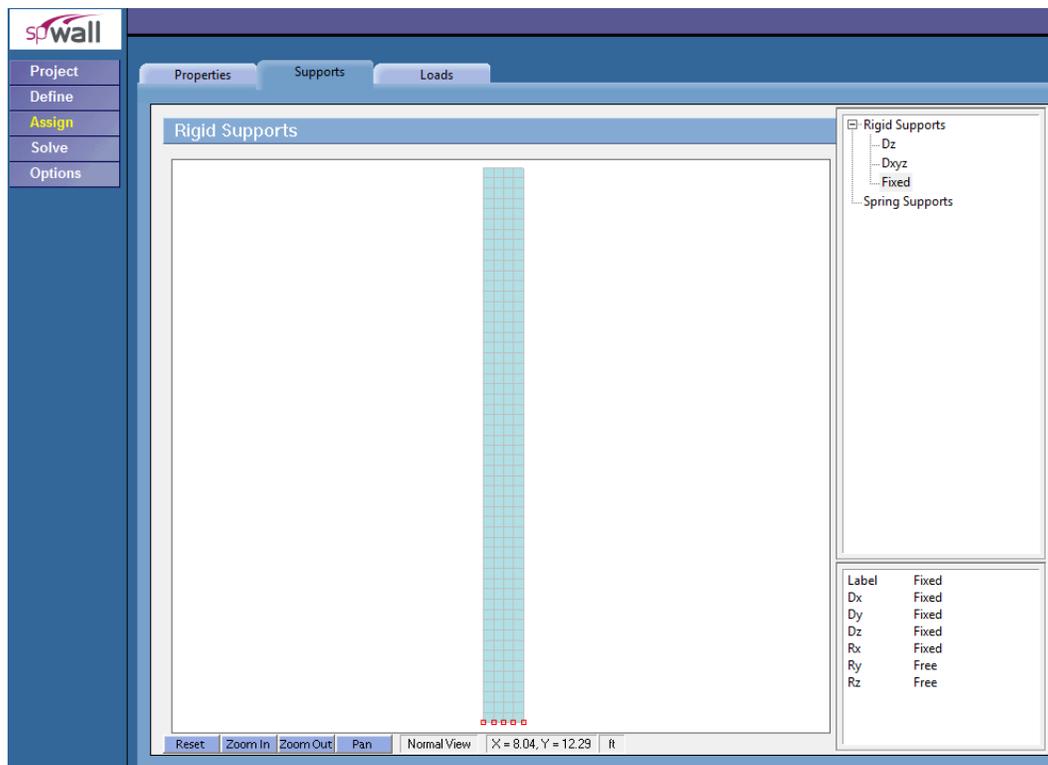


Figure 6 – Assigning Wall Stem Restraints

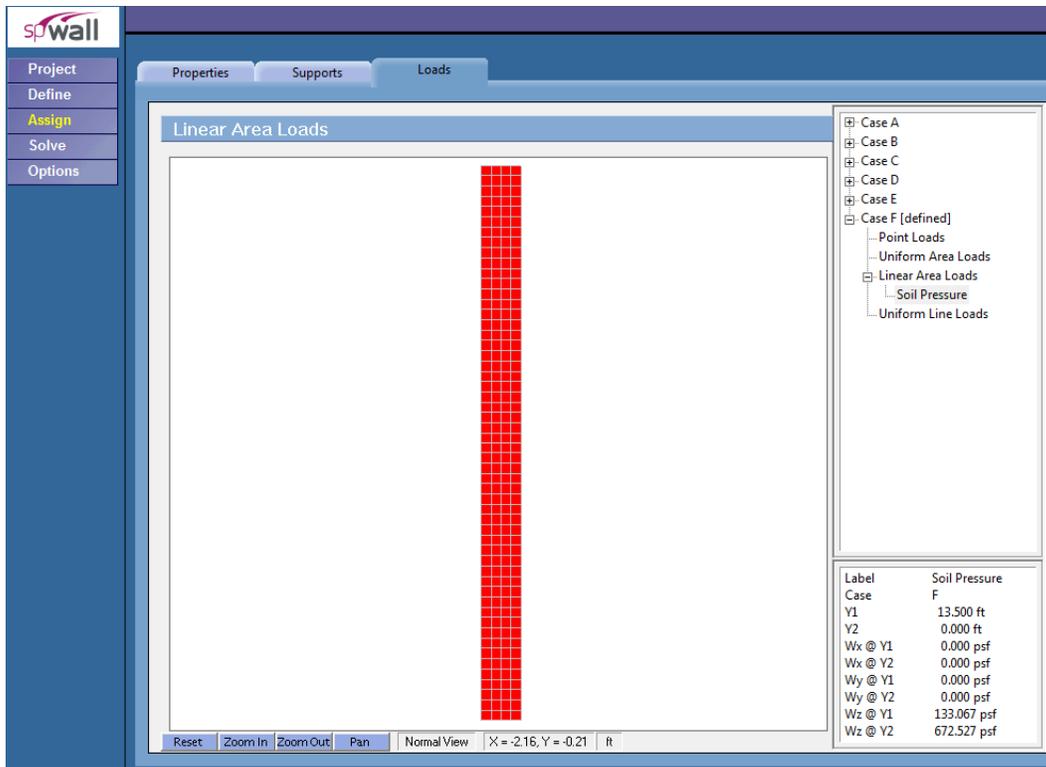


Figure 7 – Assigning Soil Lateral Pressure

4.2. Cantilever Retaining Wall Result Contours

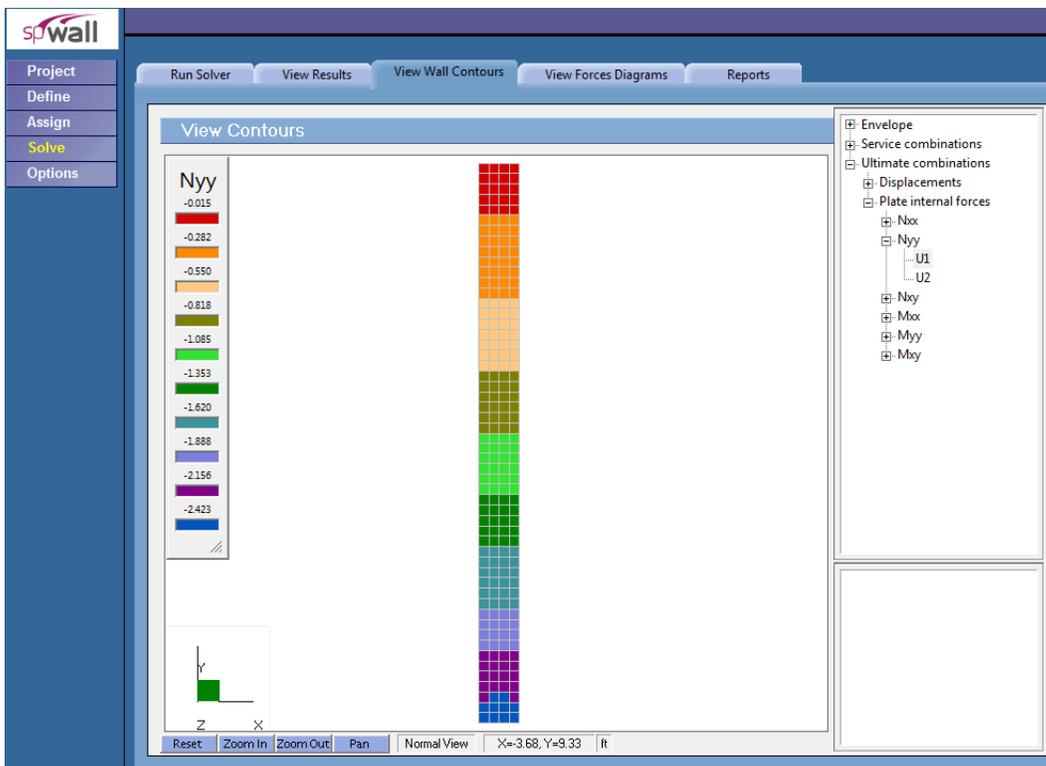


Figure 8 – Factored Axial Force Contour

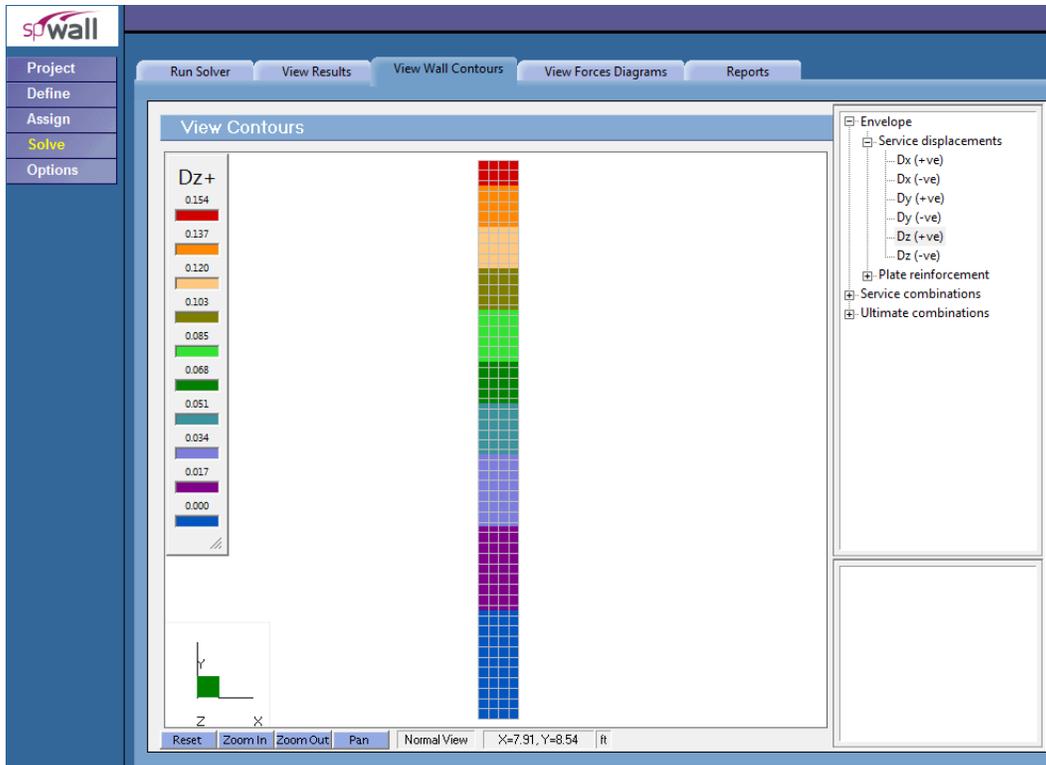


Figure 9 – Lateral Displacement Contour (Out-of-Plane)

