

Project	Gravity Wall Design - ASD	Project #	20004.00	Date	12/5/23
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**GRAVITY WALL DESIGN - ASD**  
**STONE STRONG PRECAST MODULAR BLOCK**

This engineering section presents information for design of Stone Strong retaining walls in a gravity configuration using conventional procedures with safety factors.

The design methodologies presented conform substantially to AASHTO specifications (Standard Specifications for Highway Bridges - 2002). This section includes the following documents:

- Gravity Wall Design Methodology (15 pages)
- Example Gravity Wall Calculations (9 pages)
- Example Spreadsheet Output (12 pages)

The example calculations and example spreadsheet output match identical design conditions and are intended as verification of the spreadsheet method. Note that the Gravity Analysis Spreadsheet is available on the Stone Strong website.

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**GRAVITY WALL DESIGN METHODOLOGY (ASD)**  
**STONE STRONG PRECAST MODULAR BLOCK**

Evaluate gravity retaining wall using allowable stress design approach following AASHTO and NCMA analytical techniques. Additional requirements, analytical methods, and theories are taken from the International Building Code, other AASHTO versions, and FHWA publications. Refer to:

AASHTO Standard Specifications for Highway Bridges 2002, 17<sup>th</sup> Edition

NCMA Design Manual for Segmental Retaining Wall, 3<sup>rd</sup> Edition

FHWA Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, NHI-00-043

International Building Code

**Properties of Soil/Aggregate**

Soil and material properties should be determined for the specific materials to be used:

unit fill -  $\gamma_u = 110$  pcf ( $17.3 \text{ kN/m}^3$ ) max (see AASHTO 5.9.2) &  $\phi_u$

leveling base -  $\gamma_b$  &  $\phi_b$  for typical aggregate base (or concrete base may be substituted)

retained soil -  $\gamma$  &  $\phi$  by site conditions (where select backfill is used, select material must encompass entire retained soil influence zone)

foundation soil -  $\gamma$   $\phi$  &  $c$  by site conditions

interface angle (see AASHTO 5.9.2)

For stepped modules, when the block width varies within a vertical section,  $\delta = \frac{3}{4} \phi$

For cases where all blocks are substantially uniform width,  $\delta = \frac{1}{2} \phi$

Note: infill weight is reduced to account for infill material not engaged by modular units in overturning. Only 80% of the weight of aggregate is included in the overturning calculations,  $W'$  (see AASHTO 5.9.2)

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## Precast Modular Unit Geometric Properties

### Block Library – Imperial Units

(not all units available from all dealers, verify availability)

Block Type	Description	Conc. Wt. (lbs)	Void Vol. (ft <sup>3</sup> )	Length (ft)	Height (ft)	Unit Width (in)	Conc. Cen. of Gravity x <sub>b</sub> (in)	Void Cen. of Gravity x <sub>a</sub> (in)
6-28	6SF-28 unit (6 square feet)	950	6.65	4	1.50	28	12.8	14.0
6-44	6SF-44 unit (6 square feet)	1,500	10.95	4	1.50	44	21.0	23.5
24-44	24SF-44 unit (24 square feet)	6,000	43.21	8	3.00	44	21.2	24.8
24-ME	24SF Mass Extender unit	10,000	44.94	8	3.00	56	32.7	25.8
24-62	24SF-62 unit	6,800	76.05	8	3.00	62	29.1	33.0
24-86	24SF-86 unit	7,600	117.90	8	3.00	86	40.0	45.1
D150	D150 Assembly (24SF-150)	12,650	210.32	8	3.00	150	74.5	75.5

dimensions are for battered units - for vertical face 24SF units, the width and center of gravity dimensions are all reduced by 1 inch

### Block Library – Metric Units

(not all units available from all dealers, verify availability)

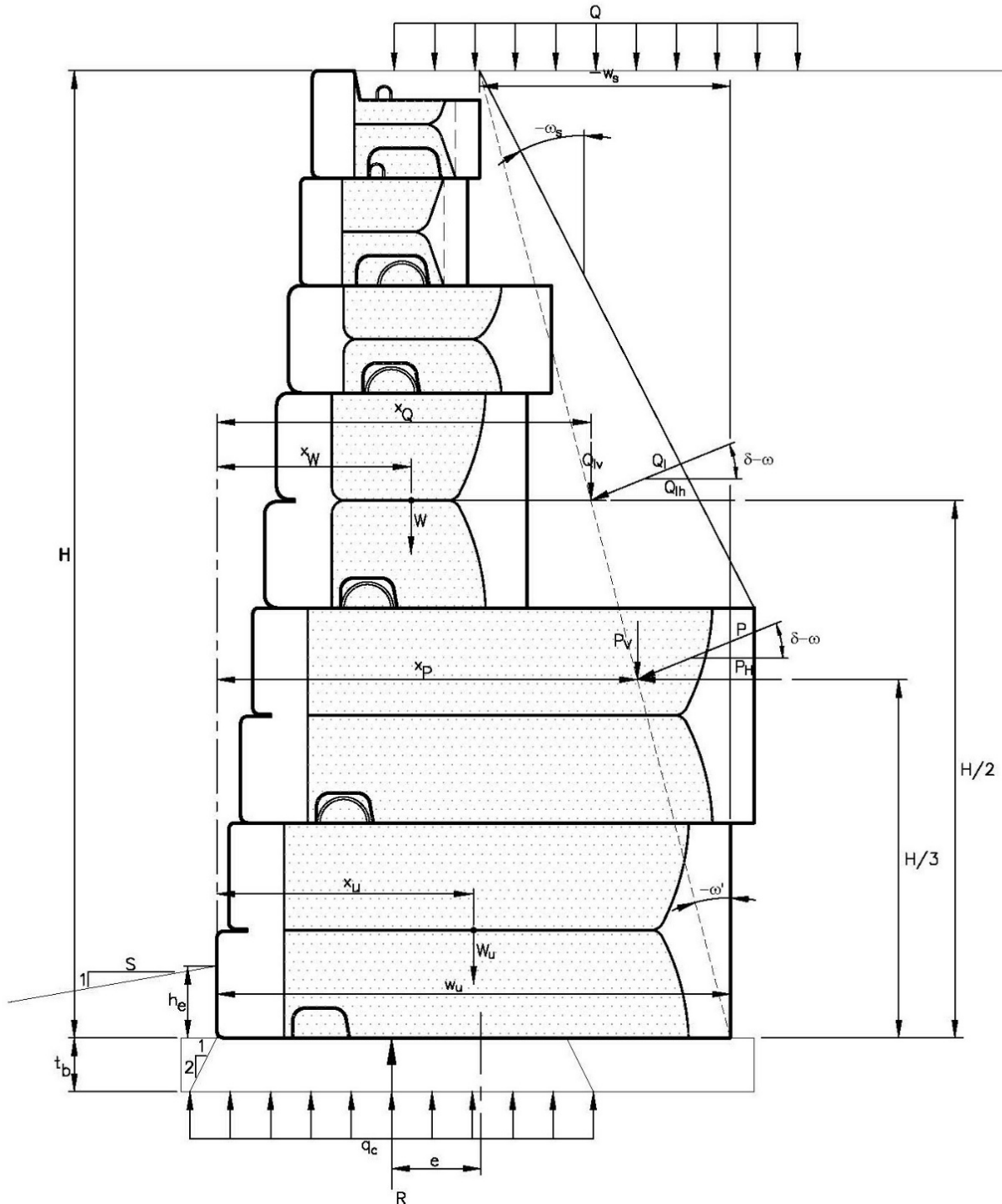
Block Type	Description	Conc. Wt. (kN)	Void Vol. (m <sup>3</sup> )	Length (m)	Height (m)	Unit Width (mm)	Conc. Cen. of Gravity x <sub>b</sub> (mm)	Void Cen. of Gravity x <sub>a</sub> (mm)
6-28	6SF-28 unit (6 square feet)	4.23	0.19	1.22	0.46	711	324	356
6-44	6SF-44 unit (6 square feet)	6.67	0.31	1.22	0.46	1,118	533	597
24-44	24SF-44 unit (24 square feet)	26.69	1.22	2.44	0.91	1,118	538	630
24-ME	24SF Mass Extender unit	44.48	1.28	2.44	0.91	1,422	831	655
24-62	24SF-62 unit	30.25	2.16	2.44	0.91	1,575	739	838
24-86	24SF-86 unit	33.80	3.35	2.44	0.91	2,184	1,016	1,146
D150	D150 Assembly (24SF-150)	56.27	5.96	2.44	0.91	3,810	1,892	1,918

dimensions are for battered units - for vertical face 24SF units, the width and center of gravity dimensions are all reduced by 25 mm

Wall stability calculations are performed per unit length of wall, so all weights and forces are expressed per foot or m of wall length.

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Typical gravity wall configuration, variables, and nomenclature:



Note that surcharge loads over the top of the wall are a stabilizing force and are neglected as conservative.

[illegible]

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Wall units that vary in width are referred to as “stepped” modules. Wider wall units are typically placed at the bottom of the wall. In addition to using wider precast units, the stability of a gravity wall can be improved by using cast-in-place tail extensions to increase the width of the units. The width of the CIP extension is not limited, but it is recommended that the height be at least 2 times the width to provide shear through the tail openings (unless connecting with reinforcing steel).

#### Wall batter

In common applications, the block units are installed in a battered configuration. In a typical batter, the 24-44, 24-62, 24-86, and 24-ME units are 36 inches (914 mm) high and the next block atop a 24 SF block will batter back 4 inches (102 mm). The 6-44 and 6-28 units are 18 inches (457 mm) tall, and the next block atop a 6 SF block will batter 2 inches (51 mm). These blocks may be interchanged within a wall stack, but the batter is determined by the height of the unit below.

