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July 29, 2021

King County Housing Authority
c/o Lawhead Architects, P.S.
1239 120th Avenue NE, Suite D
Bellevue, Washington 98005

Attention: Frank Lawhead

Subject: Geotechnical Engineering Services
Park Royal Apartments – Retaining Wall Design
18309 96th Avenue NE
Bothell, Washington 98011
File No. 1329-015-01

This letter summarizes our geotechnical design recommendations and calculations for a gravity retaining wall to replace the existing rockery where improvements to the elevated walkway and stairs are planned at King County Housing Authority's (KCHA's) Park Royal Apartments in Bothell, Washington. The rockery is located along the southeast corner of the south building adjacent to entrance to the basement level apartment.

Our understanding of the project is based on discussions with, and information provided by Matthew Utley with Lawhead Architects as well as a site visit to observe existing conditions. We understand that new columns and associated footings will be constructed to support a new elevated walkway for the first level apartments in the area adjacent to the rockery. New foundations for the elevated walkway are planned at the basement and first floor levels. GeoEngineers was requested to review the condition of the rockery and planned foundation improvements to determine potential impacts to the rockery and to develop recommendations for the project with respect to the planned improvements.

Figure 1. View of existing rockery, looking north.

EXISTING ROCKERY

The existing rockery is approximately 8 feet high at the north end and tapers down to just a few feet high across from the entrance to the basement level apartment. Many of the existing rockery boulders (roughly 20 to 25 percent) have fractures, are low quality, and are not in a condition to be reused. If the rockery would be reconstructed, the City of Bothell will likely require a building permit and engineered design since the rockery is over 4 feet in height. In addition, a rockery would likely need to be reconstructed as a reinforced rockery with geosynthetic reinforcement to meet current design standards. In lieu of reconstructing a rockery, we understand the design team has decided to use a gravity block wall to replace the rockery.

Figure 2. Typical cracks in existing rockery boulders.

GEOLOGIC CONDITIONS

Published geologic information for the project vicinity includes a United States Geological Survey (USGS) *Geologic Map of the Bothell Quadrangle, Snohomish and King Counties, Washington* (Minard 1985). Mapped soils in the immediate project vicinity consist of Vashon Till deposits (glacial till). Glacial till is generally a non-sorted, non-stratified mixture of sand, gravel and silt that has been overridden by several thousand feet of ice. It typically has high shear strength, low consolidation and low permeability characteristics in the undisturbed state. It typically develops a “weathered” zone where seasonal groundwater perches on top of the relatively impermeable unweathered till and the perched groundwater occurs as seepage following the site topography.

We anticipate that fill associated with construction of the Park Royal Apartments exists throughout the project site overlying the glacial till. Fill likely exists behind the existing rockery and below the adjacent parking lot.

Groundwater seepage was not observed discharging from the rockery during our site visit and we anticipate that the regional groundwater level is likely well below the project site and below the glacial till deposits.

WALL DESIGN RECOMMENDATIONS AND CALCULATIONS

An overview of wall analyses methods, design recommendations, construction considerations, wall performance, and other factors for the gravity retaining wall (Ultrablock wall) is provided in the following sections. A typical section for a Ultrablock gravity wall is presented in Figure 1.

Analysis Methods

Engineering analysis to develop the typical section for the gravity block wall was completed using the commercial computer program UltraWall (Version 5.1.24.19, 2021) by Ultrablock, Inc. This program includes calculations for internal stability.

Subgrade Preparation

Prior to placing the lower row of blocks, the subgrade for the wall should be probed to locate any soft or pumping soils. Prior to probing, all unsuitable soils should be removed from below the block footprint. If soft or loose soils are observed, we recommend these soils be removed and replaced with suitable structural fill down to undisturbed medium dense to dense native soil. The structural fill zone should extend horizontally beyond the edge of the gravity blocks (front and back) by the depth of the excavation. Structural fill should meet the criteria for gravel borrow as described in Section 9-03.14(1) of the 2021 Washington State Department of Transportation (WSDOT) Standard Specifications. The structural fill should be compacted to at least 95 percent of the maximum dry density (MDD) obtained using the ASTM International (ASTM) D 1557 test method.

Soil Properties

The design parameters summarized in Table 1 were used for design of the proposed gravity block wall. The soil strength parameters reflect the assumption that the base of the wall will be within dense glacial till. Wall backfill should consist of imported gravel borrow and the backfill soils should be compacted to at least 90 percent of the MDD obtained using ASTM D 1557.