4.3. Cantilever Retaining Wall Cross-Sectional Forces

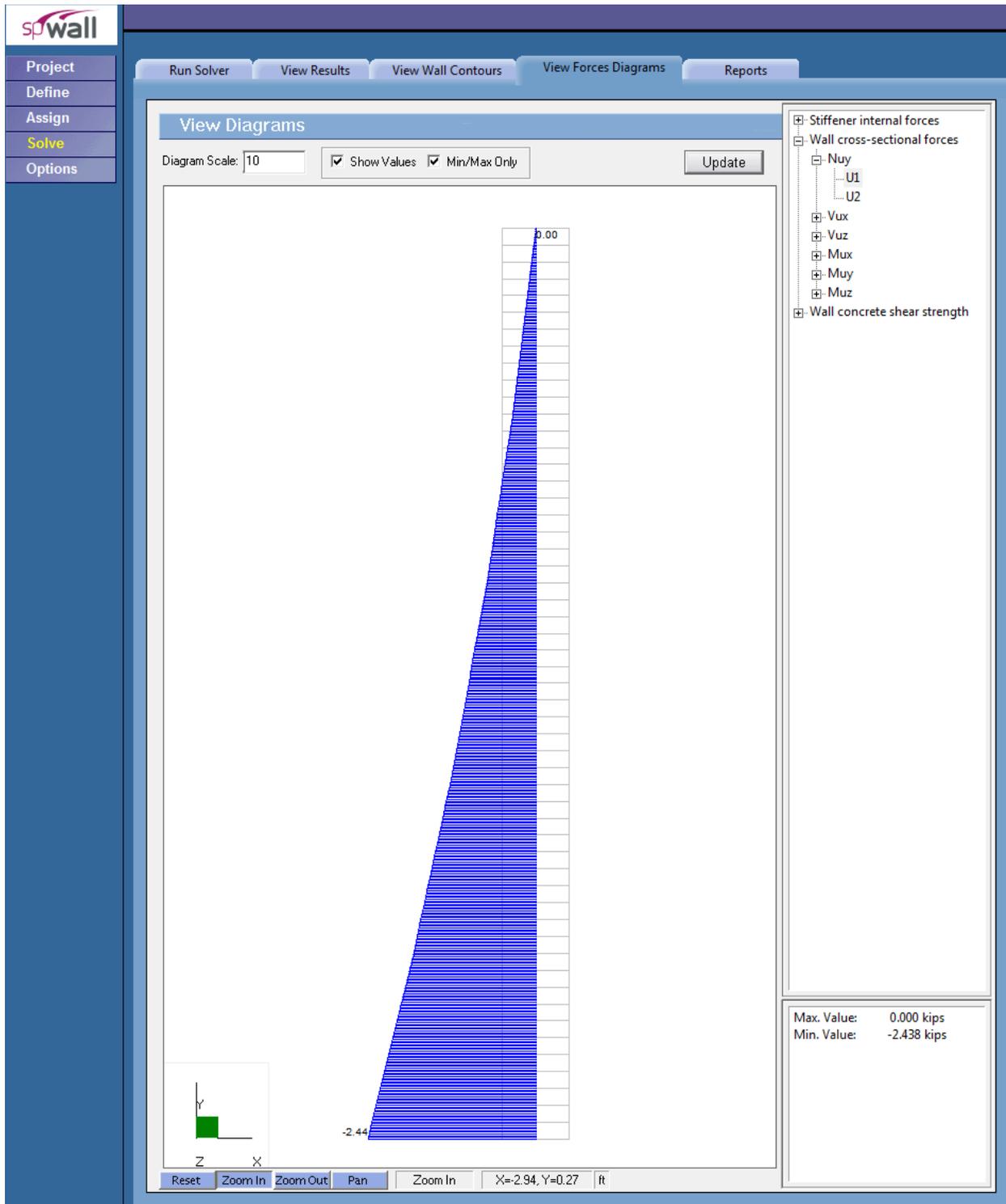


Figure 10 – Axial Load Diagram

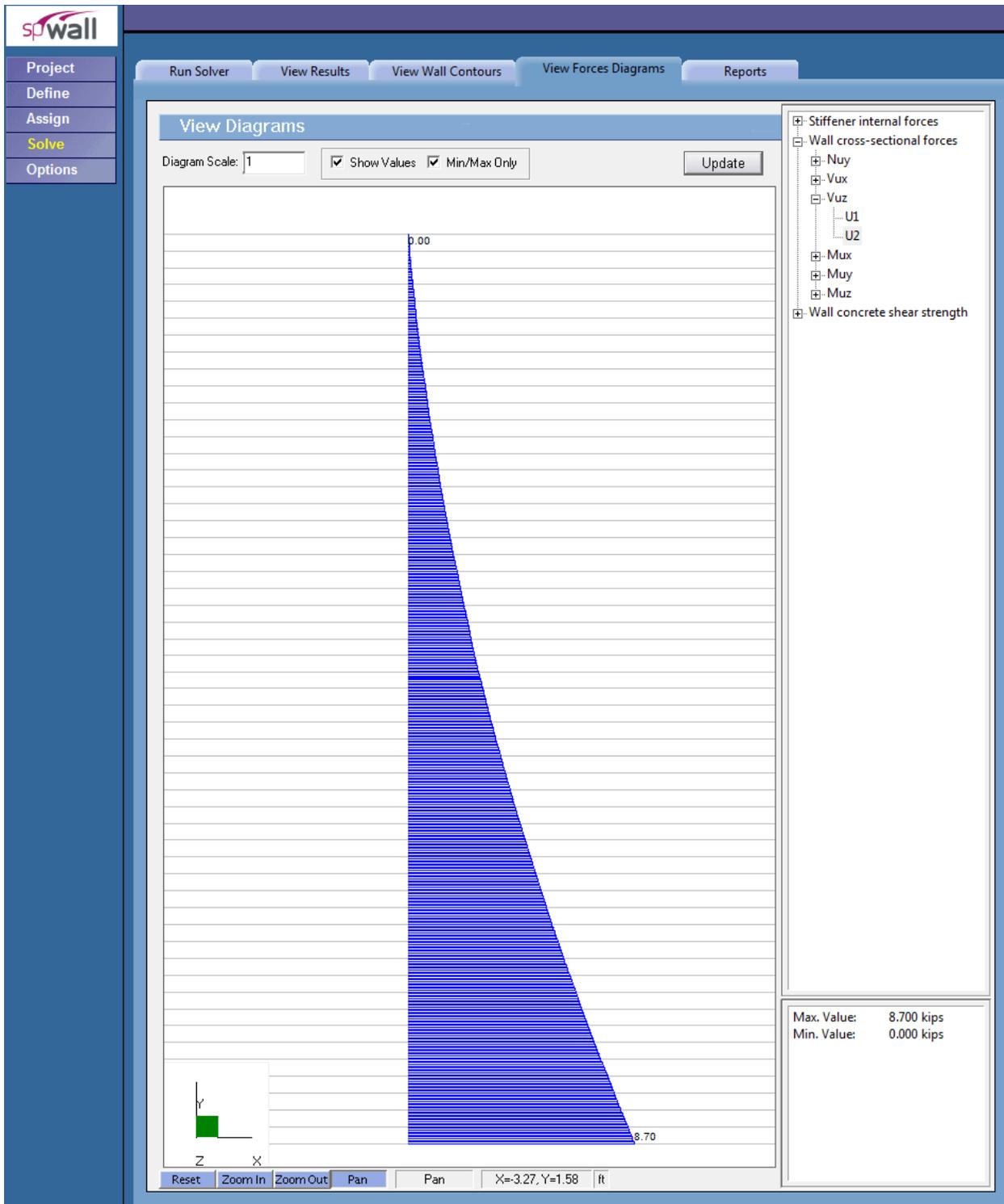


Figure 11 – Out-of-Plane Shear Diagram

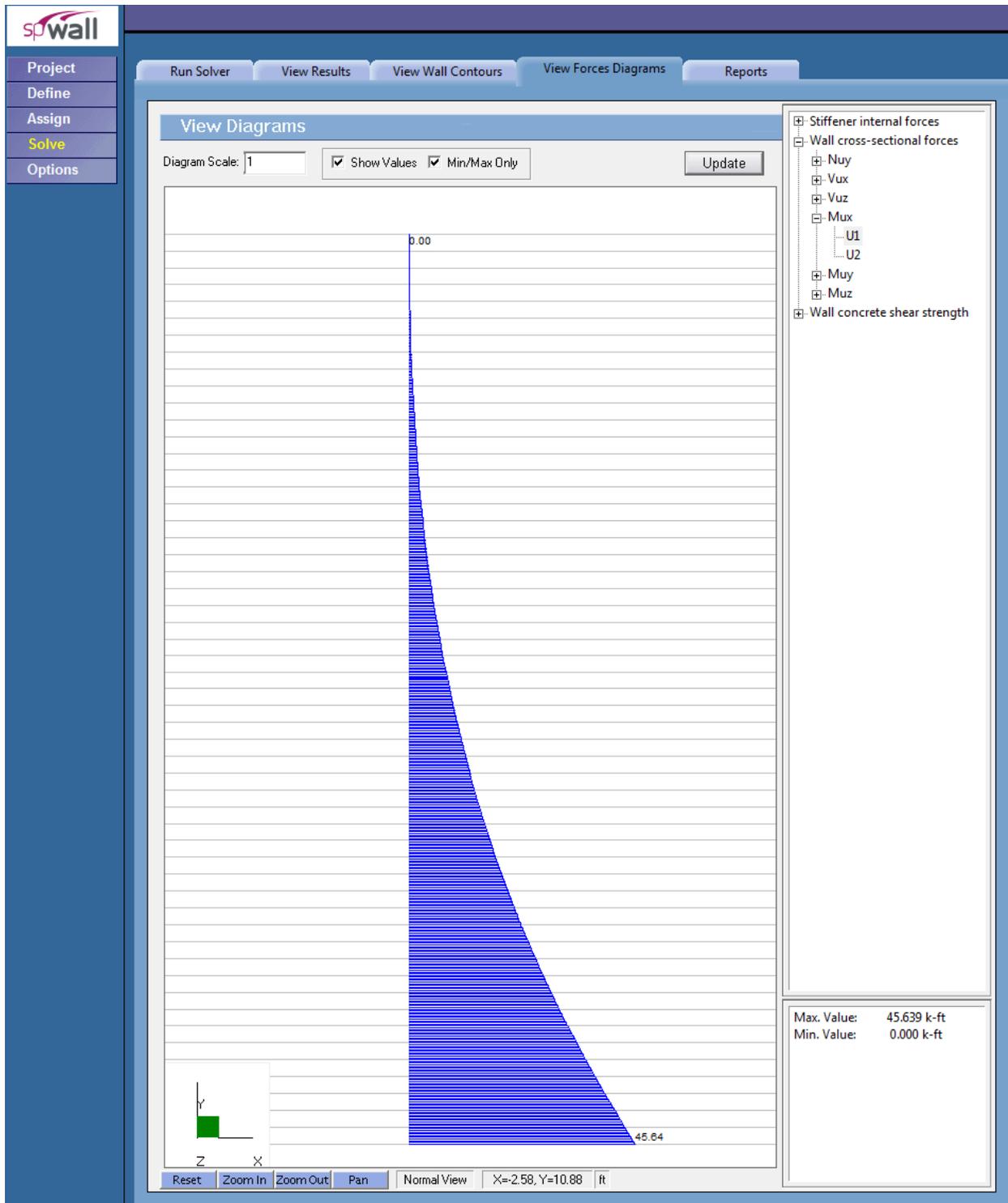


Figure 12 – Bending Moment Diagram

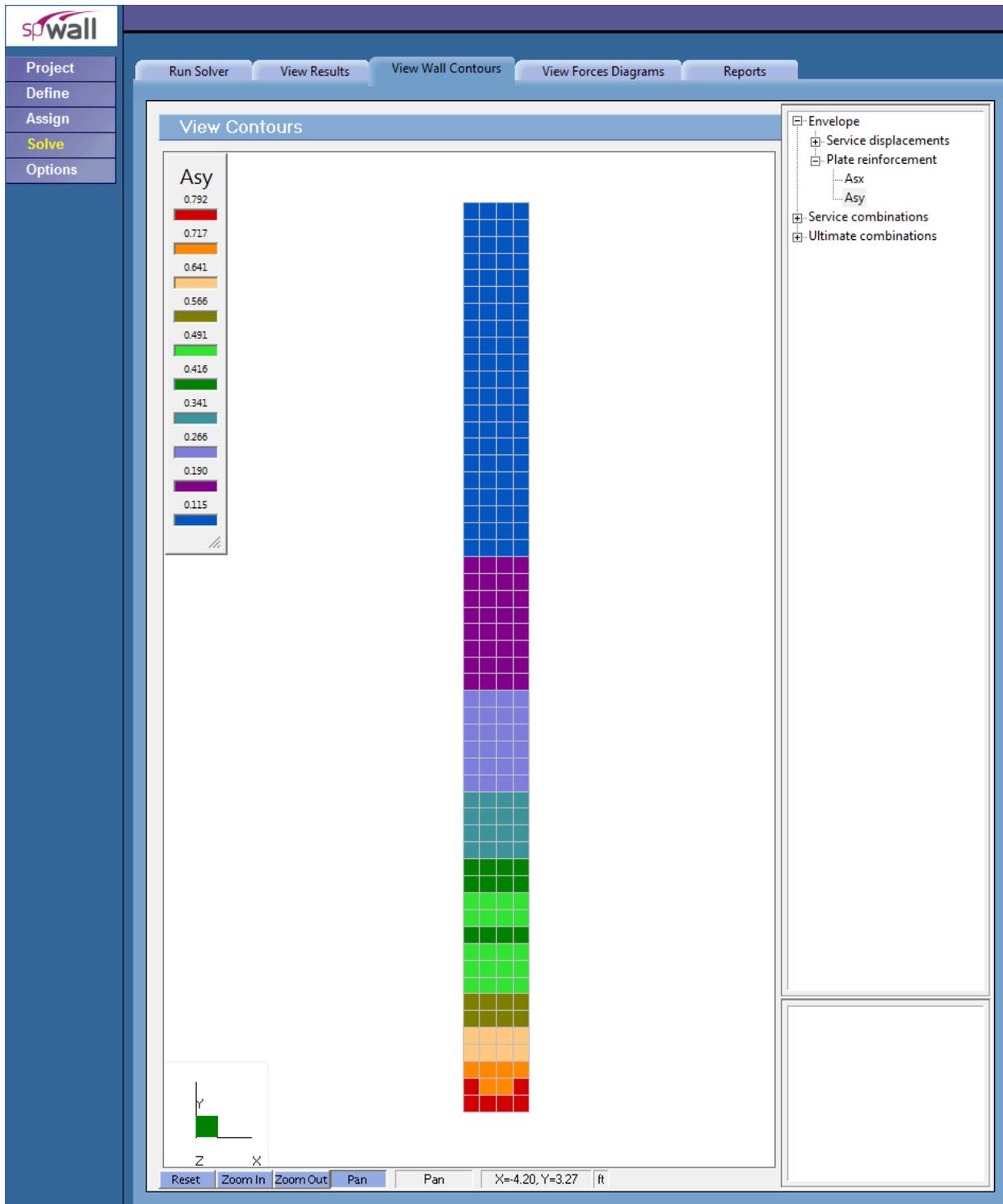


Figure 13 – Required Vertical Reinforcement

(Note: Minimum reinforcement value shown is based on the top wall stem thickness of 8” while the hand calculations show the minimum required at the wall stem base with 16” thickness)

4.4. Cantilever Retaining Wall Maximum Displacement

```

Service combinations | Displacements | S1
=====
Coordinate System: Global
=====

Units:
=====
Displacement (Dx, Dy, Dz): in

Node      Dx          Dy          Dz
-----
271 -1.02e-007 -2.17e-004 1.54e-001
272 -2.81e-008 -2.17e-004 1.54e-001
273 -2.14e-015 -2.17e-004 1.54e-001
274  2.81e-008 -2.17e-004 1.54e-001
275  1.02e-007 -2.17e-004 1.54e-001

```

Figure 14 – Displacement at Critical Section (Service Combinations)

```

Ultimate combinations | Displacements | U1
=====
Coordinate System: Global
=====

Units:
=====
Displacement (Dx, Dy, Dz): in

Node      Dx          Dy          Dz
-----
271 -1.22e-007 -2.60e-004 2.46e-001
272 -3.37e-008 -2.60e-004 2.46e-001
273 -2.58e-015 -2.60e-004 2.46e-001
274  3.37e-008 -2.60e-004 2.46e-001
275  1.22e-007 -2.60e-004 2.46e-001

```

Figure 15 – Displacement at Critical Section (Ultimate Combinations)

4.5. Cantilever Retaining Wall Cross-Sectional Forces at Stem Base

```

Ultimate combinations | Wall cross-sectional forces | U1
=====