4 in. setback per 24 SF block (36 in. tall)      102 mm setback per 24 SF block (914 mm tall)

2 in. setback per 6 SF block (18 in. tall)      51 mm setback per 6 SF block (457 mm tall)

The face batter is calculated as:

$$\omega = \arctan(4/36) = 6.34^\circ$$

$$\omega = \arctan(102/914) = 6.34^\circ$$

$$\text{or } \omega = \arctan(2/18) = 6.34^\circ$$

$$\omega = \arctan(51/457) = 6.34^\circ$$

In some applications, the units may be installed with no batter to create a vertical face,  $\omega = 0^\circ$

For uniform modules, the batter of the back face matches the batter of the front face. For stepped modules, the batter is recalculated along the back of the wall from the rear of the bottom unit to the rear of the top of the wall. Use  $\omega'$  in Coulomb equation and earth pressure component calculations. To calculate  $\omega'$  it is necessary to know the effective setback width,  $w_s$ , which is the horizontal distance between the back edge of the top block and the back edge of the lower unit including any tail extension.  $w_s$  is negative when the mass extender projects further than the back of the top block. Knowing this distance and the height of wall:

$$\omega' = \arctan(w_s/H_w)$$

#### Base Thickness/Embedment

The type and thickness of wall base or leveling pad and depth of embedment can vary by site requirements. A granular base with a thickness of 9 inches (225 mm) is commonly used, but the thickness can be adjusted to reduce the contact pressure. A concrete leveling pad or footing can also be used. The required embedment to the top of the base is related to the exposed height of the wall and by the slope at the toe, as well as other factors. The required embedment can be calculated for slopes steeper than 6H:1V using the following equation:

$$h_e = H'/(20 \cdot S/6)$$

where S is the run of the toe slope per unit fall and H' is the exposed height of the wall

A minimum embedment of 6 to 9 inches (150 to 225 mm) is recommended for private projects. A minimum embedment of 20 inches (500 mm) or more may be required for roadway applications

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### Weight of Wall

The weight of the wall includes the contributions of the blocks, the aggregate unit fill, the tail extension, and the soil wedge atop extended modules or tail extension

The weight of the tail extension is calculated:

$$W_{te} = (w_{te} * H_{te}) * 145 \text{ pcf (22.8 kN/m}^3\text{)} \quad \text{(typical unit weight for concrete)}$$

where  $w_{te}$  is the width of the tail extension and  $H_{te}$  is the height of the extension (both in ft.)

The angle of the batter (from vertical) of the soil wedge above the tail extension,  $\omega_s$ , is calculated:

$$\omega_s = \arctan(-w'_s/H_{\text{wedge}})$$

The weight of soil in the wedge above the tail extension is calculated for the trapezoidal area of the wedge that lies behind each block

$h_s$  = height of the soil trapezoid behind the block (may differ from height of the block)

$w_u$  = width of the block

$h_1$  = dist. from the top of wall to top of the soil trapezoid behind the block

$h_2$  = dist. from the top of wall to bottom of the soil trapezoid behind the block

$s$  = dist. from the face of wall to face of the block

$s_u$  = dist. from the face of wall to back of the block =  $s + w_u$

$s_T$  = dist. from the face of wall to the back of top-most block of wall

$b_1$  = length of top side of trapezoid of soil behind block =  $h_1 * \tan(\omega_s) + (s_T - s_u)$

$b_2$  = length of bottom side of trapezoid of soil behind block =  $h_2 * \tan(\omega_s) + (s_T - s_u)$

The weight of the soil wedge above the tail extension behind each block,  $W_s$ , is calculated as the trapezoidal area multiplied by the lesser of the unit weight of the retained soil or the unit fill:

$$W_s = [h_s * (b_1 + b_2)/2] * (\text{min of } \gamma_{\text{ret}} \text{ or } \gamma_u)$$

The center of gravity of the trapezoidal wedge behind each block, measured from the face of the wall at the bottom course, is calculated:

$$x_s = [(b_1 * b_2 + (b_2^2 - 2 * b_1 * b_2 + b_1^2)/3)/(b_1 + b_2)] + s + w_u$$

$$y_s = [h_s/3 * (2b_1 + b_2)/(b_1 + b_2)] + H - h_2$$

$W_s$  is treated as aggregate infill subject to 80% limitations for overturning calculations (conservative)

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## Static Forces

Coulomb active earth pressure coefficient (see AASHTO 5.5.2-1)

$$K_a = \frac{\cos^2(\phi + \omega')}{\cos^2(\omega') \cos(\omega' - \delta) \left[ 1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - \beta)}{\cos(\omega' - \delta) \cos(\omega' + \beta)}} \right]^2}$$

As an alternate, a trial wedge technique may be used to determine the earth pressure forces acting on the modular wall.

Earth Load Components (see AASHTO 5.5.2-1)

Vertical forces:

$$P_v = 0.5 K_a \gamma H^2 \sin(\delta - \omega')$$

$$Q_{lv} = K_a Q H \sin(\delta - \omega') \text{ where } Q \text{ is the effective surcharge in psf (kPa)}$$

Horizontal forces:

$$P_h = 0.5 K_a \gamma H^2 \cos(\delta - \omega')$$

$$Q_{lh} = K_a Q H \cos(\delta - \omega') \text{ where } Q \text{ is the effective surcharge in psf (kPa)}$$

Resultants of earth load components:

$$y_P = H/3$$

$$x_P = (H/3) \tan(\omega') + w_u$$

$$y_{Ql} = H/2$$

$$x_{Ql} = (H/2) \tan(\omega') + w_u$$

where  $w_u$  is the width of the bottom unit, including any tail extension ( $w_{te}$ )

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### Weight Components

Vertical forces:

$W_b$  – Weight of wall units

$W_{te}$  – Weight of concrete tail extension, if used

$W_a$  – Weight of infill aggregate (use 80% aggregate weight for overturning)

$W_s$  – Weight of soil atop tail extension (use 80% aggregate weight for overturning)

$$W_b = \sum(W_{b1} + W_{b2} + \dots + W_{bn})$$

$$W_{te} = \sum(W_{te1} + W_{te2} + \dots + W_{te})$$

$$W_a = \sum(W_{a1} + W_{a2} + \dots + W_{an})$$

$$W_s = \sum(W_{s1} + W_{s2} + \dots + W_{sn})$$

Resultants of weight components:

The center of mass of the stack of blocks is calculated as:

$$x_b = \sum(W_{b1} * x_{b1} + W_{b2} * x_{b2} + \dots + W_{bn} * x_{bn}) / \sum(W_{b1} + W_{b2} + \dots + W_{bn})$$

$$y_b = \sum(W_{b1} * y_{b1} + W_{b2} * y_{b2} + \dots + W_{bn} * y_{bn}) / \sum(W_{b1} + W_{b2} + \dots + W_{bn})$$

The center of mass of the aggregate fill is:

$$x_a = \sum(W_{a1} * x_{a1} + W_{a2} * x_{a2} + \dots + W_{an} * x_{an}) / \sum(W_{a1} + W_{a2} + \dots + W_{an})$$

$$y_a = \sum(W_{a1} * y_{a1} + W_{a2} * y_{a2} + \dots + W_{an} * y_{an}) / \sum(W_{a1} + W_{a2} + \dots + W_{an})$$

The center of mass of the soil wedge over the tail is:

$$x_s = \sum(W_{s1} * x_{s1} + W_{s2} * x_{s2} + \dots + W_{sn} * x_{sn}) / \sum(W_{s1} + W_{s2} + \dots + W_{sn})$$

$$y_s = \sum(W_{s1} * y_{s1} + W_{s2} * y_{s2} + \dots + W_{sn} * y_{sn}) / \sum(W_{s1} + W_{s2} + \dots + W_{sn})$$

The center of mass of the tail extension can be calculated with the following equation:

$$x_{te} = \sum(W_{te1} * x_{te1} + W_{te2} * x_{te2} + \dots + W_{ten} * x_{ten}) / \sum(W_{te1} + W_{te2} + \dots + W_{te})$$

$$y_{te} = \sum(W_{te1} * y_{te1} + W_{te2} * y_{te2} + \dots + W_{ten} * y_{ten}) / \sum(W_{te1} + W_{te2} + \dots + W_{te})$$

The overall adjusted center of mass of the blocks and tail extension:

$$x_{b+te} = (W_b * x_b + W_{te} * x_{te}) / (W_b + W_{te})$$

$$y_{b+te} = (W_b * y_b + W_{te} * y_{te}) / (W_b + W_{te})$$

The overall adjusted center of mass of the aggregate and the soil above the tail is:

$$x_{a+s} = (W_a * x_a + W_s * x_s) / (W_a + W_s)$$

$$y_{a+s} = (W_a * y_a + W_s * y_s) / (W_a + W_s)$$

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## Seismic Loads

Seismic components of force are calculated according to the procedures in FHWA 4.2h.

The maximum acceleration  $A_m = (1.45 - A) \cdot A$  where  $A$  is the peak horizontal ground acceleration.

The seismic earth pressure coefficient is calculated with the following equation:

$$K_{ae} = \frac{\cos^2(\phi + \omega' - \xi)}{\cos(\xi) \cos^2(-\omega') \cos(\delta - \omega' + \xi) \left[ 1 + \sqrt{\frac{\sin(\phi + \delta) \sin(\phi - \xi - \beta)}{\cos(\delta - \omega' + \xi) \cos(\omega' + \beta)}} \right]^2}$$

where  $\xi = \arctan [k_h / (1 - k_v)]$

The trial wedge technique is recommended in high seismicity regions to determine the dynamic thrust forces acting on the modular wall.

### Seismic Earth load components

$k_v$  is generally taken as 0.  $k_h$  is the maximum horizontal acceleration of the wall, and is a function of the maximum allowable displacement of the wall during a seismic event. It is calculated with the following equation:

$$k_h = 0.74 \cdot A_s \cdot [A_s / (d)]^{0.25} \quad (\text{where } d \text{ is in inches})$$

$$k_h = 1.66 \cdot A_s \cdot [A_s / (d)]^{0.25} \quad (\text{where } d \text{ is in mm})$$

$d$  is the maximum horizontal displacement and is typically set at 2 inches (50 mm) as conservative.

$$A_s = \text{PGA} \cdot F_{\text{pga}}$$

Note that when PGA is not explicitly provided, it can be calculated from seismic response values provided in the International Building Code. IBC 1802.2.7 allows for PGA to be taken as  $S_{DS}/2.5$ . Following IBC Eq. 16-37 and 16-39:

$$\text{PGA} = 0.267 \cdot S_s \cdot F_a$$

The horizontal inertial force  $P_{ir}$  is calculated as follows:

$$P_{ir} = (W_b + W_{te} + W_a + W_s) \cdot k_h$$

The seismic thrust is calculated as follows:

$$\Delta P_{ae} = 0.5 \cdot \gamma \cdot H^2 \cdot (K_{ae} - K_a)$$

$$\Delta P_{aeh} = 0.5 \cdot \gamma \cdot H^2 \cdot (K_{ae} - K_a) \cdot \cos(\delta - \omega')$$

$$\Delta P_{aev} = 0.5 \cdot \gamma \cdot H^2 \cdot (K_{ae} - K_a) \cdot \sin(\delta - \omega')$$

### Resultants of Seismic Earth load components

In overturning analysis, the inertial force is applied at the vertical center of gravity of the wall, while the seismic thrust is applied at 60% of the wall height.

