Project	Project #	Date
Gravity Wall Design Methodology	08110.00	5/12/09

GRAVITY WALL DESIGN METHODOLOGY
STONE STRONG PRECAST MODULAR BLOCK

Evaluate according to industry practice following AASHTO and NCMA analytical techniques – refer to:

AASHTO Standard Specifications for Highway Bridges 2002, 17th Addition

NCMA Design Manual for Segmental Retaining Wall, Second Edition

Additional analytical methods and theories are taken from other AASHTO versions and other FHWA guidelines – refer to:

Mechanically Stabilized Earth Walls and Reinforced Slopes design and Construction Guidelines, NHI-00-043

Properties of Soil/Aggregate

soil and material properties should be determined for the specific materials to be used.

unit fill - γ_a = 110 pcf max, (see AASHTO 2002 5.9.2) & ϕ_u

leveling base – aggregate base typical γ_b & ϕ_b (or concrete base may be substituted)

retained soil - γ & ϕ by site conditions

foundation soil - γ ϕ & c by site conditions

interface angle - $\delta = ½ \phi$ (see AASHTO 2002 5.9.2)

Geometric Properties

Effective weight of unit

block weight	24 SF unit – 750 lb/ft of wall	
	6 SF unit – 450 lb/ft of wall	
weight of aggregate	24 SF unit – 596 lb/ft of wall	
	6 SF unit – 296 lb/ft of wall	

Only 80% of the weight of aggregate and soil is included in the overturning calculations, W' (see AASHTO 2002 5.9.2).

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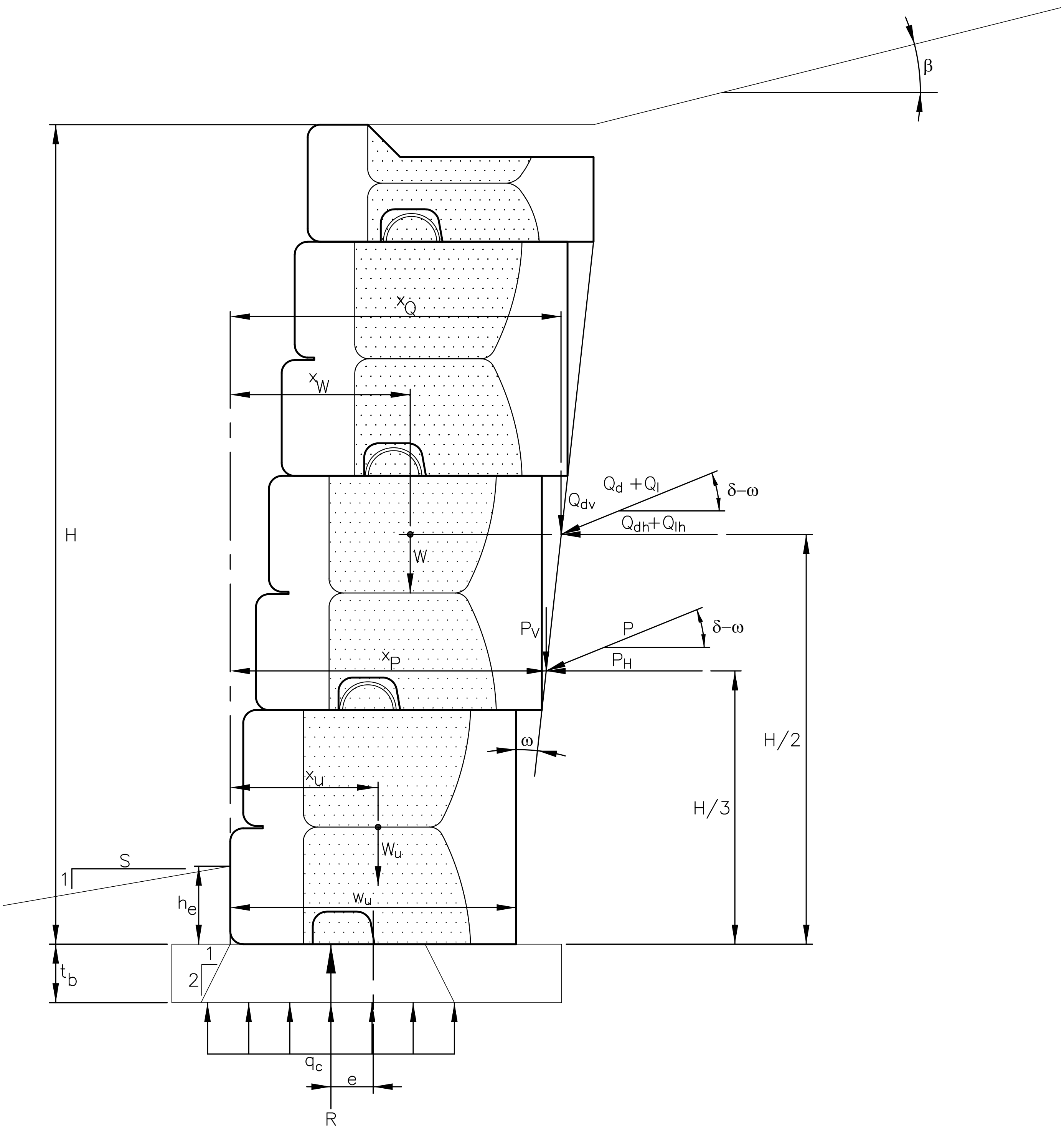
Typical gravity wall configuration:



Unit Width/Center of Mass

The nominal unit width is 44 inches for both 24 SF and 6 SF blocks. The combined center of mass of the concrete block and the unit fill is at 22.7 inches from the face. These values may be reduced by up to 2 inches to account for the rounding of the face.

$w_u = 3.50$ ft

$x_u = 1.73$ ft

Wall batter

The wall system is based around the 24 SF block that is 36 inches of height. The next block atop a 24 SF block will batter back 4 inches. The 6 SF block is 18 inches tall, and the next block atop a 6 SF block will batter 2 inches.

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

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

$\omega = \tan^{-1}(4/36) = 6.34°$

$\omega' = \tan^{-1}(4/36) = 6.34°$ (batter along back face matches the batter along the front)

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 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:

$h_e = H'/(20*S/6)$

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

A minimum embedment of 6 to 9 inches is recommended for private projects. A minimum embedment of 20 inches or more may be required for highway applications.

Tail Extension Adjustments

The gravity wall capability can be increased by using a precast Mass Extender block (limited to approximately 12 additional inches, for a total block width of 56 inches) or a cast-in-place tail extension (width is not limited – recommend height be at least 2 times the width to provide shear through the tail openings).

If tail extensions are used, the following adjustments are made:

Wall batter

Wall batter is recalculated along the back of the wall from the rear of the tail extension to the rear of the top of the wall. Use ω' in Coulomb equation and earth pressure component calculations. To calculate ω' 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 mass extender at the bottom. w_s is the batter of the front face minus the length of tail extension, w_{te}. 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:

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

Interface Angle

$$\delta = \tfrac{3}{4}\phi \quad \text{(see AASHTO 2002 5.9.2)}$$

Weight of Wall

The weight of the wall includes the contributions of the mass extender and the soil wedge atop the mass extender. A typical concrete unit weight is 145 pcf. Use the soil unit weight for the soil wedge.

$$W_{te} = (w_{te} * H_{te}) * 145 \text{ pcf}$$

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

The weight of the soil triangle is calculated using the following equation:

$$W_s = (H - H_{te}) * \gamma * w_{te}/2$$

Note: The soil wedge is defined by the limit of the tail extension and not by the simplified batter of the back of the wall. The simplified batter is used in the earth pressure analysis. Since the minimum width of the tail extension is typically maintained, it may project beyond the extension at the first course.