Coordinate System: Global
=====

Units:
=====
Y-coordinate, X-centroid: ft
Force (Vux, Nuy, Vuz): kips, Moment (Mux, Muy, Muz): k-ft

Notes:
=====
(-) Horizontal cross-section below Y-coordinate
(+) Horizontal cross-section above Y-coordinate

Wall Cross-section      In-plane Forces      Out-of-plane Forces
No.  Y-coordinate  X-centroid  Vux      Nuy      Muz      Vuz      Mux      Muy
-----
1+   0.000      0.500      0.0000e+000 -2.4375e+000 1.3141e-016 8.7004e+000 4.5639e+001 3.4564e-016

```

Figure 16 – Wall Cross-Sectional Forces

5. Cantilever Retaining Wall Foundation Analysis and Design – spMats Software

[spMats](#) uses the Finite Element Method for the structural modeling, analysis and design of reinforced concrete slab systems or mat foundations subject to static loading conditions.

The slab, mat, or footing is idealized as a mesh of rectangular elements interconnected at the corner nodes. The same mesh applies to the underlying soil with the soil stiffness concentrated at the nodes. Slabs of irregular geometry can be idealized to conform to geometry with rectangular boundaries. Even though slab and soil properties can vary between elements, they are assumed uniform within each element. Piles and/or supporting soil are modeled as springs connected to the nodes of the finite element model. Unlike for springs, however, punching shear check is performed around piles.

For illustration purposes, the following figures provide a sample of the input modules and results obtained from an spMats model created for the cantilever retaining wall foundation in this design example.