TABLE 1. GRAVITY BLOCK WALL DESIGN PARAMETERS

Soil Properties	Retained Soil (Structural Fill)	Foundation Bearing Soil
Unit Weight (pcf)	125	135
Friction Angle (deg)	34	40
Cohesion (psf)	0	0

For purposes of internal wall design, the groundwater level was assumed to be below the base of the wall and that the wall backfill consists of gravel borrow.

Earthquake Loads

Given the building egress associated with the gravity wall, we recommend that the seismic loading be designed in accordance with the 2018 International Building Code (IBC). The 2018 IBC references the 2016 version of *Minimum Design Loads for Buildings and Other Structures* (American Society of Civil Engineers [ASCE] 7-16). Based on ASCE 7-16, the site modified peak ground acceleration (PGA) expected at the site from an earthquake with a 2 percent probability of exceedance in 50 years is approximately

0.60g. We recommend the internal stability of the wall be analyzed using a horizontal seismic coefficient of 0.30g.

Performance Limit Values

The performance limit values presented in Table 2 were used as minimum safety factors for design of the gravity block wall.

TABLE 2. PERFORMANCE LIMIT VALUES

Criteria	Minimum Static Safety Factor	Minimum Seismic Safety Factor
Sliding	1.5	1.125
Overturning Stability	1.5	1.125
Bearing Capacity	2	1.5

Surcharge Loading

Surcharge loading was considered behind both the north and east gravity walls given the site constraints. Loading behind the north wall consisted of an 80 pound per square foot (psf) surcharge for foot traffic along the slab-on-grade near the transition to the elevated slab. We also evaluated the planned spread foundation for the elevated walkway that will be located behind the north end of the gravity wall and we included a 1,500 psf surcharge for the footing. Loading behind the shorter east wall consisted of a 250 psf surcharge for traffic loading in the parking area and access drive.

As mentioned above, the new elevated walkway footing load was taken into account as a surcharge load behind the north wall. The new footing should be constructed so that the bottom of the footing is a minimum of 2.5 feet below the top of the wall.

Design

GeoEngineers completed design of the gravity block wall to develop our recommended typical wall section shown in Figure 1. Calculations supporting the design of the gravity block wall are attached.

LIMITATIONS

We have prepared this letter for use by KCHA and members of the design team for use in design of the gravity block wall located outside of the basement level apartment at the southeast corner of the south building at the Park Royal Apartments in Bothell, Washington.

Our services were provided to assist in the design of the gravity block wall that will replace the existing rockery. Our recommendations are intended to improve the overall stability of the existing retaining wall and to reduce the potential for future property damage related to earth movements, drainage or erosion. Qualified engineering and construction practices can help mitigate the risks inherent in construction of retaining walls, although those risks cannot be eliminated completely. Favorable performance of structures in the near term is useful information for anticipating future performance, but it cannot predict or imply a certainty of long-term performance, especially under conditions of adverse weather or seismic activity.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this report was prepared. No warranty or other conditions, express or implied, should be understood.

Sincerely,
GeoEngineers, Inc.