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$$y_{Pae} = 0.6 \cdot H$$

$$x_{Pae} = 0.6 \cdot H \cdot \tan(\omega') + w_u$$

$$y_{Pir} = (W_b \cdot y_b + W_{te} \cdot y_{te} + W_a \cdot y_a + W_s \cdot y_s) / (W_b + W_{te} + W_a + W_s)$$

Since the inertial and thrust forces are generally not in sync and do not peak simultaneously, the full inertial force is applied along with 50% of the seismic thrust (FHWA 4.2h).

Stability including seismic load conditions should be separately verified for sliding, overturning/eccentricity, and bearing. Live loads are typically excluded from seismic analysis.

### Base Friction

Friction across the base of the wall is used to resist sliding failure. Frictional resistance must be determined both between the wall assembly and the base and between the base and the foundation soil (or through the foundation soil).

The sliding resistance is calculated as the smaller result of the following equations:

For base to foundation soil failure, use:

$$R_{s(\text{foundation soil})} = (W_b + W_{te} + W_a + W_s + P_v + w_u \cdot t_b \cdot \gamma_b) \tan \phi + B_w \cdot c$$

where  $\phi$  represents foundation soil friction angle,  $B_w$  is base width (bottom block width including any tail extension plus  $\frac{1}{2}H:1V$  distribution through base), and  $c$  represents foundation soil cohesion. The weight of the base is included in the wall weight.

For block to base material sliding, use:

$$R_{s(\text{footing})} = \mu_b (W_b + W_{te} + W_a + W_s + P_v)$$

where  $\mu_b$  represents a composite coefficient of friction for the base

The composite friction coefficient is calculated using contributory areas. The base of a Stone Strong unit consists of a percentage of open void space to be filled with aggregate and a percentage of concrete. These percentages are calculated as follows:

$$\%_{\text{void}} = V_{\text{void}} / (V_{\text{void}} + V_{\text{concrete}})$$

$$\%_{\text{concrete}} = V_{\text{concrete}} / (V_{\text{void}} + V_{\text{concrete}})$$

If a tail extension is used, the area of the tail extension must also be calculated and the total area is also increased accordingly. Thus, the equation for composite friction coefficient across the base becomes:

$$\mu_b = (\%_{\text{void}} \cdot w_{u(\text{bottom})} \cdot \mu_{p - \text{unit fill/base}} + \%_{\text{concrete}} \cdot w_{u(\text{bottom})} \cdot \mu_{p - \text{block/base}} + w_{te} \cdot \mu_{p - \text{extension/base}}) / (w_{u(\text{bottom})} + w_{te})$$

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Partial friction coefficients can be interpreted from the following table:

	<b>Coefficient of Friction</b>
<b>Block to Aggregate Base</b> formed precast surface on compacted aggregate surface (includes Mass Extender)	$0.8 \cdot \tan \phi_b$
<b>Unit Fill to Aggregate Base</b> screened aggregate (loose to moderate relative density - dumped) on compacted aggregate surface	lower $\tan \phi_b$ or $\tan \phi_u$
<b>Block to Concrete Base</b> formed precast surface on floated concrete surface (includes Mass Extender)	0.60
<b>Unit Fill Aggregate to Concrete Base</b> screened aggregate (loose to moderate relative density - dumped) on floated concrete surface	$0.8 \cdot \tan \phi_u$
<b>Concrete Tail Extension to Aggregate Base</b> cast in place concrete on aggregate surface	$\tan \phi_b$
<b>Concrete Tail Extension to Concrete Base</b> cast in place concrete on floated concrete surface	0.75
<b>Concrete Tail Extension Directly on Foundation Soil (Sand)</b> cast in place concrete on granular soil	$\tan \phi_f$
<b>Note:</b> These typical values may be used for evaluation of base sliding at the discretion of the user. The licensed engineer of record is responsible for all design input and for evaluating the reasonableness of calculation output based upon his/her knowledge of local materials and practices and on the specific design details.	

Since the unit fill aggregate is typically placed to a moderately loose state, the friction angle for the screened unit fill aggregate typically controls for the interface between the unit fill and the base aggregate.

If actual test data for the project specific materials is not available, or for preliminary design, the following conservative friction angles are suggested for base and infill aggregates:

	<b>Friction Angle (degrees)</b>		
	Well Graded, Aggregate, Densely Compacted	Screened Aggregate, Compacted	Screened Aggregate, Loose to Moderate Relative Density
<b>Crushed Hard Aggregate</b> >75% w/ 2 fractured faces, hard natural rock	42	40	36
<b>Crushed Aggregate</b> >75% w/ 2 fractured faces, medium natural rock or recycled concrete	40	38	35
<b>Cracked Gravel</b> >90% w/ 1 fractured face	36	35	32
<b>Note:</b> Physical testing of specific aggregates is recommended. When test data is not available, these typical values may be used at the discretion of the user. The licensed engineer of record is responsible for all design input and for evaluating the reasonableness of calculation output based upon his/her knowledge of local materials and practices and on the specific design details.			

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### Table of Forces & Moments

	Force (lb) or (kN)	Arm (ft) or (m)	Moment about toe (lb*ft) or (kN *m)
<b>Vertical Forces</b>			
weight of blocks	$W_b + W_{te}$	$x_{b+te}$	$(W_b + W_{te}) * x_{b+te}$
weight of agg. & soil over tail	$W_a + W_s$	$x_{a+s}$	$(W_a + W_s) * x_{a+s}$
modified weight of a & s (80%)	$0.8 * (W_a + W_s)$	$x_{a+s}$	$0.8 * (W_a + W_s) * x_{a+s}$
earth pressure	$P_v$	$x_P$	$P_v * x_P$
seismic thrust	$P_{aev}/2$	$x_{Pae}$	$P_{aev}/2 * x_{Pae}$
LL surcharge	$Q_{lv}$	$x_{Ql}$	$Q_{lv} * x_{Ql}$
<b>Horizontal Forces</b>			
earth pressure	$P_h$	$y_{Ph}$	$P_h * y_{Ph}$
seismic thrust	$\Delta P_{aeh}/2$	$y_{Pae}$	$\Delta P_{aeh}/2 * y_{Pae}$
inertial force	$P_{ir}$	$y_{Pir}$	$P_{ir} * y_{Pir}$
LL surcharge	$Q_{lh}$	$y_{Ql}$	$Q_{lh} * y_{Ql}$

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### Overturning

For overturning, the modified weights using 80% of the aggregate weight (including the soil over the tail extension) are used for all overturning calculations.

$M'_V$	$\Sigma$ moments from vertical forces (using 80% $W_s$ & $W_a$ )
$M_H$	$\Sigma$ moments from horizontal forces
FS	$M'_V / M_H$

The overturning safety factor should be greater than 1.5 for private projects (NCMA 4.3 and IBC 1806.1). A minimum safety factor of 2.0 may be required for highway applications (AASHTO 5.5.5).

check that  $FS > 1.5$  with static earth pressure loads and surcharge loads

Safety factors are typically reduced 25% for seismic loading due to the extreme nature of these events. Surcharge loads are generally not applied concurrent with seismic loads.

check that  $FS > 1.13$  with static earth pressure loads and seismic loads

### Sliding

The minimum value for sliding resistance is calculated as follows:

$F_H$	$\Sigma$ horizontal forces
$F_V$	$\Sigma$ vertical forces (using 100% $W_s$ & $W_a$ )
$R_s$ (footing)	$\mu_b F_V$
$R_s$ (foundation soil)	$(F_V + t_b * w_b * \gamma_b) * \tan(\phi) + B_w * c$
min $R_s$	smaller of $R_s$ (footing) or $R_s$ (foundation soil)
FS	min $R'_s / F_H$

The safety factor for sliding should be greater than 1.5

check that  $FS > 1.5$  with static earth pressure loads and surcharge loads

check that  $FS > 1.13$  with static earth pressure loads and seismic loads

<b>Project</b> Gravity Wall Design Methodology	<b>Project #</b> 20004.00	<b>Date</b> 12/5/23
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### Bearing/Eccentricity

$B_f'$  is the equivalent bearing area. This is the base block width adjusted for eccentricity, and including a 1/2H:1V distribution through granular base or 1H:1V distribution through concrete base.

$$B_f' = w_u + w_{te} + t_b - 2 \cdot e \quad \text{or} \quad B_f' = w_u + w_{te} + 2 \cdot t_b - 2 \cdot e \quad (\text{for concrete base})$$

$F_v$	$\Sigma$ vertical forces (using 100% $W_s$ & $W_a$ )
weight of base	$t_b \cdot \gamma_b$
$M_v$	$\Sigma$ moments from vertical forces (using 100% $W_s$ & $W_a$ )
$M_H$	$\Sigma$ moments from horizontal forces
$e$	$(w_u + w_{te})/2 - (M_v - M_H)/F_v$
$B_f'$ (granular base)	$w_u + w_{te} + t_b - 2 \cdot e$
$B_f'$ (concrete base)	$w_u + w_{te} + 2 \cdot t_b - 2 \cdot e$
contact pressure $q_c$	$F_v / B_f' + t_b \cdot \gamma_b$
bearing resistance $q_{ult}$	$c \cdot N_c \cdot d_c \cdot g_c + (h_e + t_b) \cdot \gamma_{found} \cdot N_q \cdot d_q \cdot g_q + 0.5 \cdot \gamma_{found} \cdot B_f' \cdot N_\gamma \cdot d_\gamma \cdot g_\gamma$
FS	$q_{ult} / q_c$

Note that inclined loading factors are customarily ignored for retaining systems.

The safety factor for bearing should be greater than 2

check that  $FS > 2.0$  with static earth pressure loads and surcharge loads

check that  $FS > 1.5$  with static earth pressure loads and seismic loads

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### Internal Analysis

Internal stability analysis is conducted for each section above the wall base. Since bearing conditions are addressed in the external stability analysis, only topping and shear failures are evaluated.

Toppling is evaluated similarly to external overturning analysis, except that the overturning point is set in 1 inch (25 mm) to account for face rounding.

$$FS = M'_V / M_H$$

check that  $FS > 1.5$  with static earth pressure loads and surcharge loads

check that  $FS > 1.13$  with static earth pressure loads and seismic loads

Shear, or sliding, resistance is calculated based on the interface shear test (see interaction test reports for complete test data)

$$R_s = [S_i + (W + P_v + Q_{lv}) * \tan (35.2^\circ)]$$

where  $S_i = 362 \text{ lb/ft}$  or  $5.28 \text{ kN/m}$

$$FS = R_s / F_H$$

check that  $FS > 1.5$  with static earth pressure loads and surcharge loads

check that  $FS > 1.13$  with static earth pressure loads and seismic loads

At a minimum, internal stability should be evaluated at each change in block width (including any tail extension), at the base of any dual-face units, and for the top course(s) if a surcharge or lateral load is applied.

Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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**EXAMPLE GRAVITY WALL CALCULATIONS**  
**ALLOWABLE STRESS METHOD USING IBC SAFETY FACTORS**

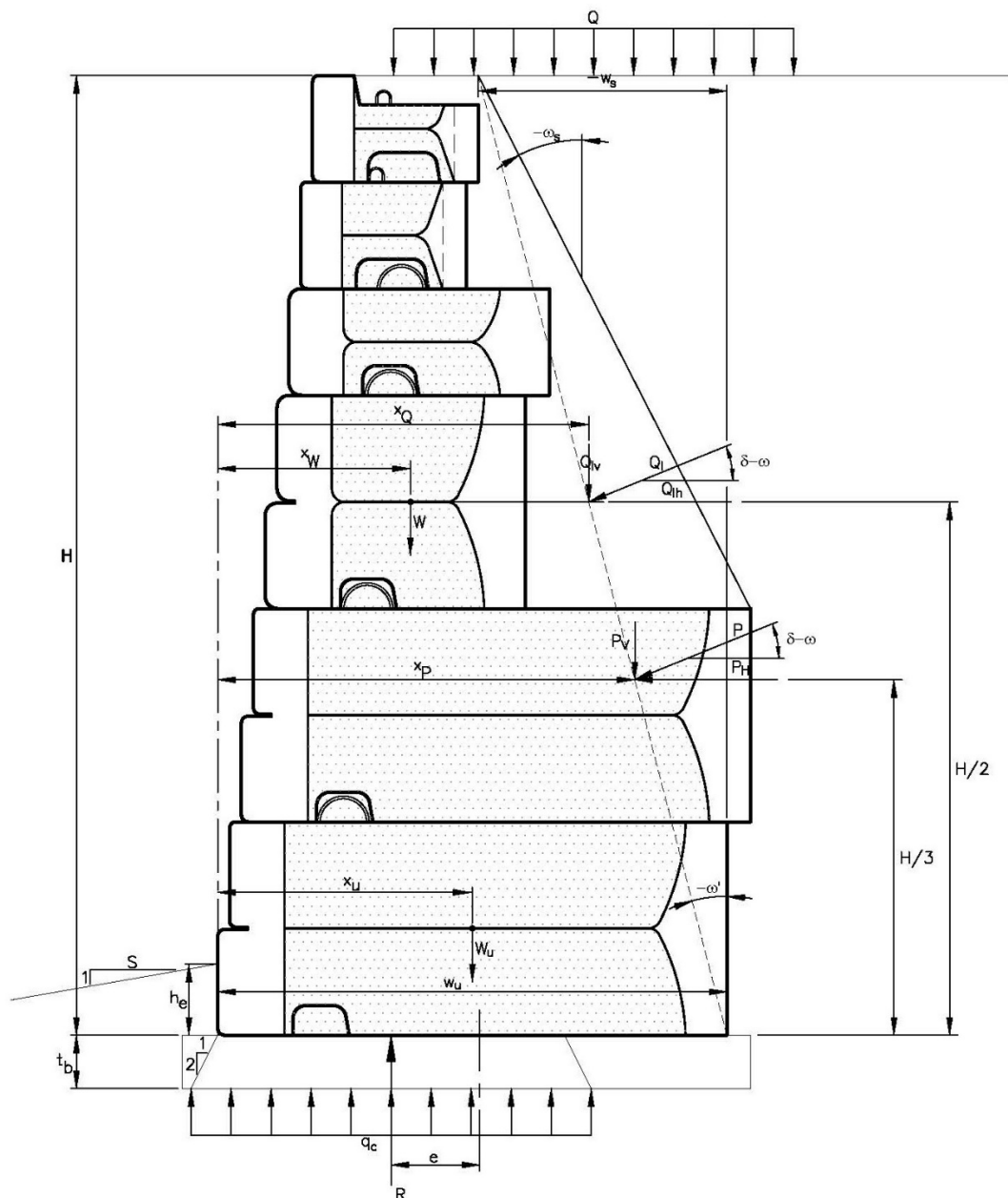
**Example 1: 13.5 feet tall wall, level back slope, 150 psf parking surcharge**

Retained Soil: sand with  $\gamma = 120$  pcf and  $\phi = 30$  degrees

Foundation Soil: clay with  $\gamma = 125$  pcf,  $\phi = 26$  degrees, and  $c' = 150$  psf

Infill Aggregate: screened crushed aggregate with  $\gamma = 110$  pcf and  $\phi = 35$  degrees

Base Aggregate: well graded crushed aggregate with  $\gamma = 125$  pcf and  $\phi = 40$  degrees



Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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Wall Configuration (all weights per foot along length of wall)

### External Stability Analysis

Modular Units			Setback (in)		Concrete (/ft.)		Unit Fill (/ft.)		Soil Wedge (/ft.)	
unit	w (in)	h (ft)	face	tail	W <sub>b</sub> (lb)	x <sub>b</sub> (in)	W <sub>a</sub> (lb)	x <sub>a</sub> (in)	W <sub>s</sub> (lb)	x <sub>s</sub> (in)
6-28	28.0	1.50	16.0	-42.0	238	28.8	183	30.0	63	47.1
6-28	28.0	1.50	14.0	-44.0	238	26.8	183	28.0	217	50.1
6-44	44.0	1.50	12.0	-30.0	375	33.0	301	35.5	151	61.8
24-44	44.0	3.00	8.0	-34.0	750	29.2	594	32.8	792	66.9
24-86	86.0	3.00	4.0	4.0	950	44.0	1,621	49.1	0	0.0
24-86	86.0	3.00	0.0	0.0	950	40.0	1,621	45.1	0	0.0

### Weight and Center of Gravity of Wall Components

$$W_b = 950+950+750+375+238+238 = 3,500 \text{ lb/ft}$$

$$W_a = 1,621+1,621+594+301+183+183 = 4,503 \text{ lb/ft}$$

$$W_s = 792+151+217+63 = 1,224 \text{ lb/ft}$$

$$\text{Total Wall Weight} = 3,500+4,503+1,224 = 9,227 \text{ lb/ft}$$

$$x_b = (950*40.0+950*44.0+750*29.2+375*33.0+238*26.8+238*28.8) / 3,500 = 36.4 \text{ in}$$

$$x_a = (1,621*45.1+1,621*49.1+594*32.8+301*35.5+183*28.0+183*30.0) / 4,503 = 43.0 \text{ in}$$

$$x_s = (792*66.9+151*61.8+217*50.1+62*47.1) / 1,224 = 62.3 \text{ in}$$

### Earth Pressure Components

$$\omega' = \arctan(-42/12/13.5) = -14.53^\circ$$

$$\delta = 0.75*30 = 22.5^\circ$$

$$K_a = \frac{\cos^2(30-14.53)}{\cos^2(-14.53) \cos(-14.53-22.5) \left[ 1 + \sqrt{\frac{\sin(30+22.5) \sin(30-0)}{\cos(-14.53-22.5) \cos(-14.53+0)}} \right]^2}$$

$$K_a = 0.421$$

$$P_h = 0.5*0.421*120*(12.0)^2*\cos(22.5 + 14.53) = 3,679 \text{ lb}$$

$$P_v = 0.5*0.421*120*(12.0)^2*\sin(22.5 + 14.53) = 2,776 \text{ lb}$$

$$Q_{lh} = 0.421*150*12.0*\cos(22.5 + 14.53) = 681 \text{ lb}$$

$$Q_{lv} = 0.421*150*12.0*\sin(22.5 + 14.53) = 514 \text{ lb}$$

$$x_P = (13.5/3)*\tan(-14.53)+86/12 = 6.00 \text{ ft}$$

$$y_P = 13.5/3 = 4.50 \text{ ft}$$

$$x_{Ql} = (13.5/2)*\tan(-14.53)+86/12 = 5.42 \text{ ft}$$

$$y_{Ql} = 13.5/2 = 6.75 \text{ ft}$$

Project	ASD Example Calculations	Project #	20004.00	Date	12/5/23
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### Base Friction

Use the smaller sliding resistance, R, of the following:

Determine composite friction coefficient across base:

$$\%_{\text{void}} = (1,621/110) / (950/145 + 1,621/110) = 0.6922$$

$$\%_{\text{concrete}} = (950/145) / (950/145 + 1,621/110) = 0.3078$$

$$\mu_b = 0.6922 \cdot \tan(35) + 0.3078 \cdot 0.8 \cdot \tan(40) = 0.691$$

$$R_{\text{footing}} = 0.691 \cdot (9,227 + 2,776 + 514) = 8,653 \text{ lb/ft}$$

$$R_{\text{soil}} = (9,227 + 2,776 + 514 + (86/12 \cdot 9/12) \cdot 125) \cdot \tan(26) + ((86+9)/12) \cdot 150 \\ = 7,620 \text{ lb/ft}$$

### **Factors of Safety**

#### Overturning

$$FS = [3,500 \cdot (36.4/12) + 0.8 \cdot 4,503 \cdot (43.0/12) + 0.8 \cdot 1,224 \cdot (62.3/12) + 2,776 \cdot 6.00 + 514 \cdot 5.42] / \\ (3,679 \cdot (4.50) + 681 \cdot 6.75) = 2.27 > 1.5 \quad \text{OK!!}$$