5.1. Cantilever Retaining Wall Foundation Model Input

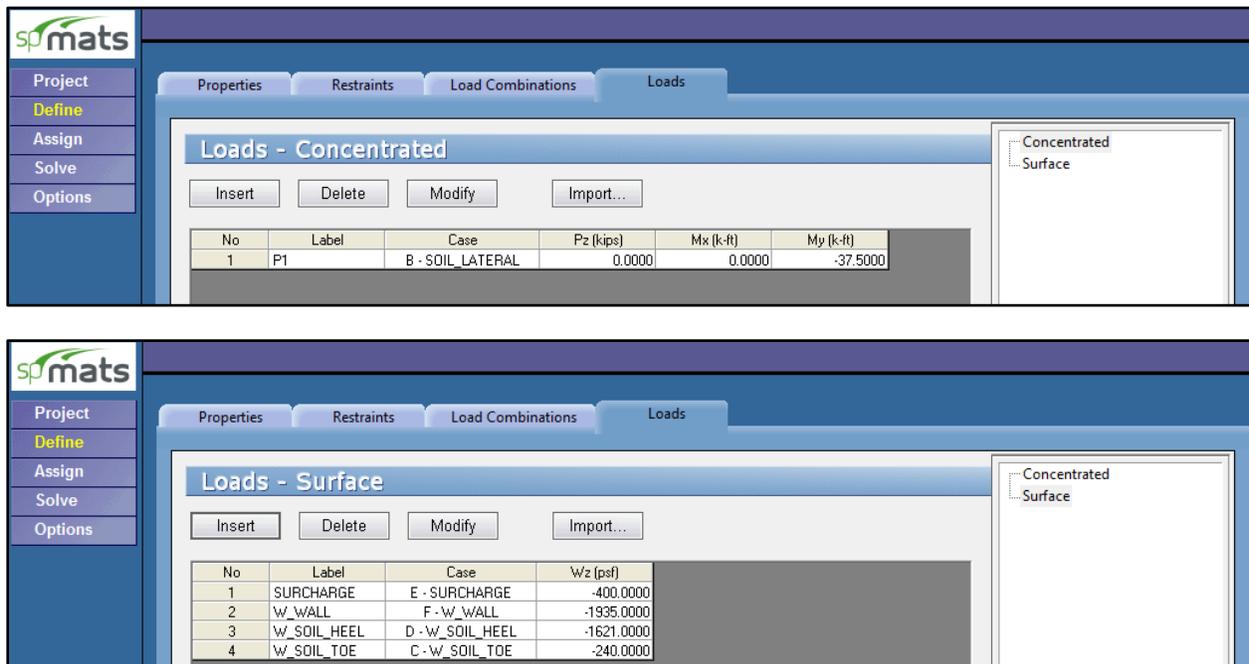


Figure 17 – Defining Loads

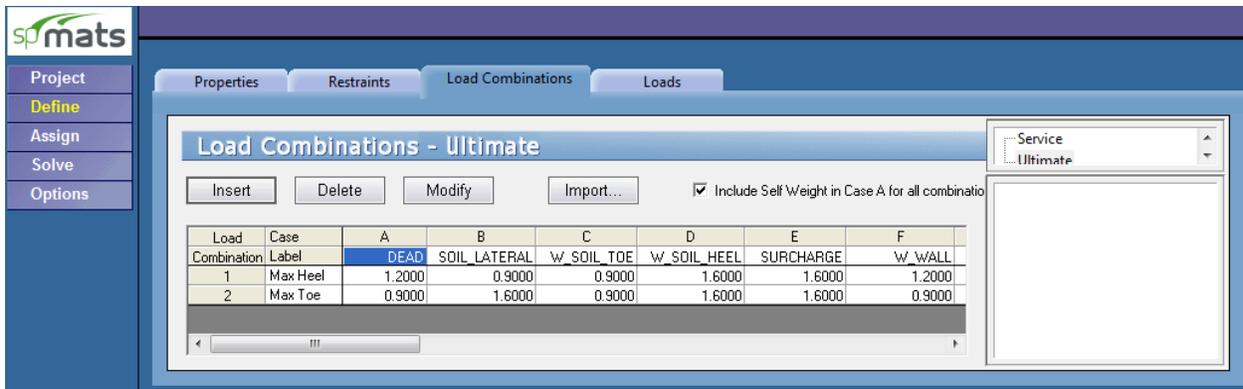


Figure 18 – Defining Load Combinations

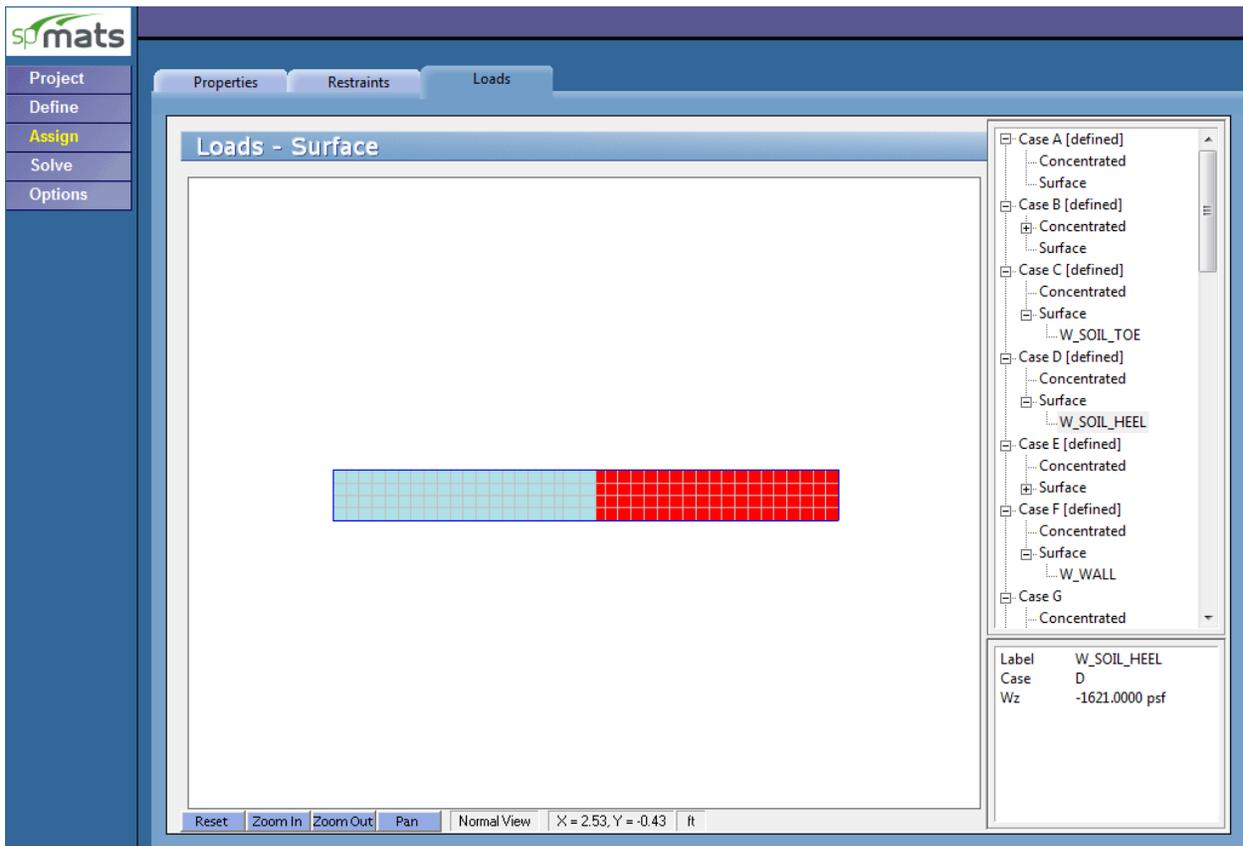


Figure 19 – Assigning Loads