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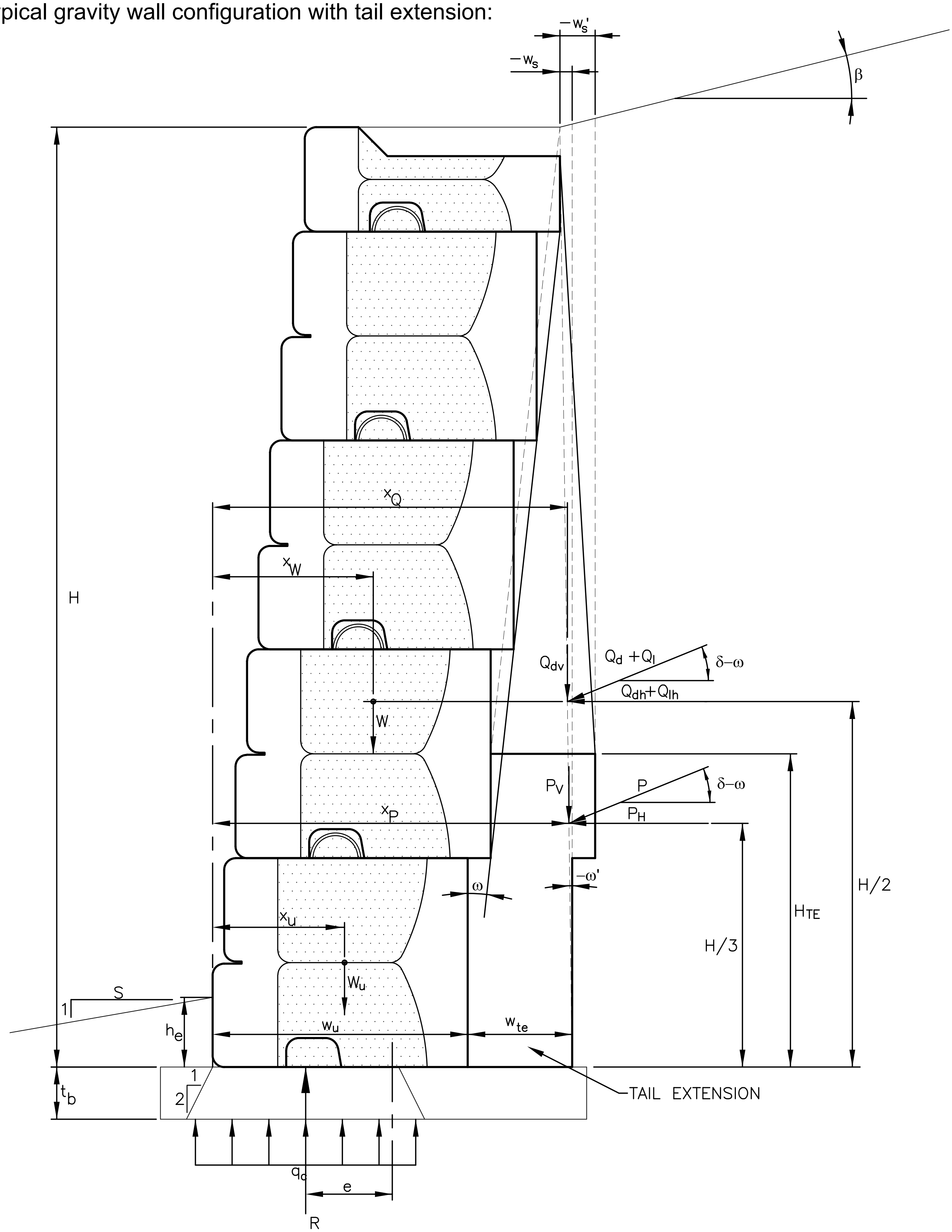
Typical gravity wall configuration with tail extension:



Calculate Forces

Coulomb active earth pressure coefficient (see AASHTO 2002 5.5.2-1)

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

Earth load components (see AASHTO 2002 5.5.2-1)

Vertical Forces:

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

$Q_{dv} = K_a Q^* H^* \sin(\delta - \omega')$ where Q is the effective surcharge in psf

Horizontal Forces:

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

$Q_{dh} = K_a Q^* H^* \cos(\delta - \omega')$ where Q is the effective surcharge in psf

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

Note: Surcharge loads may be divided into dead and live load components. The vertical component of the live load (Q_{lv}) is a stabilizing force and should be neglected as conservative.

Resisting forces

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% weight for overturning)

The center of gravity of the components of the wall can be calculated by laying out the components of the wall and taking a weighted average of their weight and distance from the hinge point of the block (see AASHTO 2002 5.9.2). Alternately, the center of mass can be calculated using the following equations:

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

$x_b = x_u + (H - h_u)/2 * \tan(\omega)$

The center of mass of the soil triangle over the tail is;

$x_s = w_u + (H_{te} - h_u) * \tan(\omega) + 2 * w_{te}/3 - w_s'/3$

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

$x_{te} = w_u + w_{te}/2$

This leads to an overall adjusted center of mass of:

$x_w = [[x_u + (H - h_u)/2 * \tan(\omega)] * (W_b + W_a) + x_{te} * W_{te} + x_s * W_s]/(W_b + W_a + W_{te} + W_s)$

Note: the height of unit, h_u, is taken as 3 ft. based on the 24 SF unit instead of 1.5 ft. based on the 6 SF unit to produce the more conservative result (units can be stacked with either unit as the bottom course).

The resultants of the earth load components are calculated as follows:

$x_{Pv}=(H/3)*\tan(\omega') + w_u + w_{te}$

$x_{Qdv}=(H/2)\ )*\tan(\omega') + w_u + w_{te}$

$x_{Ph}=H/3$

$x_{Qdh}=H/2$

$x_{Qlh}=H/2$

Table of Forces & Moments

	Force (lb)	**x (ft)**	**Moment about toe (lb*ft)**
Vertical Forces			
weight of wall	$W_b + W_a + W_{te} + W_s$	x_w	$(W_b + W_a + W_{te} + W_s) * x_w$
modified weight	$W_b + 0.8*W_a + W_{te} + 0.8*W_s$	x_w	$(W_b + 0.8*W_a + W_{te} + 0.8*W_s) * x_w$
earth pressure	P_v	x_{Pv}	P_v*x_{Pv}
DL surcharge	Q_{dv}	x_{Qdv}	$Q_{dv}*x_{Qdv}$
Horizontal Forces			
earth pressure	P_h	x_{Ph}	P_h*x_{Ph}
DL surcharge	Q_{dh}	x_{Qdh}	$Q_{dh}*x_{Qdh}$
LL surcharge	Q_{lh}	x_{Qlh}	$Q_{lh}*x_{Qlh}$