#### Sliding

$$FS = 7,620 / (3,679 + 681) = 1.75 > 1.5 \quad \text{OK!!}$$

#### Bearing

$$e = (86/12) / 2 - [(3,500 \cdot (36.4/12) + 4,503 \cdot (43.0/12) + 1,224 \cdot (62.3/12) + 2,776 \cdot 6.00 + 514 \cdot 5.42) - \\ (3,679 \cdot 4.50 + 681 \cdot 6.75)] / (3,500 + 4,503 + 1,224 + 2,776 + 514) = 1.08 \text{ ft}$$

$$B_f' = (86+9)/12 - 2 \cdot 1.08 = 5.76 \text{ ft.}$$

$$q_c = (9,227 + 2,776 + 514) / 5.76 + 9/12 \cdot 125 = 2,266 \text{ psf}$$

Bearing Factors (Vesic):

$$N_c = 22.25$$

$$N_q = 11.85$$

$$N_\gamma = 12.54$$

$$d_c = 1.10$$

$$d_q = 1.08$$

$$d_\gamma = 1.00$$

$$g_c = 1.00$$

$$g_q = 1.00$$

$$g_\gamma = 1.00$$

$$q_{\text{ult}} = 150 \cdot 22.25 \cdot 1.10 \cdot 1.00 + ((9+9)/12) \cdot 125 \cdot 11.85 \cdot 1.08 \cdot 1.00 + 0.5 \cdot 125 \cdot 5.76 \cdot 12.54 \cdot 1.00 \cdot 1.00 \\ = 10,602 \text{ psf}$$

$$FS = 10,602 / 2,266 = 4.68 > 2.0 \quad \text{OK!!}$$

Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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### Internal Stability Analysis

Internal stability should be checked at each change in block width, at all dual-face unit, and at the top unit at a minimum. The following is taken at the first change from 24-86 to 24-44. Internal stability of the block stack above this interface is calculated as follows:

Wall Configuration (all weights per foot along length of wall)

Modular Units			Setback (in)		Concrete (/ft.)		Unit Fill (/ft.)		Soil Wedge (/ft.)	
unit	w (in)	h (ft)	face	tail	W <sub>b</sub> (lb)	x <sub>b</sub> (in)	W <sub>a</sub> (lb)	x <sub>a</sub> (in)	W <sub>s</sub> (lb)	x <sub>s</sub> (in)
6-28	28.0	1.50	8.0	-8.0	238	19.8	183	21.0	41	37.0
6-28	28.0	1.50	6.0	-10.0	238	17.8	183	19.0	151	38.6
6-44	44.0	1.50	4.0	4.0	375	24.0	301	26.5	0	0.0
24-44	44.0	3.00	0.0	0.0	750	20.2	594	23.8	0	0.0

### Weight and Center of Gravity of Wall Components

$$W_b = 750 + 375 + 238 + 238 = 1,600 \text{ lb/ft}$$

$$W_a = 594 + 301 + 183 + 183 = 1,261 \text{ lb/ft}$$

$$W_s = 151 + 41 = 193 \text{ lb/ft}$$

$$\text{Total Wall Weight} = 1,600 + 1,261 + 193 = 3,054 \text{ lb/ft}$$

$$x_b = (750 \cdot 20.2 + 375 \cdot 24.0 + 238 \cdot 17.8 + 238 \cdot 19.8) / 1,600 = 20.7 \text{ in}$$

$$x_a = (594 \cdot 23.8 + 301 \cdot 26.5 + 183 \cdot 19.0 + 183 \cdot 21.0) / 1,261 = 23.3 \text{ in}$$

$$x_s = (151 \cdot 38.6 + 41 \cdot 37.0) / 193 = 38.3 \text{ in}$$

### Earth Pressure Components

$$\omega' = \arctan(-8/12/7.5) = -5.08^\circ$$

$$\delta = 0.75 \cdot 30 = 22.5^\circ$$

$$K_a = \frac{\cos^2(30 + -5.08)}{\cos^2(-5.08) \cos(-5.08 - 22.5) \left[ 1 + \sqrt{\frac{\sin(30 + 22.5) \sin(30 - 0)}{\cos(-5.08 - 22.5) \cos(-5.08 + 0)}} \right]^2}$$

$$K_a = 0.335$$

$$P_h = 0.5 \cdot 0.335 \cdot 120 \cdot (7.5)^2 \cdot \cos(22.5 + 5.08) = 1,003 \text{ lb}$$

$$P_v = 0.5 \cdot 0.335 \cdot 120 \cdot (7.5)^2 \cdot \sin(22.5 + 5.08) = 524 \text{ lb}$$

$$Q_{lh} = 0.335 \cdot 150 \cdot 7.5 \cdot \cos(22.5 + 5.08) = 334 \text{ lb}$$

$$Q_{lv} = 0.335 \cdot 150 \cdot 7.5 \cdot \sin(22.5 + 5.08) = 175 \text{ lb}$$

$$x_P = (7.5/3) \cdot \tan(-5.08) + 43/12 = 3.36 \text{ ft}$$

$$y_P = 7.5/3 = 2.5 \text{ ft}$$

$$x_{Ql} = (7.5/2) \cdot \tan(-5.08) + 43/12 = 2.61 \text{ ft}$$

$$y_{Ql} = 7.5/2 = 3.75 \text{ ft}$$

Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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#### Interface Shear

$$R_s = 362 + (3,054 + 524 + 175) \cdot \tan(35.2) = 3,009$$

#### **Factors of Safety**

##### Overtopping/Toppling

$$FS = [1,600 \cdot (20.7/12) + 0.8 \cdot 1,261 \cdot (23.3/12) + 0.8 \cdot 193 \cdot (38.3/12) + 524 \cdot 3.36 + 175 \cdot 2.61] / (1,003 \cdot 2.50 + 334 \cdot 3.75) = 2.00 > 1.5 \quad \textbf{OK!!}$$

##### Sliding/Internal Shear

$$FS = 3,009 / (1,003 + 334) = 2.25 > 1.5 \quad \textbf{OK!!}$$

All other interfaces **OK!!**

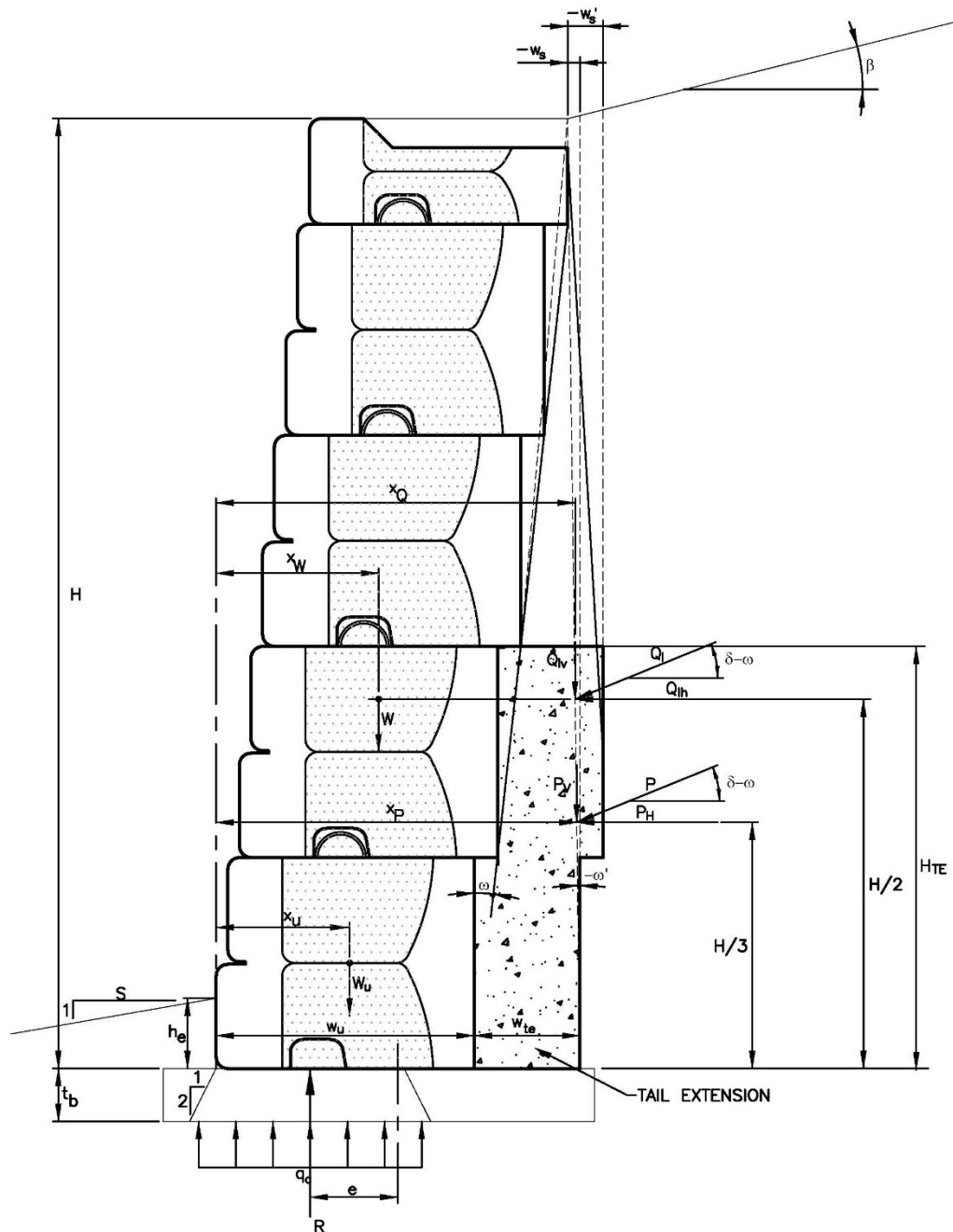
Project ASD Example Calculations

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Date 12/5/23

**Example 2: 13.5 feet tall wall, 3H:1V back slope, CIP tail extension**

Retained Soil: sand with  $\gamma = 120$  pcf and  $\phi = 30$  degrees  
 Foundation Soil: clay with  $\gamma = 125$  pcf,  $\phi = 26$  degrees, and  $c' = 150$  psf  
 Infill Aggregate: screened crushed aggregate with  $\gamma = 110$  pcf and  $\phi = 35$  degrees  
 Base Aggregate: well graded crushed aggregate with  $\gamma = 125$  pcf and  $\phi = 40$  degrees  
 Tail Extension: 30 inches wide by 72 inches tall, placed on aggregate base



Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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Wall Configuration including CIP tail extension (all weights per foot along length of wall)

Modular Units			Setback (in)		Concrete (/ft.)		Unit Fill (/ft.)		Soil Wedge (/ft.)	
unit	w (in)	h (ft)	face	tail	W <sub>b</sub> (lb)	x <sub>b</sub> (in)	W <sub>a</sub> (lb)	x <sub>a</sub> (in)	W <sub>s</sub> (lb)	x <sub>s</sub> (in)
6-44	44.0	1.50	16.0	-14.0	375	37.0	301	39.5	25	61.2
24-44	44.0	3.00	12.0	-18.0	750	33.2	594	36.8	308	61.8
24-44	44.0	3.00	8.0	-22.0	750	29.2	594	32.8	616	63.3
24-44	74.0	3.00	4.0	4.0	1,838	47.6	594	28.8	0	0.0
24-44	74.0	3.00	0.0	0.0	1,838	43.6	594	24.8	0	0.0