5.2. Cantilever Retaining Wall Foundation Result Contours

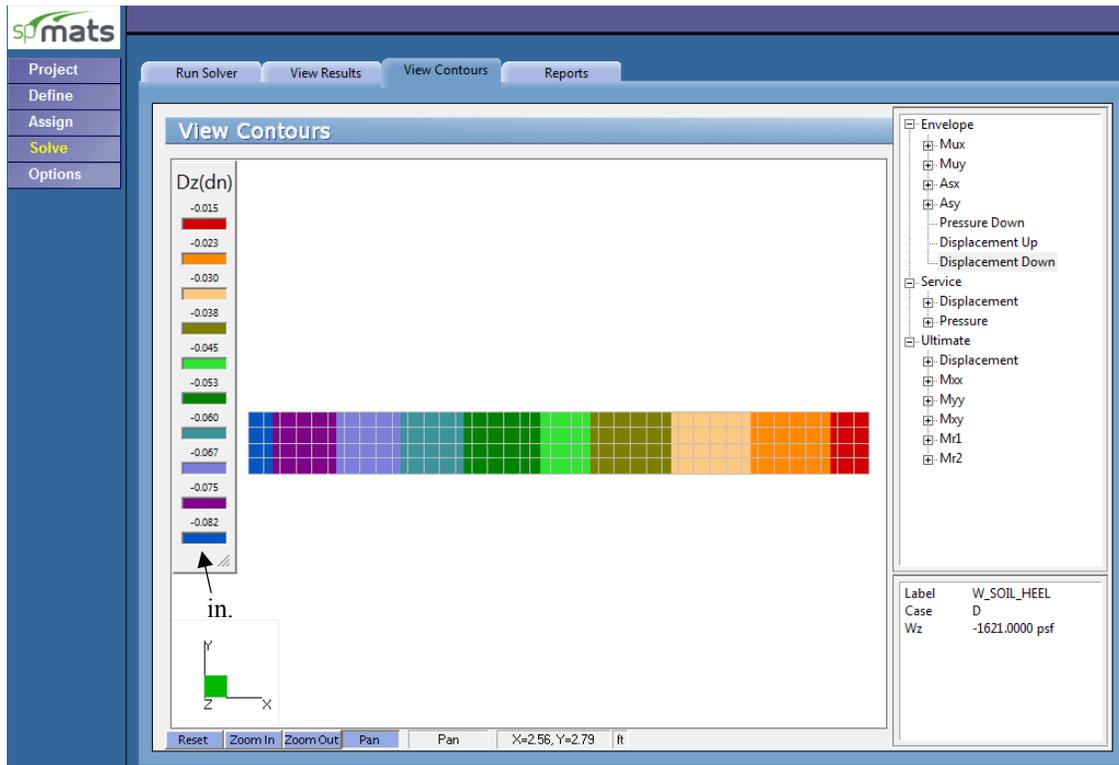


Figure 20 – Vertical (Down) Displacement Contour

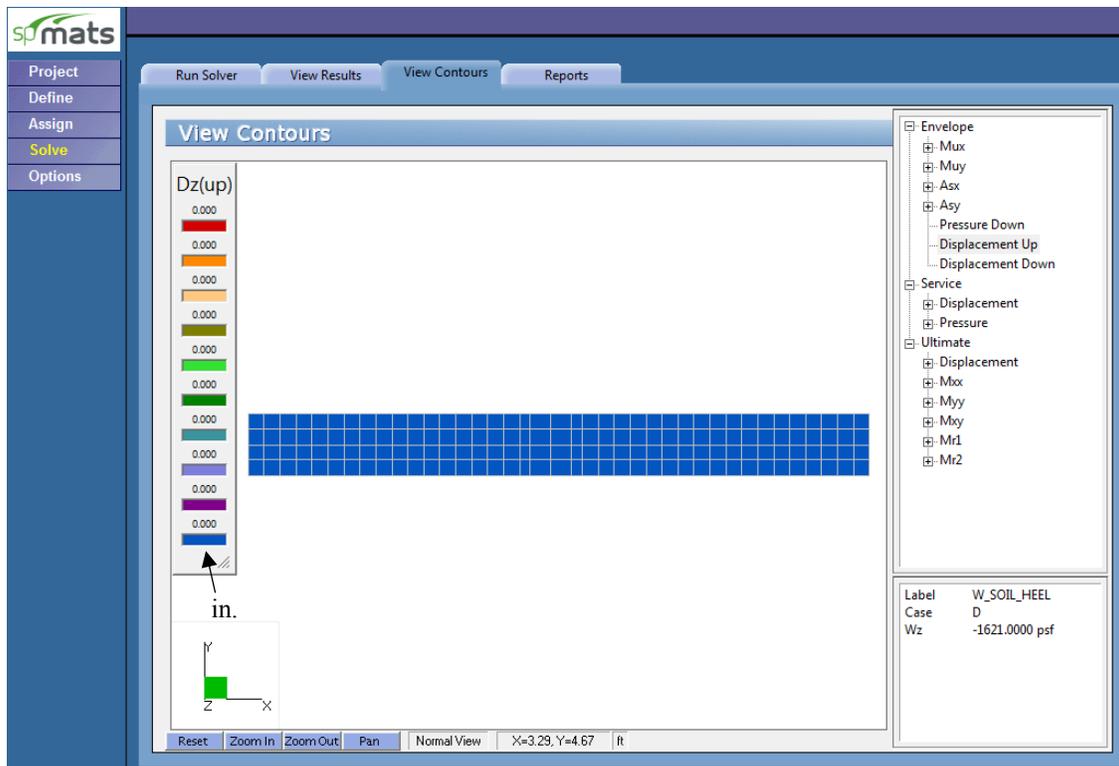


Figure 21 – Vertical (Up) Displacement Contour
(Note: figure indicates no uplift in the wall base)