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	Σ moments from vertical forces (using 80% W_s & W_a)
M_H	Σ 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 ICBO 2006 1806.1). A minimum safety factor of 2.0 may be required for highway applications (AASHTO 2002 5.5.5).

Check that FS > 1.5

Sliding

Friction on 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:

$$R_{s(\text{foundation soil})} = (W + P_v + Q_{dv}) \tan \phi + B_w{*}c$$

$$B_w = w_t + w_{te} + t_b$$

where ϕ represents foundation soils, B_w is base width (block width plus ½H:1V distribution through base), and c represents foundation soil cohesion

For block to base material sliding, use:

$$R_{s(\text{footing})} = \mu_b\,(W + P_v + Q_{dv})$$

where μ_b represents a composite coefficient of friction for the base

The composite friction coefficient is calculated using contributory areas. The base of the standard Stone Strong 24 SF unit is 80 percent open and 20 percent concrete. On a unit width basis, the contributory area is 0.73 sf of concrete and 2.94 sf of aggregate.

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:

$$\mu_b = (2.94{*}\mu_{p\text{ - unit fill/base}} + 0.73{*}\mu_{p\text{ - block/base}} + w_{te}{*}\mu_{p\text{ - extension/base}})/(3.67 + w_{te})$$

where μ_p is the partial friction coefficient for the indicated materials (dimensions in ft)

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Partial friction coefficients can be interpreted from the following table:

	Coefficient of Friction
Block to Aggregate Base formed precast surface on compacted aggregate surface (includes Mass Extender)	$0.8 \cdot \tan \phi_b$
Unit Fill to Aggregate Base screened aggregate (loose to moderate relative density - dumped) on compacted aggregate surface	lower $\tan \phi_b$ or $\tan \phi_u$
Block to Concrete Base formed precast surface on floated concrete surface (includes Mass Extender)	0.60
Unit Fill Aggregate to Concrete Base screened aggregate (loose to moderate relative density - dumped) on floated concrete surface	$0.8 \cdot \tan \phi_u$
Concrete Tail Extension to Aggregate Base cast in place concrete on aggregate surface	$\tan \phi_b$
Concrete Tail Extension to Concrete Base cast in place concrete on floated concrete surface	0.75
Concrete Tail Extension Directly on Foundation Soil (Sand) cast in place concrete on granular soil	$\tan \phi_f$

Note: 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 material:

	Friction Angle (degrees)		
	Well Graded, Densely Compacted	Screened Aggregate, Compacted	Screened Aggregate, Loose to Moderate Relative Density
Crushed Hard Aggregate >75% w/ 2 fractured faces, hard natural rock	42	40	36
Crushed Aggregate >75% w/ 2 fractured faces, medium natural rock or recycled concrete	40	38	35
Cracked Gravel >90% w/ 1 fractured face	36	35	32

Note: 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.

The minimum value for sliding resistance is calculated as follows:

F_H	Σ horizontal forces
F_V	Σ vertical forces (using 100% W_s & W_a)
$R'_{s\ (footing)}$	$\mu_b F_V$
$R'_{s\ (foundation\ soil)}$	$[F_V \cdot \tan(\phi) + B_w \cdot c]$
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

Bearing/Eccentricity

B_f' is the equivalent bearing area. This is the base block width adjusted for eccentricity, and including a ½H:1V distribution through granular base or 1H:1V distribution through concrete base.

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

F_V	Σ vertical forces (using 100% W_s & W_a)
weight of base	$t_b \cdot \gamma_b$
M_v	Σ moments from vertical forces (using 100% W_s & W_a)
M_H	Σ 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_b	$[c \cdot N_c + (h_e + t_b) \cdot \gamma_{found} \cdot N_q + 0.5 \cdot \gamma_{found} \cdot B_f' \cdot N_\gamma]$
FS	q_b / q_c

The safety factor for bearing should be greater than 2

Check that FS > 2.0

Seismic Design

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

The maximum acceleration $A_m = (1.45 - A)*A$ 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 $\xi = \arctan[K_h/(1 - K_v)]$. 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:

$K_h = 1.66 * A_m * [A_m/(d*25.4)]^{0.25}$

with d = 2 inches, the conservatively assumed maximum horizontal displacement

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

$P_{ir} = 0.5 * K_h * \gamma * H_2 * H + 0.125 * K_h * \gamma * H_2^2 * \tan(\beta)$

where H_2 is the height of backfill at the back of the block.