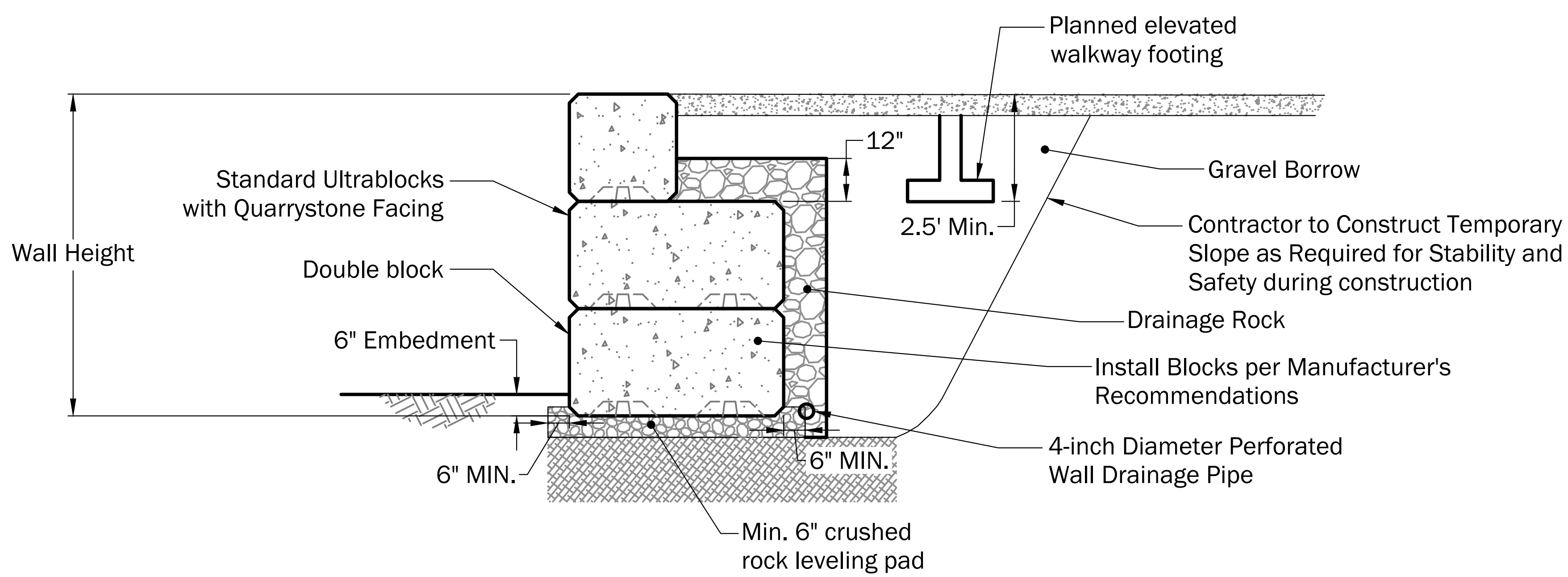
Colton W. McInelly, PE
Geotechnical Engineer

Robert C. Metcalfe, PE, LEG
Principal

CWM:RCM:tt

Attachments:
Figure 1. Gravity Block Retaining Wall Section and Notes
Gravity Block Wall Calculations

cc: Matthew Utley, Lawhead Architects, P.S. (one copy by email)



Retaining Wall Cross Section
Not to Scale

Wall Height[1] (ft, rounded)	Number of Blocks (total)	Number of 59-inch wide blocks[2]	Number of 29.5-inch wide blocks[3]	Number of Half Size Cap Blocks[4]
7.25 (North Wall)	3	2	1[5]	0
7.25 (East Wall)	3	2	1[5]	0
4.75 (East Wall)	2	1	1[5]	0
3.75 (East Wall)	2	0	1	1

1. Total wall height including embedment
2. Includes 59 inch by 29.5 inch blocks turned so that the long direction is perpendicular to the wall
3. Includes 59 inch by 29.5 inch blocks turned so that the long direction is parallel to the wall
4. Includes 59 inch by 14.75 inch blocks turned so that the long direction is parallel to the wall
5. Top full size block recommended to be a cap block when a half-size cap block is not required

Construction Notes

Materials:

A. Concrete Block Units
1. Wall units shall be 2.46'x 2.46' x 4.92' blocks produced to ULTRABLOCK specifications.

B. Drainage Rock
1. Drainage Rock shall meet WSDOT standard specification 9-03.12(4).

C. Crushed Rock Leveling Pad
1. Crushed rock used as a leveling pad at the base of the wall shall meet WSDOT Standard Specification 9-03.9(3) "Crushed Surfacing".

D. Backfill Materials
1. Backfill material shall meet WSDOT 9-03.14(1) Gravel Borrow or other material as approved by Geotechnical Engineer.

Execution:

A. Subgrade Preparation
1. Subgrade bearing surfaces shall be cleared and free of loose soil and debris. Soft areas shall be overexcavated and replaced with structural fill prior to placing blocks, as directed by Geotechnical Engineer.
2. Subgrade shall be excavated to a depth such that the base of the first course of block is embedded at least 6 inches or as directed by Geotechnical Engineer.
3. Subgrade shall be approved by Geotechnical Engineer. Soil shall be compacted before construction proceeds. Subgrade materials not meeting Geotechnical Engineer's approval shall be removed and replaced with structural fill material at direction of Geotechnical Engineer.