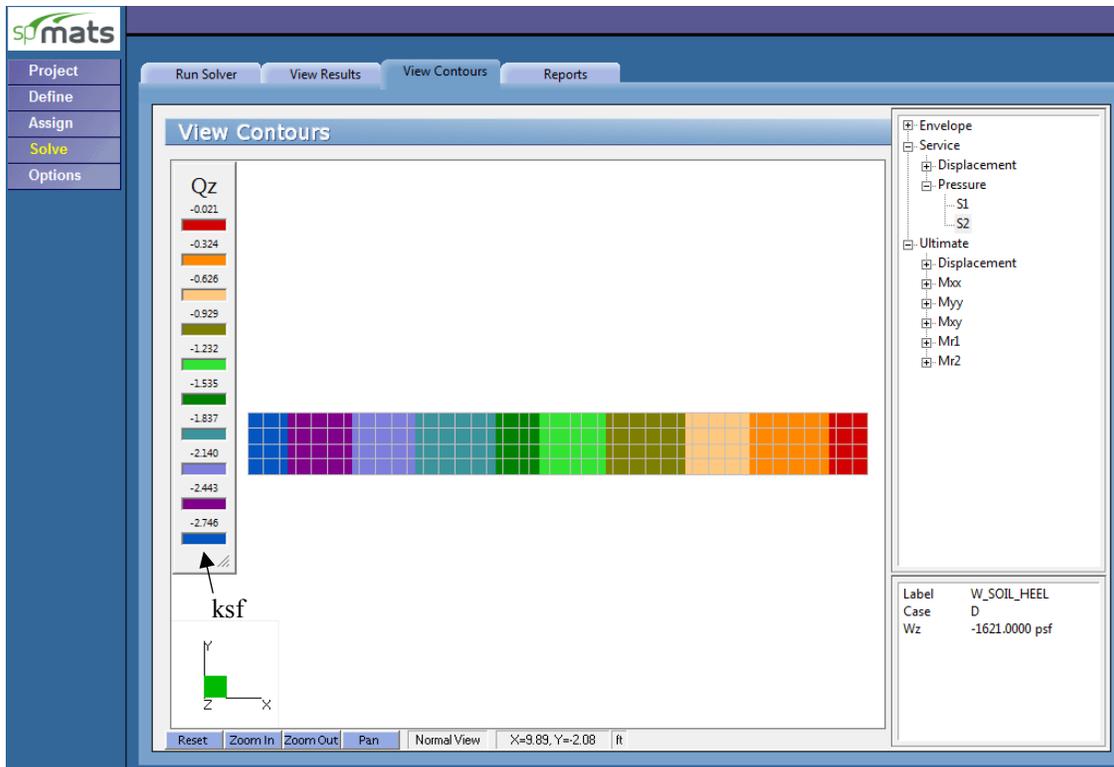


Figure 22 – Soil Bearing Pressure Contour for Case 1

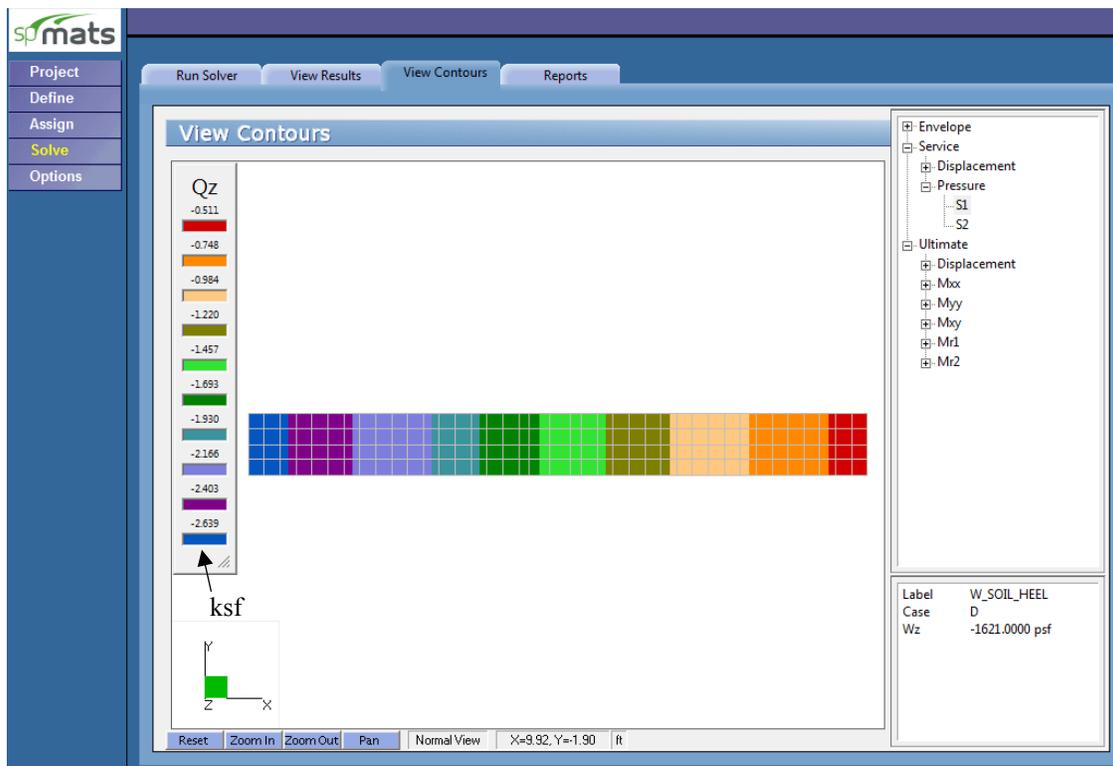


Figure 23 – Soil Bearing Pressure Contour for Case 2

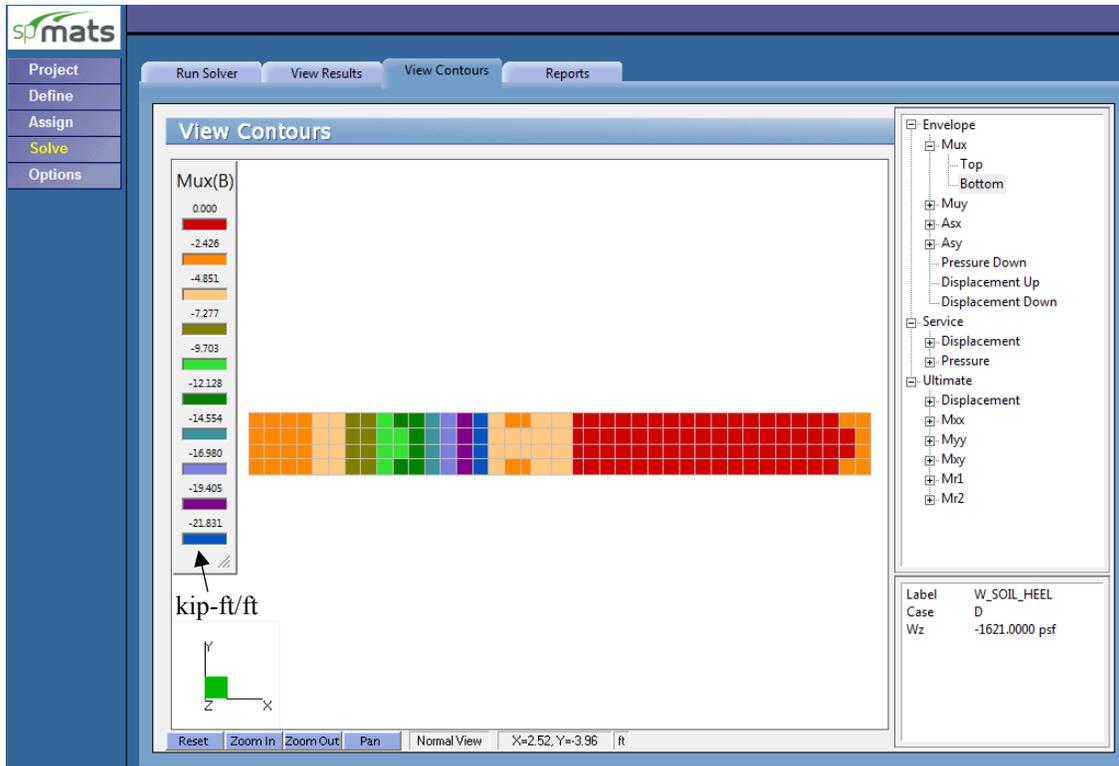


Figure 24 – Moment Contour along X-Axis (Max for Toe)