The seismic thrust is calculated as follows:

$P_{ae} = 0.5 * \gamma * H_2^2 * (K_{ae} - K_a)$

$P_{aeh} = 0.5 * \gamma * H_2^2 * (K_{ae} - K_a) * \cos(\delta - \omega)$

In overturning analysis, the inertial force is applied at half the height of the wall, while the seismic thrust is applied at 60% of the wall height. By AASHTO requirements, the full inertial force is applied along with 50% of the seismic thrust (FHWA 4.2h).

The total overturning moment is increased as shown in the following equation:

$M_H + P_{ir}*H/2 + (P_{aeh}/2)*(0.6*H)$

The total horizontal sliding force is increased as shown in the following equation:

$F_H + P_{ir} + (P_{aeh}/2)$

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

Internal Analysis

Internal stability analysis is conducted for each segment of block. Since bearing conditions are addressed in the external stability analysis, only overturning and shearing failures are possible.

Overturning is evaluated identically to external stability analysis.

Sliding resistance is calculated based on the interface shear test (see interaction test reports for complete test data)

$R'_s = [362 + (W + P_v + Q_{dv})* \tan(35.2°)]$

For each load case, the sliding safety factor must be greater than 1.5:

$FS = R'_s / F_H$

check that FS > 1.5

At a minimum, internal stability should be evaluated at each change in block width (i.e. immediately above the mass extender), any change in mass extender size and at the base of any dual-face units.

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Example Gravity Calculation	08110.00	6/28/09

Note: Examples to demonstrate method of analysis only - not intended to conform w/ AASHTO safety factors

Example section – 9 ft tall unreinforced wall, 4H:1V backslope, sand backfill

Uniform soil (sand) - γ = 125 pcf ϕ = 30°   c = 0 psf

Wall is composed of three 24 SF blocks

ω' = arctan((3*4")/(9ft*12"/ft)) = 6.34°   δ = ½*30° = 15°

Granular base aggregate – ϕ = 40°

Unit fill aggregate – ϕ = 35°

Weight of Wall

W_b = (3*6,000 lb)/8 ft = 2,250 lb/ft block

W_a = (3*43.32 ft^3*110 pcf)/8 ft = 1,787 lb/ft aggregate fill

Total Wall Weight = 2,250 + 1,787 = 4,037 lb/ft

W' = 1,787 lb/ft*0.80 + 2,250 lb/ft = 3,680 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73' total

x_w = [(1.73+0.5*(9 ft-3 ft)*tan(6.34°))*(2,250 lb + 1,787 lb)]/4,037 lb = 2.06 ft

w_u = (44 in-2 in)/12 = 3.5 ft

Soil force components

$$K_a = \frac{\cos^2(30° + 6.34°)}{\cos^2(6.34°)\cos(6.34° - 15°)\left[1 + \sqrt{\dfrac{\sin(30° + 15°)\sin(30° - 14.0°)}{\cos(6.34° - 15°)\cos(6.34° + 14.0°)}}\right]^2} = 0.313$$

P_h = 0.5*(0.313)*125pcf*(9 ft)^2*cos(15° - 6.34°) = 1,564 lb/ft

P_v = 0.5*(0.313)*125pcf*(9 ft)^2*sin(15° - 6.34°) = 238 lb/ft

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Example Gravity Calculation	08110.00	6/28/09

Overturning

FS = [3,680 lb/ft*2.06 ft + 238 lb*(3.5 ft+9 ft/3*tan(6.34°))] / [1,564 lb*9 ft/3]

= 1.81 > 1.5 **OK!**

Sliding

μ_b = [(0.8*3.67 ft*tan(35°)) + (0.2*3.67 ft*0.8*tan(40°))]/(3. 67 ft) = 0.69

Use the smaller of the following:

R_s = 0.69*(4,037 lb/ft + 238 lb/ft) = 2,950 lb/ft

R_s = (4,037 lb/ft + 238 lb/ft)*tan(30°) + 0 = 2,468 lb/ft

FS = 2,468 lb/ft / 1,564 lb/ft = 1.58 > 1.5 **OK!**

Bearing

$N_q = e^{\pi * \tan(30°)} * (\tan(45°+30°/2))^2 = 18.40$

N_c = (18.40-1)/tan(30°) = 30.14

$N\gamma$ = 2*(18.40+1)*tan(30°) = 22.40

e = [1,564 lb/ft*9 ft/3-4,037 lb/ft*(2.06 ft – 3.5 ft/2)-238 lb/ft*(3.5 ft/2+9 ft/2*tan(6.34°))]