### External Stability Analysis

#### Weight and Center of Gravity of Wall Components

$$W_b + W_{te} = 750 + 2.5 \times 3.0 \times 145 + 750 + 2.5 \times 3.0 \times 145 + 750 + 750 + 375 = 5,550 \text{ lb/ft}$$

$$W_a = 594 + 594 + 594 + 594 + 301 = 2,678 \text{ lb/ft}$$

$$W_s = 616 + 308 + 25 = 949 \text{ lb/ft}$$

$$\text{Total Wall Weight} = 5,500 + 2,678 + 949 = 9,176 \text{ lb/ft}$$

$$x_{b+te} = (1,838 \times 43.6 + 1,838 \times 47.6 + 750 \times 29.2 + 750 \times 33.2 + 375 \times 37.0) / 5,550 = 41.1 \text{ in}$$

$$x_a = (594 \times 24.8 + 594 \times 28.8 + 594 \times 32.8 + 594 \times 36.8 + 301 \times 39.5) / 2,678 = 31.8 \text{ in}$$

$$x_s = (616 \times 63.3 + 308 \times 61.8 + 25 \times 61.2) / 949 = 62.8 \text{ in}$$

#### Earth Pressure Components

$$\omega' = \arctan(-14/12/13.5) = -4.94^\circ$$

$$\delta = 0.75 \times 30 = 22.5^\circ$$

$$K_a = \frac{\cos^2(30 + 4.94)}{\cos^2(-4.94) \cos(-4.94 - 22.5) \left[ 1 + \sqrt{\frac{\sin(30 + 22.5) \sin(30 - 18.4)}{\cos(-4.94 - 22.5) \cos(-4.94 + 18.4)}} \right]^2}$$

$$K_a = 0.456$$

$$P_h = 0.5 \times (.456) \times 120 \times (13.5)^2 \times \cos(22.5 + 4.94) = 4,425 \text{ lb}$$

$$P_v = 0.5 \times (.456) \times 120 \times (13.5)^2 \times \sin(22.5 + 4.94) = 2,298 \text{ lb}$$

$$x_P = (13.5/3) \times \tan(-4.94) + (74/12) = 5.78 \text{ ft}$$

$$y_P = (13.5/3) = 4.5$$

Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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### Base Friction

Use the smaller sliding resistance, R, of the following:

Determine composite friction coefficient across base:

$$\%_{\text{void}} = (1,621/110) / (750/145 + 2.0 \cdot 3.0 + 1,621/110) = 0.5688$$

$$\%_{\text{prescast}} = (750/145) / (750/145 + 2.0 \cdot 3.0 + 1,621/110) = 0.1996$$

$$\%_{\text{CIP}} = (2.0 \cdot 3.0) / (750/145 + 2.0 \cdot 3.0 + 1,621/110) = 0.2316$$

$$\mu_b = 0.5688 \cdot \tan(35) + 0.1996 \cdot 0.8 \cdot \tan(40) + 0.2316 \cdot \tan(40) = 0.606$$

$$R_{\text{footing}} = 0.606 \cdot (9,176 + 2,298) = 6,953 \text{ lb/ft}$$

$$R_{\text{soil}} = (9,176 + 2,289 + (74/12 \cdot 9/12) \cdot 125) \cdot \tan(26) + ((74+9)/12) \cdot 150 = 6,916 \text{ lb/ft}$$

### Factors of Safety

#### Overturning

$$\begin{aligned} FS &= [(5,550 \cdot (41.1/12) + 0.8 \cdot 2,678 \cdot (31.8/12) + 0.8 \cdot 949 \cdot (62.8/12) + 2,298 \cdot 5.78) / (4,425 \cdot 4.5)] \\ &= 2.11 > 1.5 \quad \text{OK!!} \end{aligned}$$

#### Sliding

$$FS = 6,916 / 4,425 = 1.56 > 1.5 \quad \text{OK!!}$$

#### Bearing

$$e = (74/12) / 2 - [5,550 \cdot (41.1/12) + 2,678 \cdot (31.8/12) + 949 \cdot (62.8/12) + 2,298 \cdot 5.78] / (4,425 \cdot 4.5) = 0.95$$

$$B_f' = (74+9)/12 - 2 \cdot 0.95 = 5.01 \text{ ft.}$$

$$q_c = ((5,550 + 2,678 + 949 + 2,298) / 5.01) + (9/12) \cdot 125 = 2,385 \text{ psf}$$

Bearing Factors (Vesic):

$$N_c = 22.25$$

$$N_q = 11.85$$

$$N_\gamma = 12.54$$

$$d_c = 1.12$$

$$d_q = 1.09$$

$$d_\gamma = 1.00$$

$$g_c = 1.00$$

$$g_q = 1.00$$

$$g_\gamma = 1.00$$

$$\begin{aligned} q_{\text{ult}} &= 150 \cdot 22.25 \cdot 1.12 \cdot 1.00 + ((9+9)/12) \cdot 125 \cdot 11.85 \cdot 1.09 \cdot 1.00 + 0.5 \cdot 125 \cdot 5.01 \cdot 12.54 \cdot 1.12 \cdot 1.00 \\ &= 10,090 \text{ psf} \end{aligned}$$

$$FS = 9,485 / 2,385 = 4.23 > 2.0 \quad \text{OK!!}$$

Project ASD Example Calculations	Project # 20004.00	Date 12/5/23
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### Internal Stability Analysis

Internal stability should be checked at each change in block width, at all dual-face unit, and at the top unit at a minimum. The following is taken at the change from 24-44 unit with tail extension to a standard 24-44 unit. Internal stability of the block stack above this interface is calculated as follows:

Wall Configuration (all weights per foot along length of wall)

Modular Units			Setback (in)		Concrete (/ft.)		Unit Fill (/ft.)	
unit	w (in)	h (ft)	face	tail	W <sub>b</sub> (lb)	x <sub>b</sub> (in)	W <sub>a</sub> (lb)	x <sub>a</sub> (in)
6-44	44.0	1.50	8.0	8.0	375	28.0	301	30.5
24-44	44.0	3.00	4.0	4.0	750	24.2	594	27.8
24-44	44.0	3.00	0.0	0.0	750	20.2	594	23.8

### Weight and Center of Gravity of Wall Components

$$W_b = 750 + 750 + 375 = 1,875 \text{ lb/ft}$$

$$W_a = 594 + 594 + 301 = 1,489 \text{ lb/ft}$$

$$\text{Total Wall Weight} = 1,875 + 1,489 = 3,364 \text{ lb/ft}$$

$$x_b = (750 \cdot 20.2 + 750 \cdot 24.2 + 375 \cdot 28.0) / 1,875 = 23.4 \text{ in}$$

$$x_a = (594 \cdot 24.8 + 594 \cdot 28.8 + 296 \cdot 35.5) / 1,489 = 26.8 \text{ in}$$

### Earth Pressure Components

$$\omega' = 6.34^\circ$$

$$\delta = 0.5 \cdot 30 = 15.0^\circ$$

$$K_a = \frac{\cos^2(30 + 6.34)}{\cos^2(6.34) \cos(6.34 - 15.0) \left[ 1 + \frac{\sin(30 + 15.0) \sin(30 - 18.4)}{\cos(6.34 - 15.0) \cos(6.34 + 18.4)} \right]^2}$$

$$K_a = 0.340$$

$$P_h = 0.5 \cdot 0.340 \cdot 120 \cdot (7.5)^2 \cdot \cos(15 - 6.34) = 1,135 \text{ lb}$$

$$P_v = 0.5 \cdot 0.340 \cdot 120 \cdot (7.5)^2 \cdot \sin(15 - 6.34) = 173 \text{ lb}$$

$$x_P = (7.5/3) \cdot \tan(6.34) + (44/12) = 3.94 \text{ ft} \quad y_P = 7.5/3 = 2.5 \text{ ft}$$

### Interface Shear

$$R_s = 362 + (3,364 + 173) \cdot \tan(35.2) = 2,857 \text{ lb}$$

### Factors of Safety

#### Overturning/Toppling

$$FS = [1,875 \cdot (23.4/12) + 0.8 \cdot 1,489 \cdot (26.7/12) + 173 \cdot 3.94] / (1,135 \cdot 2.5) = 2.46 > 1.5 \quad \text{OK!!}$$

#### Sliding/Internal Shear

$$FS = 2,857 / 1,135 = 2.52 > 1.5 \quad \text{OK!!}$$

All other interfaces **OK!!**



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## External stability

© S T O N E S T R O N G S Y S T E M S

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #1, level grade w/ surcharge  
 Calc by: D Thiele

**Seismic Load** Ss  G site class (A to E or 1)  D Fpga 1.60 Fa 1.60 k<sub>h</sub> 0.00

**Backfill Slope & Surcharge**

length 1	<input type="text"/> 30	feet (horizontal)	rise in grade	<input type="text"/>	ft	LL surcharge	<input type="text"/> 150	psf	tier height	<input type="text"/>	ft
length 2	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
length 3	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
length 4	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
effective slope		H:1V slope	β	0.0	deg	avg q	150	psf			
failure plane α	60.23	deg	zone of influence	14.89	ft						

**Analysis**

K <sub>a</sub> = 0.421	Q <sub>lh</sub> = 681 lb	ΔK <sub>AE</sub> = 0.000	e = 1.08 ft
P <sub>h</sub> = 3,679 lb	Q <sub>lv</sub> = 514 lb	P <sub>IR</sub> = 0 lb	B <sub>r</sub> ' = 5.76 ft
P <sub>v</sub> = 2,776 lb	R <sub>s</sub> = 7,620 lb	ΔP <sub>AEh</sub> = 0 lb	e <sub>eq</sub> = 0.82 ft
	q <sub>ult</sub> = 10,602 psf	ΔP <sub>AEv</sub> = 0 lb	B <sub>r</sub> ' <sub>eq</sub> = 6.28 ft