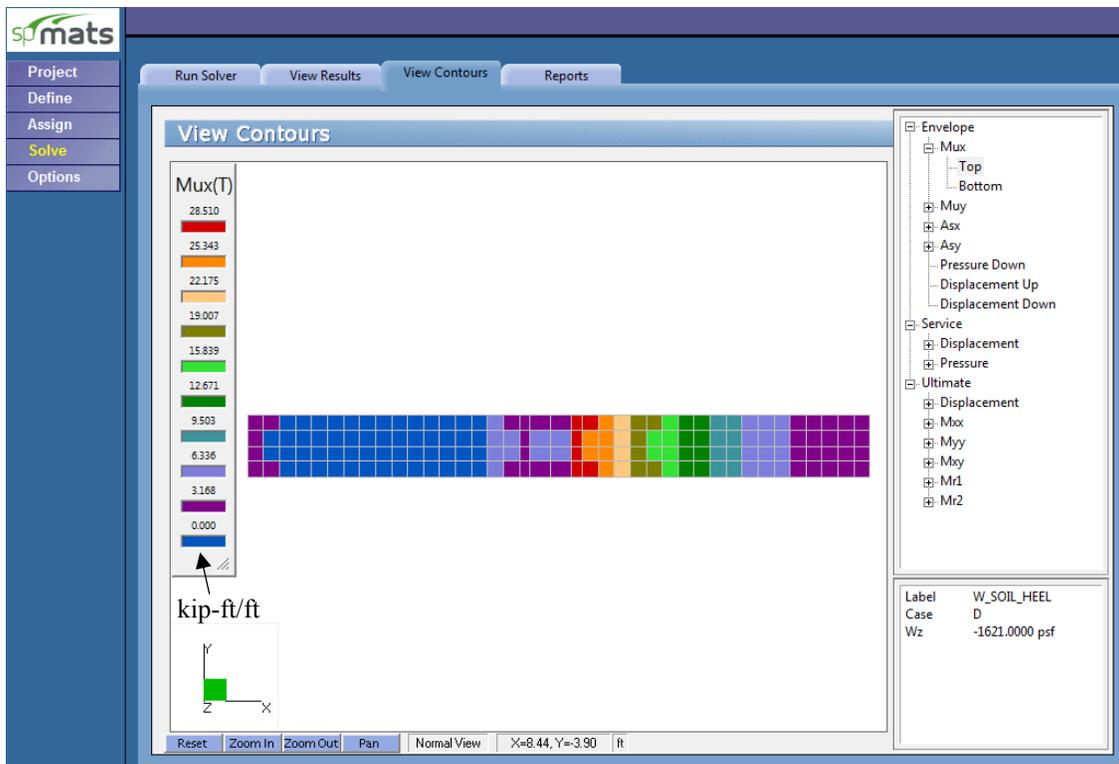


Figure 25 – Moment Contour along X-Axis (Max for Heel)

5.3. Cantilever Retaining Wall Foundation Required Reinforcement

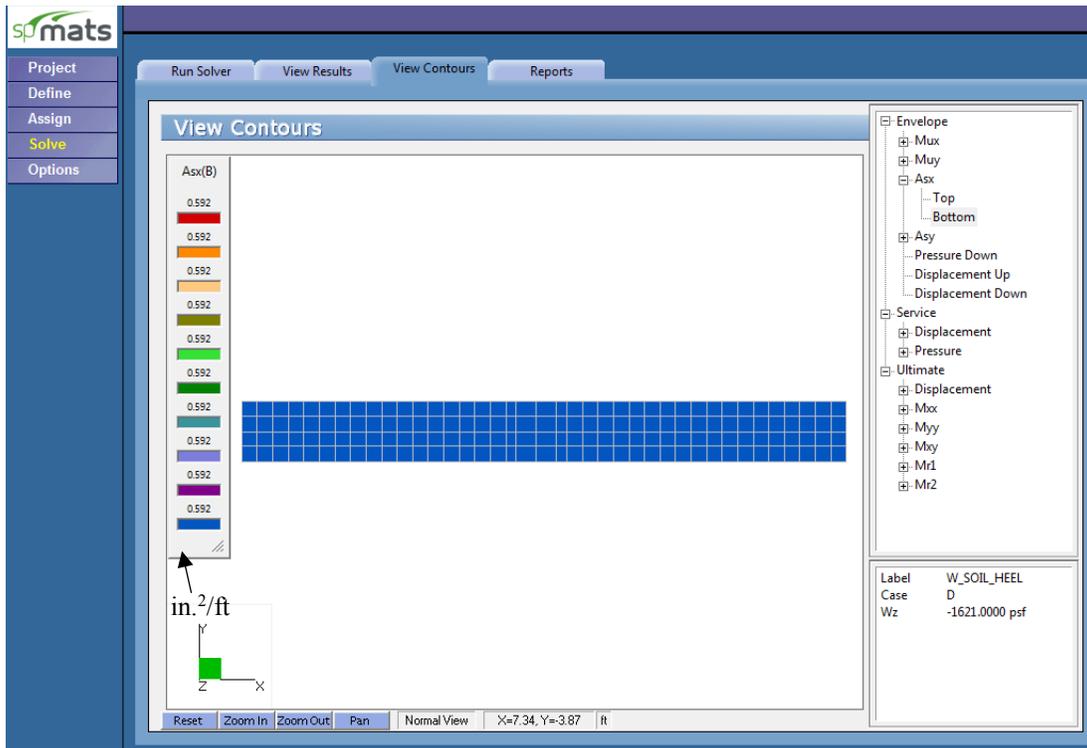


Figure 26 – Required Reinforcement Contour along X Direction (Bottom – Toe Design)
(Note minimum reinforcement governs)