B. Leveling Pad
1. Leveling pad shall be placed as shown on the construction plans.
2. Leveling pad shall be placed on undisturbed native soils or on properly compacted structural fill.
3. Leveling pad shall be compacted to 95 percent of modified proctor dry density to ensure a hard, level surface on which to place the first course of blocks. Pad shall be constructed at the proper elevation and slope be level to ensure the final elevations as shown on the plans.
4. Leveling pad shall have a minimum thickness of 6 inches. Leveling pad shall extend beyond the blocks in all directions at least 6 inches.

C. Unit Installation
1. The first course of wall units shall be placed on the prepared base with the front edges tight together. The units shall be checked for level and alignment as they are placed.
2. Ensure that units are in full contact with base. Proper care shall be taken to develop straight lines and smooth curves on base course as per wall layout.
3. Fill a minimum of 12 inches behind the base course with Drainage Rock. Use approved soils to backfill behind the wall rock and in front of the base course to firmly lock in place. Check again for level and alignment. Use a plate compactor to consolidate the area behind the first course. All excess material shall be swept from top of units.

D. Backfill Placement
1. Backfill material shall be placed in lifts and compacted to a minimum 90 percent of Maximum Dry Density (MDD) as determined by ASTM D-1557, except that the top two feet shall be compacted to at least 95 percent MDD.
2. Only hand-operated compaction equipment shall be allowed within 5 feet behind the wall.

D. Wall Drainage Pipe
1. The wall drainage pipe shall consist of 4-inch diameter perforated solid wall PVC pipe.
2. The pipe shall discharge to a nearby catch basin, as directed by the Architect.

DESIGN PARAMETERS

ALLOWABLE SOIL BEARING PRESSURE = 3,000 PSF
DESIGN OF THE RETAINING STRUCTURE IS BASED ON THE FOLLOWING PARAMETERS:

	FRICTION ANGLE, PHI (degrees)	COHESION, C (psf)	MOIST UNIT WEIGHT (pcf)
RETAINED SOIL OR BACKFILL	32	0	125
FOUNDATION SOIL	40	0	130

General Notes:
- The locations of all features shown are approximate.
- This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Gravity Block Retaining Wall Section and Notes

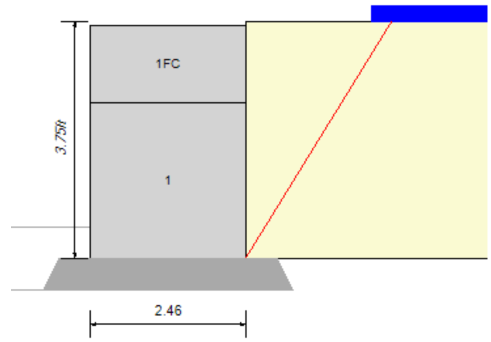
Park Royal Apartments
Bothell, Washington

GEOENGINEERS

Figure 1

UltraWall

Project:	Park Royal Apartments
Location:	Bothell, WA
Designer:	CWM
Date:	6/30/2021
Section:	Shortest Wall
Design Method:	NCMA_09_3rd_Ed, Ignore Vert. Force
Design Unit:	UltraBlock



Seismic Acc: 0.600

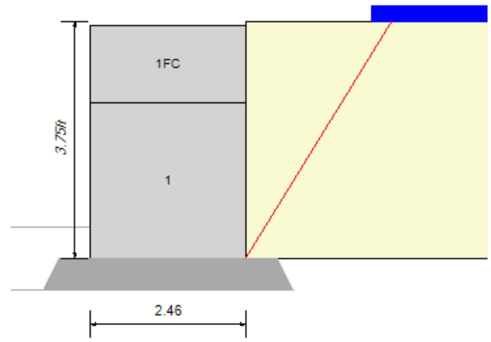
SOIL PARAMETERS	φ	coh	γ	
Retained Soil:	34 deg	0psf	125pcf	
Foundation Soil:	40 deg	0psf	135pcf	
Leveling Pad:	40 deg	0psf	135pcf	Crushed Stone

GEOMETRY

Design Height:	3.75ft	Live Load:	250psf
Wall Batter/Tilt:	0.00/ 0.00 deg	Live Load Offset:	2.00ft
Embedment:	0.50ft	Live Load Width:	20ft
Leveling Pad Depth:	0.50ft	Dead Load:	0psf
Slope Angle:	0.0 deg	Dead Load Offset:	0.0ft
Slope Length:	0.0ft	Dead Load Width:	0ft
Slope Toe Offset:	0.0ft	Leveling Pad Width:	3.46ft
Vert δ on Single Dpth			