/ [4,037 lb/ft + 238 lb/ft] = 0.69 ft

B_f'= 3.5 ft+0.75 ft-2*0.69 ft = 2.88 ft

q_c = (4,037 lb + 238 lb/ft)/2.88 ft + 0.75 ft*125 pcf= 1,580 psf

q_b = 0*30.14+(9”+9”)/12*125pcf*18.40+0.5*125pcf*2.88 ft*22.40 = 7,479 psf

FS = 7,479 psf/1,580 psf = 4.73 > 2.0 **OK!**

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Project	Project #	Date
Example Gravity Calculation	08110.00	6/28/09

Internal Analysis, Upper 2 Courses

Weight of Wall

W_b = (2*6,000 lb)/8 ft = 1,500 lb/ft block

W_a = (2*43.32 ft^3*110 pcf)/8 ft = 1,191 lb/ft aggregate fill

Total Wall Weight = 1,500 lb/ft + 1,191 lb/ft = 2,691 lb/ft

W' = 1,191 lb/ft*0.80+1,500 lb/ft = 2,453 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73' total

x_w = [(1.73+0.5*(6 ft-3 ft)*tan(6.34°))*(1,500 lb/ft + 1,191 lb/ft)]/2,153 lb/ft = 1.90 ft

w_u = (44 in-2 in)/12 = 3.5 ft

Soil force components

K_a = 0.313

P_h = 0.5*(0.313)*125pcf*(6 ft)^2*cos(15° - 6.34°) = 695 lb/ft

P_v = 0.5*(0.313)*125pcf*(6 ft)^2*sin(15° - 6.34°) = 106 lb/ft

Overturning

FS = [2,453*1.90 ft +106 lb*(3.5 ft+6 ft/3*tan(6.34°))] / [695 lb*6 ft/3]

= 3.63 > 1.5 **OK!**

Interface Shear

R_s = 362 lb/ft +(1,500 lb/ft + 1,191 lb/ft + 106 lb/ft)*tan(35.2°)= 2,335 lb/ft

FS = 2,335 lb/ft /695 lb/ft = 3.36 > 1.5 **OK!**

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Project	Project #	Date
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Internal Analysis, Top Course

Weight of Wall

W_b = (6,000 lb)/8 ft = 750 lb/ft block

W_a = (43.32 ft^3*110 pcf)/8 ft = 596 lb/ft aggregate fill

Total Wall Weight = 750 lb/ft + 596 lb/ft = 1,346 lb/ft

W' = 596 lb/ft*0.80+750 lb/ft = 1,227 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73 ft total

w_u = (44 in-2 in)/12 = 3.5 ft

Soil force components

K_a = 0.313

P_h = 0.5*(0.313)*125pcf*(3 ft)^2*cos(15° - 6.34°) = 174 lb/ft

P_v = 0.5*(0.13)*125pcf*(3 ft)^2*sin(15° - 6.34°) = 23 lb/ft

Overturning

FS = [1,227 lb/ft*1.73 ft +26 lb*(3.5 ft+3 ft/3*tan(6.34°))] / [174 lb*3 ft/3]

= 12.75 > 1.5 **OK!**

Interface Shear

R_s = 362 lb/ft +(750 lb/ft + 596 lb/ft + 26 lb/ft)*tan(35.2°)= 1,330 lb/ft

FS = 1,330 lb/ft /174 lb/ft = 7.65 > 1.5 **OK!**

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Example Gravity Calculation	08110.00	6/28/09

Note: Examples to demonstrate method of analysis only - not intended to conform w/ AASHTO safety factors

<u>Example section – 10.5 ft tall wall, 150 psf surcharge, 18"x3' tail extension, clay backfill</u>

Uniform soil (sand) - γ = 120 pcf ϕ = 26° c = 150 psf

Wall is composed of three 24 SF blocks and one 6 SF block

ω'= arctangent(-8 in/10.5 ft) = -3.63° δ = 3/4*26° = 19.5°

Granular base aggregate – ϕ = 40°

Unit fill aggregate – ϕ = 35°

<u>Weight of Wall</u>

W_b = (3*6,000 lb)/8 ft + 1,600 lb/4 ft = 2,650 lb/ft block

W_a = (3*43.32 ft^3*110 pcf)/8 ft + (10.75 ft^3*110 pcf)/4 ft = 2,083 lb/ft aggregate fill