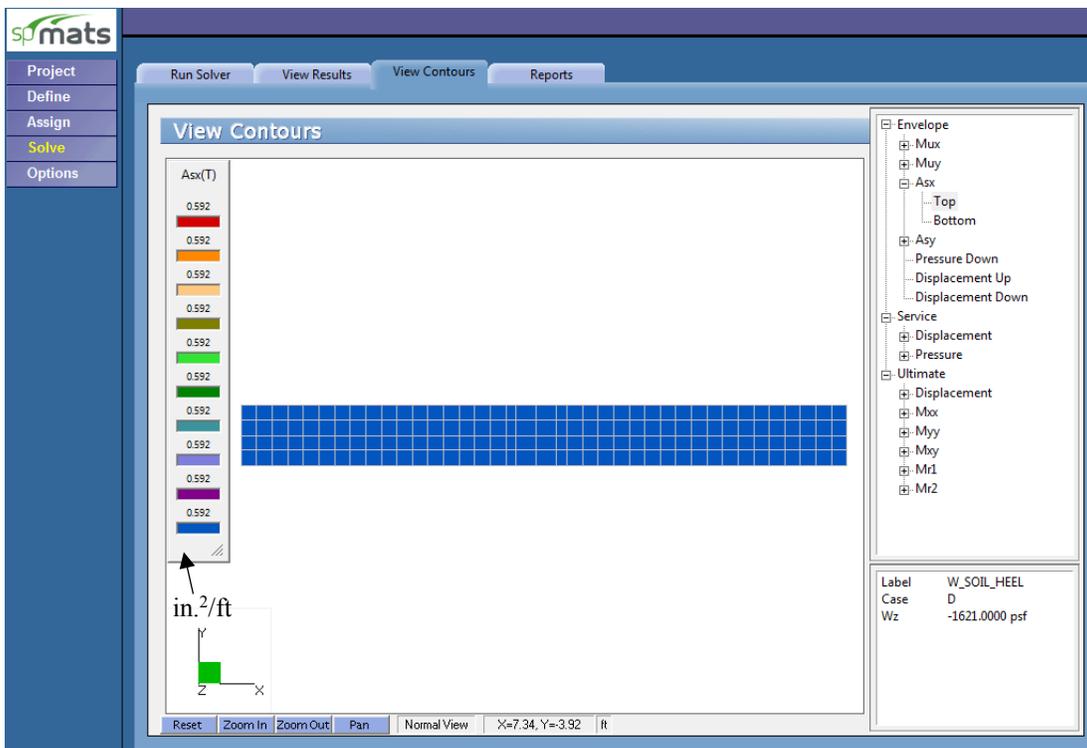


Figure 27 – Required Reinforcement Contour along X Direction (Top – Heel Design)
(Note minimum reinforcement governs)

5.4. Soil Reactions / Pressure

```

B3 - REACTIONS:
=====
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: S2
Sum of all forces and moments with respect to center of gravity (X, Y) = (4.88, 0.50) ft
  
```

Sum of Reactions	Fz	Mx	My
Soil	13.237	-0.000	22.156
Springs	-	-	-
Piles	-	-	-
Restraints	-	-	-
Slaved Nodes	0.000	0.000	0.000
Total Reactions	13.237	-0.000	22.156
Total Loads	-13.237	-0.000	-22.156

Figure 28 – Soil Service Reactions

```

B4 - SOIL DISPLACEMENTS AND PRESSURES:
=====
Units --> Displacement (in), Pressure (ksf)
Flags --> [x] Indicates allowable pressure is exceeded.
Service Load Combination: S2
  
```

Elem	Node	Disp, Dz	Pressure, Qz	Node	Disp, Dz	Pressure, Qz
79	122	-0.0803	-2.678	82	-0.0803	-2.678
	121	-0.0824	-2.746	81	-0.0824	-2.746
117	160	-0.0006	-0.021	120	-0.0006	-0.021
	159	-0.0025	-0.084	119	-0.0025	-0.084

Case 1

```

B4 - SOIL DISPLACEMENTS AND PRESSURES:
=====
Units --> Displacement (in), Pressure (ksf)
Flags --> [x] Indicates allowable pressure is exceeded.
Service Load Combination: S1
  
```

Elem	Node	Disp, Dz	Pressure, Qz	Node	Disp, Dz	Pressure, Qz
79	122	-0.0776	-2.587	82	-0.0776	-2.587
	121	-0.0792	-2.639	81	-0.0792	-2.639
117	160	-0.0153	-0.511	120	-0.0153	-0.511
	159	-0.0168	-0.559	119	-0.0168	-0.559

Case 2

Figure 29 – Soil Bearing Pressure

5.5. Cantilever Retaining Wall Foundation Model Statistics

Since spMats is utilizing finite element analysis to model and design the foundation. It is useful to track the number of elements and nodes used in the model to optimize the model results (accuracy) and running time (processing stage). spMats provides model statistics to keep tracking the mesh sizing as a function of the number of nodes and elements.

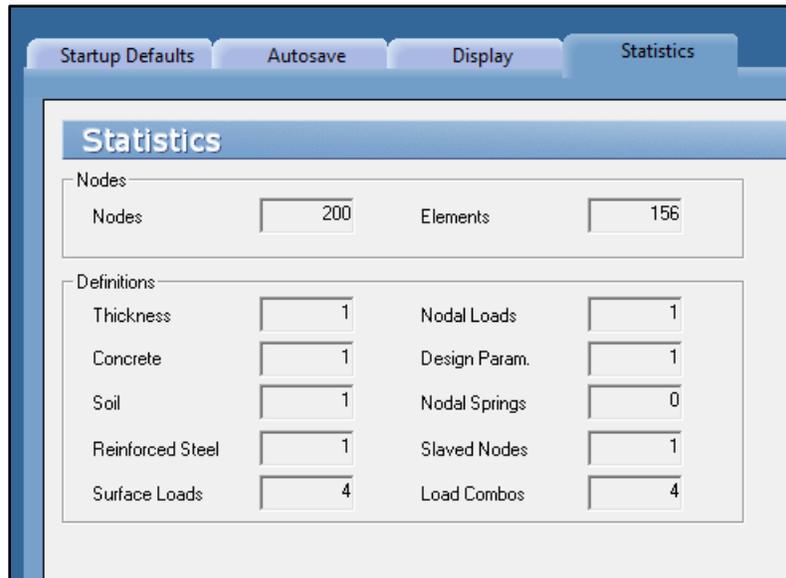


Figure 30 – Model Statistics

6. Cantilever Retaining Wall Analysis and Design Results Comparison & Conclusions

Method of Solution	M_u , kip-ft/ft	$A_{s,req}$, in. ² /ft
Reference	45.70	0.79
Hand	45.70	0.78
spWall	45.64	0.79

Method of Solution	Case 1		Case 2	
	q_1 , psf	q_2 , psf	q_1 , psf	q_2 , psf
Reference	2780	0	2710	492
Hand	2784	0	2715	496
spMats	2746	21	2639	511

Method of Solution	Toe		Heel	
	M_u , kip-ft/ft	$A_{s,req}$, in. ² /ft	M_u , kip-ft/ft	$A_{s,req}$, in. ² /ft
Reference	25.8*	0.59	38.2**	0.59
Hand	24.3	0.58	29.9	0.58
spMats	21.8	0.58	28.5	0.58

* the downward load of the earth fill over the toe is neglected by the reference
 ** the upward reaction of the soil is neglected by the reference

The results of all the hand calculations and the reference used illustrated above are in agreement with the automated exact results obtained from the [spWall](#) and [spMats](#) programs.

Note that the hand and reference considered the toe and heel as cantilever projecting outward and inward from the face of the stem, respectively. [spMats](#) provides the flexibility of modeling the foundation with the exact geometry and boundary conditions to achieve more accurate results leading to potential savings in the reinforcement required.

Some load cases were neglected by the reference for simplicity and to achieve a more conservative design. On the other hand, [spMats](#) take into account all the applied load cases and include them in the calculations of the required reinforcement for the toe and heel. Additional load combination can be easily employed in [spMats](#) to explore more loading scenarios to meet project criteria.