FACTORS OF SAFETY (Static / Seismic)

Sliding:	1.50 / 1.125	Overturning:	1.50 / 1.125
Bearing:	2.00 / 1.5		



RESULTS (Static / Seismic)

FoS Sliding:	2.64 (lvlpd) / 1.24	FoS Overturning:	4.91 / 1.26
Bearing:	597.63 / 620.07	FoS Bearing:	46.80 / 34.12

Name	Elev.	ka	kae	Pa	Pae	Pir	Paq	PaT	FSsl	FoS OT	siesFSsl	FoS SeisOT
1FC	2.46	0.254	0.498	27	52	126	0	27	741.67	51.76	104.61	4.52
1	0.00	0.238	0.498	209	437	377	76	285	2.64[100.00]	4.91	1.24[100.00]	1.26

Column Descriptions:

- ka: active earth pressure coefficient
- kae: active seismic earth pressure coefficient
- Pa: active earth pressure
- Pae: dynamic earth pressure
- Pir: inertia force
- Paq: live surcharge earth pressure
- Paq2: live load 2 surcharge earth pressure
- Paqd: dead surcharge earth pressure
- (PaC): reduction in load due to cohesion
- PaT: sum of all earth pressures
- FSsl(lvl Pad): factor of safety for sliding at each layer. (FS sliding below the leveling pad)
- FSot: factor of safety of overturning about the toe.

RETAINING WALL UNITS

STRUCTURAL PROPERTIES:

N is the normal force [or factored normal load] on the base unit
The default leveling pad to base unit shear is 0.8 tan(φ) [AASHTO 10.6.3.4] or
may be the manufacturer supplied data. φ is assumed to be 40 degrees for a stone leveling pad.

FORCE DETAILS

The details below shown how the forces are calculated for each force component. The values shown are not factored. All loads are based on a unit width (ppf / kNpm).

Layer	Block Wt	Soil Fill Wt	Soil Wt
1	423		0
2	846		

Block Weight (Force v (Block Wt + Infill Soil)) = 1269ppf X-Arm = 1.23ft
Soils Block Weight (Force v) = 0ppf X-Arm = 0.00ft

Active Earth Pressure Pa = 209ppf
Pa_h (Force H) = Pa cos(δ - batter) = 209 x cos(22.7 - (0.0)) = 193ppf
Y-Arm = 1.25ft
Pa_v (Force V) = Pa sin(δ - batter) = 209 x sin(22.7 - (0.0)) = 81ppf
X-Arm = 2.46ft

Live Load Pq = 76ppf
Pq_h (Force H) = Pq cos(δ - batter) = 76 x cos(22.7 - 0.0) = 70ppf
Y-Arm = 1.88ft
Pq_v (Force V) = Pq sin(δ - batter) = 76 x sin(22.7 - 0.0) = 29ppf
X-Arm = 2.46ft

CALCULATION RESULTS

OVERVIEW

UltraWall calculates stability assuming the wall is a rigid body. Forces and moments are calculated about the base and the front toe of the wall. The base block width is used in the calculations. The concrete units and granular fill over the blocks are used as resisting forces.

EARTH PRESSURES

The method of analysis uses the Coulomb Earth Pressure equation (below) to calculate active earth pressures. Wall friction is assumed to act at the back of the wall face. The component of earth pressure is assumed to act perpendicular to the boundary surface. The effective δ angle is δ minus the wall batter at the back face. If the slope breaks within the failure zone, a trial wedge method of analysis is used.

EXTERNAL EARTH PRESSURES

Effective δ angle (2/3 retained phi)	δ =22.7 deg
Coefficient of active earth pressure	ka =0.238
External failure plane	ρ = 58 deg
Effective Angle from horizontal	α =90.00 deg
Coefficient of passive earth pressure: kp = (1 + sin(φ)) / (1 - sin(φ))	kp =4.60

$$Ka := \frac{\cos(\phi_i + i)^2}{\cos(i)^2 \cdot \cos(\delta_i - i)\left(1 + \sqrt{\frac{\sin(\phi_i + \delta_i)\cdot\sin(\phi_i - \beta)}{\cos(\delta_i - i)\cdot\cos(i + \beta)}}\right)^2}$$

FORCES AND MOMENTS

The program resolves all the geometry into simple geometric shapes to make checking easier. All x and y coordinates are referenced to a zero point at the middle of the base block for eccentricity calculations.