W_{te} = 18 in/12*3 ft*145 pcf = 653 lb/ft

W_{sot} = (10.5 ft-3 ft)*18 in/12/2*120 pcf = 675 lb/ft

Total Wall Weight = 2,650 + 2,083 + 653 + 675= 6,061 lb/ft

W' = (2,033 lb/ft + 675 lb/ft)* 0.80+2,700 lb/ft+653 lb/ft = 5,509 lb/ft

Forces/Geometric Properties

<u>Center of Gravity</u>

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73' total

w_u = (44 in-2 in)/12 = 3.5 ft

w_s = 2*4 in+2 in-18 in = -8 in

x_w = [(1.73+0.5*(10.5 ft-3 ft)*tan(6.34°))*(2,650 lb + 2,083 lb)+(3.5 ft +18 in/12)/2*653 lb/ft
+(3.5 ft+2/3*18 in/12+1/3*(-8 in)/12)*675 lb/ft]/6,061 lb = 2.61 ft

<u>Soil force components</u>

$$K_a = \frac{\cos^2(26° + -3.63°)}{\cos^2(-3.63°)\cos(-3.63° - 19.5°)\left[1 + \sqrt{\frac{\sin(26° + 19.5°)\sin(26° - 0°)}{\cos(-3.63° - 19.5°)\cos(-3.63° + 0°)}}\right]^2} = 0.372$$

P_h = 0.5*(0.372)*120 pcf*(10.5 ft)^2*cos(19.5° - (-3.63°)) = 2,265 lb/ft

P_v = 0.5*(0.372)*120 pcf*(10.5 ft)^2*sin(19.5° - (-3.63°)) = 967 lb/ft

Q_h = 0.372*150 psf*10.5 ft*cos(19.5° - (-3.63°)) = 539 lb/ft

Project	Project #	Date
Example Gravity Calculation	08110.00	6/28/09

Overturning

FS = [5,509*2.61 ft + 967 lb*(3.5 ft+18 in/12+10.5 ft/3*tan(-3.63°))]

/ [2,265 lb*10.5 ft/3+539 lb*10.5 ft/2] = 1.77 > 1.5 **OK!**

Sliding

μ_b = [(0.8*3.67 ft*tan(35°))+(0.2*3.67 ft*0.8*tan(40°))+0.84*18 in/12]/(3.67 ft+18 in/12) = 0.74

Use the smaller of the following:

R_s = 0.74*(6,061 lb/ft + 967 lb/ft) = 5,201 lb/ft

R_s = (6,061 lb/ft + 967 lb/ft)*tan(26°) + 150 psf*(3.5 ft+18 in/12+9 in/12) = 4,290 lb/ft

FS = 4,290 lb/ft / (2,265 lb/ft + 539 lb/ft) = 1.53 > 1.5 **OK!**

Bearing

$N_q = e^{\pi*\tan(26°)} * (\tan(45°+26°/2))^2 = 11.85$

N_c = (11.85-1)/tan(26°) = 22.25

$N\gamma$ = 2*(11.85+1)*tan(26°) = 12.54

e = [2,265 lb/ft*10.5 ft/3+539 lb/ft*10.5 ft/2-6,111 lb/ft*(2.61 ft–3.5 ft/2-18 in/24)

-967 lb/ft*(3.5 ft/2+10.5 ft/2*tan(-3.63°))] / [6,061 lb/ft + 967 lb/ft] = 1.12 ft

B_f'= 3.5 ft+18 in/12+0.75 ft-2*1.12 ft = 3.51 ft

q_c = (6,061 lb + 967 lb/ft)/3.52 ft + 0.75 ft*120 pcf = 2,099 psf

q_b = 150 psf*22.25+(9”+9”)/12*120pcf*11.85+0.5*120pcf*3.52 ft*12.54 = 8,119 psf

FS = 8,119 psf/2,099 psf = 3.86 > 2.0 **OK!**

13478 Chandler Road, Omaha, Nebraska 68138 402/556-2171 (Fax 402/556-7831)

Internal Analysis, Upper 7.5 feet

Weight of Wall

W_b = (2*6,000 lb)/8 ft + 1,600 lb/4 ft= 1,900 lb/ft block

W_a = (2*43.32 ft^3*110 pcf)/8 ft+(10.75 ft^3*110 pcf)/4 ft = 1,487 lb/ft aggregate fill

Total Wall Weight = 1,900 lb/ft + 1,487 lb/ft = 3,387 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7” from face, with 2 additional inches removed due to rounding – 1.73’ total

x_w = [(1.73+0.5*(7.5 ft-3 ft)*tan(6.34°))*(1,900 lb/ft + 1,487 lb/ft)]/3,387 lb/ft = 1.98 ft

w_u = (44 in-2 in)/12 = 3.5 ft

ω = arctangent(2 in/18 in) = 6.34° δ = 1/2*26° = 13°

Soil force components

$$K_a = \frac{\cos^2(26^\circ + 6.34^\circ)}{\cos^2(6.34^\circ)\cos(6.34^\circ - 13^\circ)\left[1+\sqrt{\dfrac{\sin(26^\circ+13^\circ)\sin(26^\circ-0^\circ)}{\cos(6.34^\circ-13^\circ)\cos(6.34^\circ+0^\circ)}}\right]^2} = 0.311$$