**Results**

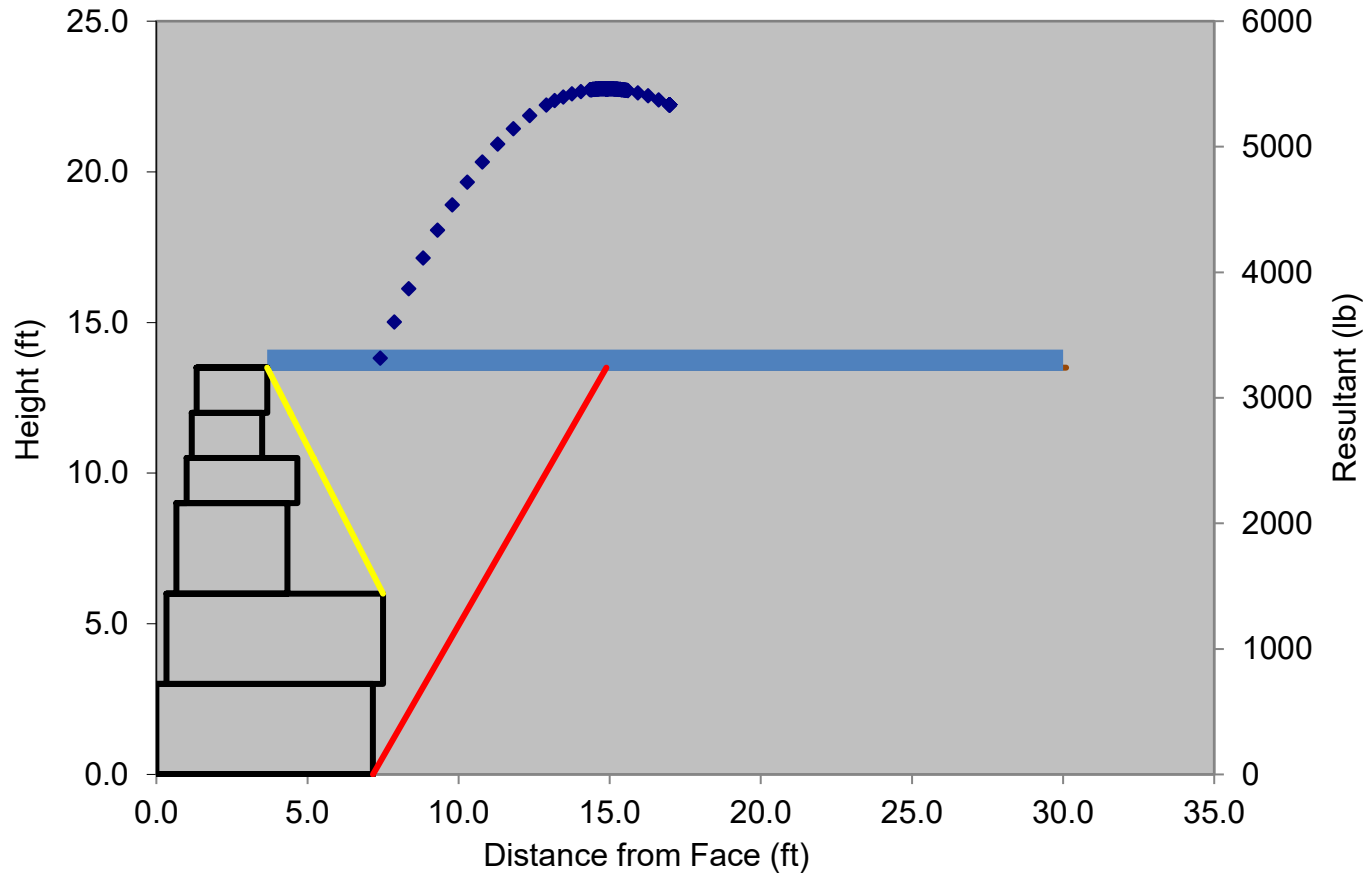
<b>Overturning:</b>	Desired FS = 1.5	<b>Actual FS = 2.27 OK!</b>
<b>Sliding:</b>	Desired FS = 1.5	<b>Actual FS = 1.75 OK!</b>
<b>Bearing Capacity:</b>	Desired FS = 2	<b>Actual FS = 4.68 OK!</b>
	q <sub>all</sub> = 5,301 psf	q <sub>c</sub> = 2,266 psf

**Internal Safety Factors**

Desired FS = 1.5  
 Desired FS = 1.5

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #1, level grade w/ surcharge  
 Calc by: D Thiele

Ground Surface & Trial Wedge Plot



Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #1, level grade w/ surcharge  
 Calc by: D Thiele

**Notes** 13.5 tall wall, 9 inches of embedment, 9 inch thick base, no tail extension, level back slope, parking lot surcharge 150 psf, battered face, 30 degree sand retained  
  
 Internal stability (top 7.5 feet)

Wall Configuration			setback (in)		modular units		unit fill		soil wedge		CIP Extension		Internal Stability FS		Seismic Internal FS	
unit	w (in)	h (ft)	face	tail	Wb (lb)	xb (in)	Wa (lb)	xa (in)	Ws (lb)	xs (in)	we (in)	h <sub>t</sub>	Topple	Shear	Topple	Shear
6-28	28.0	1.50	8.0	-8.0	238	19.8	183	21.0	41	37.0			6.60	6.47		OK!
6-28	28.0	1.50	6.0	-10.0	238	17.8	183	19.0	151	38.6			3.01	3.87		OK!
6-44	44.0	1.50	4.0	4.0	375	24.0	301	26.5	0	0.0			3.53	3.02		OK!
24-44	44.0	3.00	0.0	0.0	750	20.2	594	23.8	0	0.0						
													Internal Stability OK!			
			44.0	7.50	8.0	-8.0	1,600	20.7	1,261	23.3	193	38.3	3,054			

backfill height 7.50 feet      ω = 6.34 deg      interface friction angle  
 ω' = -5.08 deg      δ = 22.5 deg

**Retained Soil**      γ 120 pcf      **Internal ONLY**  
 φ 30 deg

**Aggregate Unit Fill**      γ 110 pcf

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #1, level grade w/ surcharge  
 Calc by: D Thiele

**Seismic Load** Ss  G site class (A to E or 1)  D Fpga 1.60 Fa 1.60 k<sub>h</sub> 0.00

**Backfill Slope & Surcharge**

length 1	<input type="text"/> 30	feet (horizontal)	rise in grade	<input type="text"/>	ft	LL surcharge	<input type="text"/> 150	psf	tier height	<input type="text"/>	ft
length 2	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
length 3	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
length 4	<input type="text"/>	feet (horizontal)		<input type="text"/>	ft		<input type="text"/>	psf		<input type="text"/>	ft
effective slope		H:1V slope	β	0.0	deg	avg q	150	psf			
failure plane α	57.31	deg	zone of influence	8.48	ft						

**Analysis**

Q <sub>lh</sub> =	334 lb	ΔK <sub>AE</sub> =	0.000	e =	0.62 ft
K <sub>a</sub> =	0.335	Q <sub>lv</sub> =	175 lb	B <sub>r</sub> ' =	3.09 ft
P <sub>h</sub> =	1,003 lb	R <sub>s</sub> =	3,009 lb	e <sub>eq</sub> =	0.37 ft
P <sub>v</sub> =	524 lb	q <sub>ult</sub> =	8,962 psf	B <sub>req</sub> ' =	3.59 ft
		ΔP <sub>AEh</sub> =	0 lb		
		ΔP <sub>AEv</sub> =	0 lb		

**Internal Safety Factors**

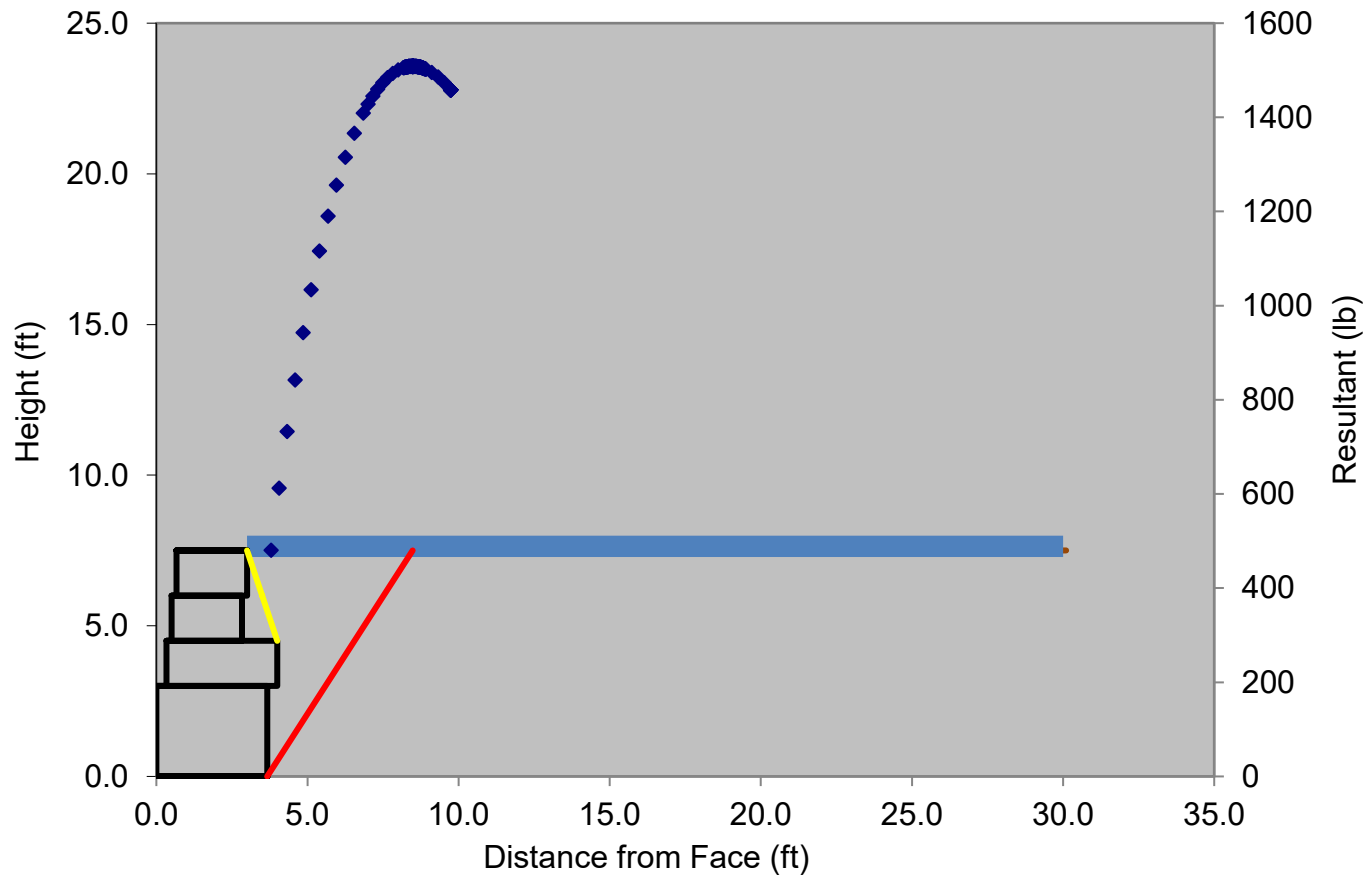
**Results**

<b>Internal Overturning:</b>	Desired FS =	1.5	<b>Actual FS =</b>	2.00	<b>OK!</b>
<b>Interface Shear:</b>	Desired FS =	1.5	<b>Actual FS =</b>	2.25	<b>OK!</b>