LOADS FOR OVERTURNING ABOUT THE TOE

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	1269	--	1.23	--	--	1560
Pa_h	1.00	--	193	--	1.25	241	--
Pa_v	1.00	81	--	2.46	--	--	198
Pq_h	1.00	--	70	--	1.88	132	--
Pq_v	1.00	29	--	2.46	--	--	72
Sum V / H	1.00	1379	263		Sum Mom	373	1830

W0: stone within units

W1: facing units

W2: soil wedge behind the face

X-Len: is measured from the center of the base (+) Driving, (-) Resisting.

Pa_h: horizontal earth pressure

Pa_v: vertical earth pressure

Pq_h: horizontal surcharge pressure

Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	1269	--	0.00	--	--	0
Pa_h	1.00	--	193	--	1.25	241	--
Pa_v	1.00	81	--	-1.23	--	--	-99
Pq_h	1.00	--	70	--	1.88	132	--
Pq_v	1.00	29	--	-1.23	--	--	-36
Sum V / H	1.00	1379	263		Sum Mom	373	-135

BASE SLIDING

Sliding at the base is checked at the block to leveling pad interface between the base block and the leveling pad.

Forces Resisting sliding = W1 + Pav + Pqv	
1269 + 81 + 29	N =1379ppf
Resisting force at pad = (N * 0.8 * tan(slope) + intercept x L)	
1379 x0.8 x tan(40.0) + 0.0	Rf =0
Passive resistance is calculated using kp = (1 + sin(40))/(1 - sin(40))	kp = 4.60
Force at top of resisting trapezoid, d1 = 0.50	Fp1 = 310.43
Force at base of resisting trapezoid, d2 = 1.00	Fp2 = 620.85
Depth of trapezoid	depth = 0.50
Pp = (Fp1 + Fp2) / 2 * depth	232.82
Friction angle = minimum of the leveling pad or Fnd	φ =40.00 deg
N1 includes N + leveling pad (LP)	
Where:	
LP = lvl pad thickness * 135pcf * (L + lvl pad thickness)	
L is the base block width	
1379 + 183	N1 = 1562ppf
Resisting force at fnd = (N1 tan(phi) + c L) + Pp	
1562 x tan(40) + 0 x 3.0 + 233	Rf1 = 0
Driving force is the horizontal component of	
Pah + Pqh	
193 + 70	Df =263
FSsl = (Rf / Df) and (Rf1 / Df)	FSsl =2.64 / 100.00

OVERTURNING ABOUT THE TOE

Overturning at the base is checked by assuming rotation about the front toe by the block mass and the soil retained on the blocks. Allowable overturning can be defined by eccentricity (e/L). For concrete leveling pads eccentricity is checked at the base of the pad.

Moments Resisting Overturning = M1 + MPav + MPqv
1560 + 198 + 72 Mr =1830ft-lbs

Moments causing Overturning = MPah + MPqh
241 + 132 Mo =373ft-lbs

FSot = Mr / Mo
FSot =1830 / 373 FSot =4.91

ECCENTRICITY AND BEARING

Eccentricity is the calculation of the distance of the resultant away from the centroid of mass. In wall design the eccentricity is used to calculate an effective footing width.

Calculation of Eccentricity

SumV = + W1 + Pav + Pqv

+ 1269 + 81 + 29 SumV = 1379

Moment Resisting Mr = -135

Moment Driving Md = 373

e = (SumMr + SumMd)/(SumV)

e = (238 /0.00) e =0.172ft

Calculation of Bearing Pressures

Qult = c * Nc + q * Nq + 0.5 * γ* (B') * Ng

where:

Nc =75.31

Nq =64.20

Ng =109.41

c =0.00psf

q = 135.00psf(soil weight above base of leveling pad)

B' = B - 2e + lvlpad = 2.61ft

Gamma =135pcf

Calculate Ultimate Bearing, Qult Qult =27967psf

Bearing Pressure = (SumVert / B') + (LP width * gamma) sigma = 597.63psf

Calculated Factors of Safety for Bearing Qult/sigma =46.80

SEISMIC CALCULATIONS

The loads considered under seismic loading are primarily inertial loadings. The wave passes the structure putting the mass into motion and then the mass will try to continue in the direction of the initial wave. In the calculations you see the one dynamic earth pressure from the wedge of the soil behind the reinforced mass, and then all the other forces come from inertia calculations of the face put into motion and then trying to be held in place.