P_h = 0.5*(0.311)*120pcf*(7.5 ft)^2*cos(13° - 6.34°) = 1,043 lb/ft

P_v = 0.5*(0.311)*120pcf*(7.5 ft)^2*sin(13° - 6.34°) = 122 lb/ft

Q_h = 0.311*150 psf*7.5 ft*cos(13° - 6.34°) = 348 lb/ft

Overturning

FS = [(1,900 lb/ft+0.8*1,487 lb/ft)*1.98 ft +122 lb*(3.5 ft+7.5 ft/3*tan(6.34°))]

/ [1,043 lb*7.5 ft/3+348 lb/ft*7.5 ft/2] = 1.68 > 1.5 **OK!**

Interface Shear

R_s = 362 lb/ft +(1,900 lb/ft + 1,487 lb/ft + 122 lb/ft)*tan(35.2°)= 2,837 lb/ft

FS = 2,837 lb/ft /(1,043 lb/ft+348 lb/ft) = 2.04 > 1.5 **OK!**

Project	Project #	Date
Example Gravity Calculation	08110.00	6/28/09

Internal Analysis, Upper 4.5 feet

Weight of Wall

W_b = (6,000 lb)/8 ft + 1,600 lb/4 ft= 1,150 lb/ft block

W_a = (43.32 ft^3*110 pcf)/8 ft+(10.75 ft^3*110 pcf)/4 ft = 891 lb/ft aggregate fill

Total Wall Weight = 1,150 lb/ft + 891 lb/ft = 2,041 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73 ft total

x_w = [(1.73+0.5*(4.5 ft-3 ft)*tan(6.34°))*(1,150 lb/ft + 891 lb/ft)]/2,041 lb/ft = 1.81 ft

w_u = (44 in-2 in)/12 = 3.5 ft

Soil force components

K_a = 0.311

P_h = 0.5*(0.311)*120 pcf*(4.5 $ft)^2$*cos(13° - 6.34°) = 376 lb/ft

P_v = 0.5*(0.311)*120 pcf*(4.5 $ft)^2$*sin(13° - 6.34°) = 44 lb/ft

Q_h = 0.311*150 psf*4.5 ft*cos(13° - 6.34°) = 209 lb/ft

Overturning

FS = [(1,150 lb/ft+0.8*891 lb/ft)*1.81 ft +44 lb*(3.5 ft+4.5 ft/3*tan(6.34°))]

/ [376 lb*4.5 ft/3+209 lb/ft*4.5 ft/2] = 3.42 > 1.5 **OK!**

Interface Shear

R_s = 362 lb/ft +(2,041 lb/ft + 44 lb/ft)*tan(35.2°)= 1,833 lb/ft

FS = 1,833 lb/ft /(376 lb/ft+209 lb/ft) = 3.14 > 1.5 **OK!**

Project	Project #	Date
Example Gravity Calculation	08110.00	6/28/09

Internal Analysis, Upper 1.5 feet

Weight of Wall

W_b = 1,600 lb/4 ft= 400 lb/ft block

W_a = (10.75 ft^3*110 pcf)/4 ft = 296 lb/ft aggregate fill

Total Wall Weight = 400 lb/ft + 296 lb/ft = 696 lb/ft

Forces/Geometric Properties

Center of Gravity

x_{block} – 22.7" from face, with 2 additional inches removed due to rounding – 1.73 ft total

w_u = (44 in-2 in)/12 = 3.5 ft

Soil force components

K_a = 0.311

P_h = 0.5*(0.311)*120 pcf*(1.5 ft)^2*cos(13° - 6.34°) = 42 lb/ft

P_v = 0.5*(0.311)*120 pcf*(1.5 ft)^2*sin(13° - 6.34°) = 5 lb/ft

Q_h = 0.311*150 psf*1.5 ft*cos(13° - 6.34°) = 70 lb/ft

Overturning

FS = [(400 lb/ft+0.8*296 lb/ft)*1.73 ft +5 lb*(3.5 ft+1.5 ft/3*tan(6.34°))]

/ [42 lb*1.5 ft/3+70 lb/ft*1.5 ft/2] = 15.23 > 1.5 **OK!**

Interface Shear

R_s = 362 lb/ft +(696lb/ft + 5 lb/ft)*tan(35.2°)= 856 lb/ft

FS = 856 lb/ft /(42 lb/ft+70 lb/ft) = 7.64 > 1.5 **OK!**