Desired FS =	1.5
Desired FS =	1.5

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #1, level grade w/ surcharge  
 Calc by: D Thiele

Ground Surface & Trial Wedge Plot





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[illegible]

backfill height	13.50 feet	$\omega =$	6.34 deg	interface friction angle
exposed height	12.75 feet	$\omega' =$	-4.94 deg	$\delta$ 22.5 deg

Retained Soil		Foundation Soil		Aggregate Unit Fill	
$\gamma$	120 pcf	$\gamma$	125 pcf		
$\phi$	30 deg	$\phi$	26 deg		
		c'	150 psf		
		allowable bearing pressure	n/a psf		
		(if specified)	(net)		
				composite friction coefficient	$\mu_b$ 0.61

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #2, 3H:1V backslope  
 Calc by: D Thiele

**Seismic Load** Ss  G site class (A to E or 1)  D Fpga 1.60 Fa 1.60 k<sub>h</sub> 0.00

**Backfill Slope & Surcharge**

	backslope	LL surcharge	tier height
length 1 <input type="text"/> 30 feet (horizontal)	<input type="text"/> 3 H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 2 <input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 3 <input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 4 <input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
effective slope 3.00 H:1V slope	β 18.4 deg	avg q 0 psf	
failure plane α 49.87 deg	zone of influence 22.45 ft		

**Analysis**

K <sub>a</sub> = 0.456	Q <sub>lh</sub> = 0 lb	ΔK <sub>AE</sub> = 0.000	e = 0.95 ft
P <sub>h</sub> = 4,425 lb	Q <sub>lv</sub> = 0 lb	P <sub>IR</sub> = 0 lb	B <sub>r</sub> ' = 5.01 ft
P <sub>v</sub> = 2,298 lb	R <sub>s</sub> = 6,916 lb	ΔP <sub>AEh</sub> = 0 lb	e <sub>eq</sub> = 0.95 ft
	q <sub>ult</sub> = 10,090 psf	ΔP <sub>AEv</sub> = 0 lb	B <sub>r</sub> ' <sub>eq</sub> = 5.01 ft

**Results**

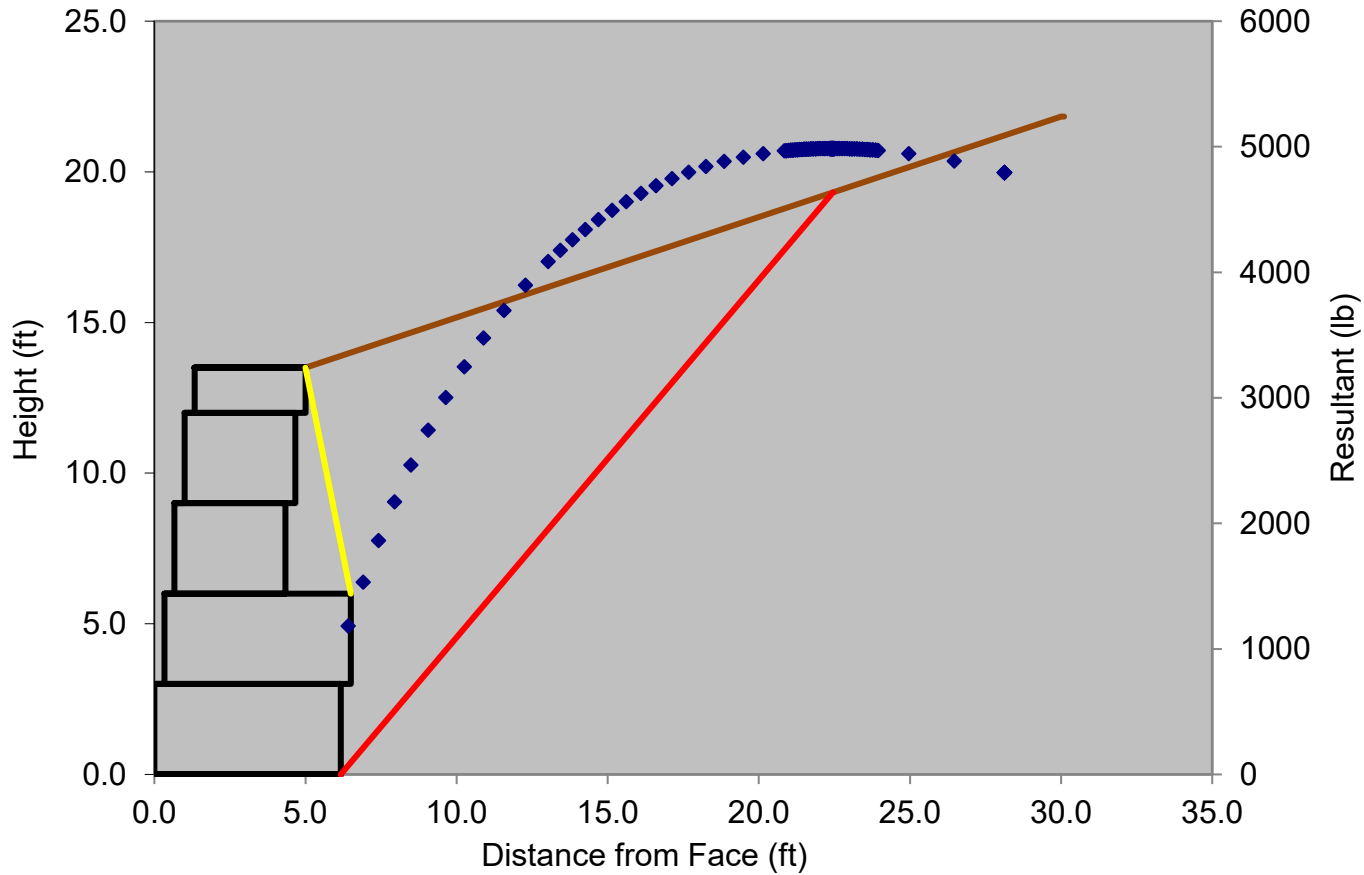
<b>Overtuning:</b>	Desired FS = 1.5	<b>Actual FS = 2.11 OK!</b>
<b>Sliding:</b>	Desired FS = 1.5	<b>Actual FS = 1.56 OK!</b>
<b>Bearing Capacity:</b>	Desired FS = 2	<b>Actual FS = 4.23 OK!</b>
	q <sub>all</sub> = 5,045 psf	q <sub>c</sub> = 2,385 psf

**Internal Safety Factors**

Desired FS = 1.5  
 Desired FS = 1.5

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #2, 3H:1V backslope  
 Calc by: D Thiele

Ground Surface & Trial Wedge Plot



Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #2, 3H:1V backslope  
 Calc by: D Thiele

**Notes** 13.5 tall wall, 9 inches of embedment, 9 inch thick base  
 3H:1V backslope, battered face, CIP tail extension on lower 6 feet  
 Internal stability (top 7.5 feet)

Wall Configuration			setback (in)		modular units		unit fill		soil wedge		CIP Extension		Internal Stability FS		Seismic Internal FS	
unit	w (in)	h (ft)	face	tail	Wb (lb)	xb (in)	Wa (lb)	xa (in)	Ws (lb)	xs (in)	we (in)	h <sub>t</sub>	Topple	Shear	Topple	Shear
6-44	44.0	1.50	8.0	8.0	375	28.0	301	30.5					43.21	16.27		OK!
24-44	44.0	3.00	4.0	4.0	750	24.2	594	27.8					6.07	4.48		OK!
24-44	44.0	3.00	0.0	0.0	750	20.2	594	23.8								
													Internal Stability OK!			
	44.0	7.50	8.0	8.0	1,875	23.4	1,489	26.8	0	0.0	3,364					

backfill height 7.50 feet      ω= 6.34 deg      interface friction angle  
 ω'= 6.34 deg      δ 15.0 deg

**Retained Soil**      γ 120 pcf      **Internal ONLY**  
 φ 30 deg

**Aggregate Unit Fill**      γ 110 pcf

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #2, 3H:1V backslope  
 Calc by: D Thiele

**Seismic Load** Ss  G site class (A to E or 1)  D Fpga 1.60 Fa 1.60 k<sub>h</sub> 0.00

**Backfill Slope & Surcharge**

	length	backslope	LL surcharge	tier height
length 1	<input type="text"/> 30 feet (horizontal)	<input type="text"/> 3 H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 2	<input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 3	<input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
length 4	<input type="text"/> feet (horizontal)	<input type="text"/> H:1V slope	<input type="text"/> psf	<input type="text"/> ft
effective slope	3.00 H:1V slope	β 18.4 deg	avg q	0 psf
failure plane α	48.61 deg	zone of influence	12.68 ft	

**Analysis**

K <sub>a</sub> = 0.340	Q <sub>lh</sub> = 0 lb	ΔK <sub>AE</sub> = 0.000	e = 0.43 ft
P <sub>h</sub> = 1,135 lb	Q <sub>lv</sub> = 0 lb	P <sub>IR</sub> = 0 lb	B <sub>r</sub> ' = 3.46 ft
P <sub>v</sub> = 173 lb	R <sub>s</sub> = 2,857 lb	ΔP <sub>AEh</sub> = 0 lb	e <sub>eq</sub> = 0.43 ft
	q <sub>ult</sub> = 9,150 psf	ΔP <sub>AEv</sub> = 0 lb	B <sub>r eq</sub> ' = 3.46 ft

**Internal Safety Factors**

**Results**

<b>Internal Overturning:</b>	Desired FS = 1.5	<b>Actual FS = 2.46 OK!</b>
<b>Interface Shear:</b>	Desired FS = 1.5	<b>Actual FS = 2.52 OK!</b>

Desired FS = 1.5  
 Desired FS = 1.5

Project Name: ASD Methodology  
 Location: Example Calculations  
 Job#: 20004.00  
 Section: Example #2, 3H:1V backslope  
 Calc by: D Thiele

Ground Surface & Trial Wedge Plot