Design Ground Acceleration	A =0.600
Horizontal Acceleration [kh = A/2]	kh =0.297
Vertical Acceleration	kv =0.000

INERTIA FORCES OF THE STRUCTURE

Face (Pif) = (W1)*kh(ext) = 1269.11 *0.297	
	Pif =376.83ppf

SEISMIC THRUST

Kae	Kae =0.498
D_Kae = Kae - Ka = (0.498 - 0.238)	D_Kae =0.260
Pae = 0.5*gamma*(H)^2*D_Kae	Pae =228.33ppf
Pae_h = Pae*cos(δ)	Pae_h =210.69ppf
Pae_v = Pae*sin(δ)	Pae_v =87.99ppf

TABLE OF RESULTS FOR SEISMIC REACTIONS

SEISMIC SLIDING

The target factor of safety for seismic is 75% of the static value. Live loads are ignored in these analysis based on the basic premise that the probability of the maximum acceleration occuring at the exact same instant as the maximum live load is small.

Details are only shown for sliding at the base of blocks, a check is made at the foundation level with the answer only shown.

The vertical resisting forces is W1 + W2 + Pav + Paev	
1269 + 0 + 81 + 88	SumVs = 1438
Resisting force = SumVs * tan(phi) + intercept x L	FRe =965ppf
Driving force = Pa_h + Pae_h + Pif	
=193 +211 +377	FDr =780ppf
FOS = FRe/FDr [leveling pad / foundation]	FoS =1.24 / 100.00

SEISMIC OVERTURNING

Overturning is rotation about the front toe of the wall. Eccentricity is also a check on overturning

Resisting Moment = M1 + M2 + MPav + MPaev	
1560 + 0 + 198 + 216 +	SumMrS =1974ftppf
Driving Moment = MPah + MPaeh + MPif	
241 + 474 + 848	SumMoS = 1563.12ftppf
Factor of Safety = SumMrS/SumMoS	FoS = 1.26

SEISMIC BEARING

Bearing is the ability of the foundation to support the mass of the structure.

Qult = c*Nc + q*Nq + 0.5*gamma*(B')*Ng

where:

Nc = 75.31

Nq = 64.20

Ng =109.41

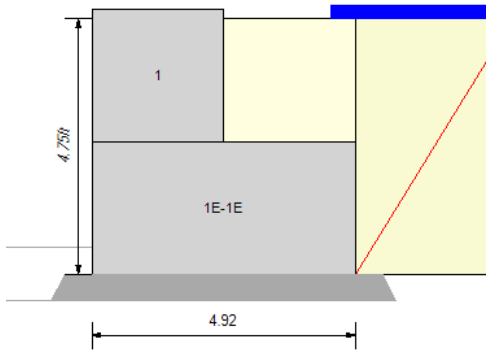
c = 0.00psf

q = 135.00psf

Calculate Ultimate Bearing, Qult (seismic)	Qult = 21155.13psf
eccentricity (e)	e =0.943
Equivalent Footing Width, B' = L - 2e + lvl pad	B' =1ft
Bearing Pressure = sumVs/B'	sigma =620psf
Factor of Safety for Bearing = Qult/Bearing	FoS =34

UltraWall

Project:	Park Royal Apartments
Location:	Bothell, WA
Designer:	CWM
Date:	6/30/2021
Section:	Mid Wall Height
Design Method:	NCMA_09_3rd_Ed, Ignore Vert. Force
Design Unit:	UltraBlock



Seismic Acc: 0.600

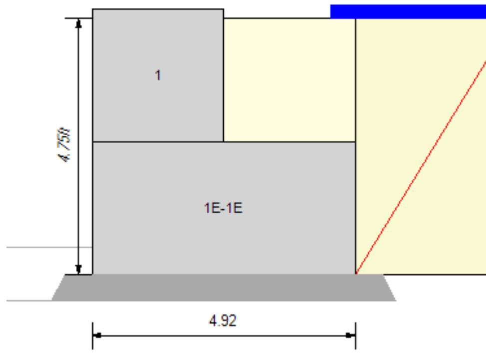
SOIL PARAMETERS	φ	coh	γ	
Retained Soil:	34 deg	0psf	125pcf	
Foundation Soil:	40 deg	0psf	135pcf	
Leveling Pad:	40 deg	0psf	135pcf	Crushed Stone

GEOMETRY

Design Height:	4.75ft	Live Load:	250psf
Wall Batter/Tilt:	0.00/ 0.00 deg	Live Load Offset:	2.00ft
Embedment:	0.50ft	Live Load Width:	20ft
Leveling Pad Depth:	0.50ft	Dead Load:	0psf
Slope Angle:	0.0 deg	Dead Load Offset:	0.0ft
Slope Length:	0.0ft	Dead Load Width:	0ft
Slope Toe Offset:	0.0ft	Leveling Pad Width:	5.92ft
Vert δ on Single Dpth			

FACTORS OF SAFETY (Static / Seismic)

Sliding:	1.50 / 1.125	Overturning:	1.50 / 1.125
Bearing:	2.00 / 1.5		



RESULTS (Static / Seismic)

FoS Sliding: 2.60 (lvlpd) / 1.62 FoS Overturning: 6.67 / 2.41

Bearing: 768.88 / 768.32 FoS Bearing: 57.79 / 54.76

Name	Elev.	ka	kae	Pa	Pae	Pir	Paq	PaT	FSsl	FoS OT	siesFSsl	FoS SeisOT
1	2.46	0.254	0.498	83	163	251	0	83	240.24	19.02	46.08	2.36
1E-1E	0.00	0.254	0.498	358	702	754	351	709	2.60[100.00]	6.67	1.62[100.00]	2.41

Column Descriptions:

- ka: active earth pressure coefficient
- kae: active seismic earth pressure coefficient
- Pa: active earth pressure
- Pae: dynamic earth pressure
- Pir: inertia force
- Paq: live surcharge earth pressure
- Paq2: live load 2 surcharge earth pressure
- Paqd: dead surcharge earth pressure
- (PaC): reduction in load due to cohesion
- PaT: sum of all earth pressures
- FSsl(lvl Pad): factor of safety for sliding at each layer. (FS sliding below the leveling pad)
- FSot: factor of safety of overturning about the toe.

RETAINING WALL UNITS

STRUCTURAL PROPERTIES:

N is the normal force [or factored normal load] on the base unit

The default leveling pad to base unit shear is 0.8 tan(φ) [AASHTO 10.6.3.4] or may be the manufacturer supplied data. φ is assumed to be 40 degrees for a stone leveling pad.

FORCE DETAILS

The details below shown how the forces are calculated for each force component. The values shown are not factored. All loads are based on a unit width (ppf / kNpm).

Layer	Block Wt	Soil Fill Wt	Soil Wt
1	846		563
2	1692		

Block Weight (Force v (Block Wt + Infill Soil)) = 2538ppf X-Arm = 2.05ft
Soils Block Weight (Force v) = 563ppf X-Arm = 3.69ft

Active Earth Pressure Pa = 358ppf
Pa_h (Force H) = Pa cos(δ - batter) = 358 x cos(22.7 - (0.0)) = 330ppf
Y-Arm = 1.58ft
Pa_v (Force V) = Pa sin(δ - batter) = 358 x sin(22.7 - (0.0)) = 138ppf
X-Arm = 4.92ft

Live Load Pq = 351ppf
Pq_h (Force H) = Pq cos(δ - batter) = 351 x cos(22.7 - 0.0) = 324ppf
Y-Arm = 2.38ft
Pq_v (Force V) = Pq sin(δ - batter) = 351 x sin(22.7 - 0.0) = 135ppf
X-Arm = 4.92ft

CALCULATION RESULTS

OVERVIEW

UltraWall calculates stability assuming the wall is a rigid body. Forces and moments are calculated about the base and the front toe of the wall. The base block width is used in the calculations. The concrete units and granular fill over the blocks are used as resisting forces.

EARTH PRESSURES

The method of analysis uses the Coulomb Earth Pressure equation (below) to calculate active earth pressures. Wall friction is assumed to act at the back of the wall face. The component of earth pressure is assumed to act perpendicular to the boundary surface. The effective δ angle is δ minus the wall batter at the back face. If the slope breaks within the failure zone, a trial wedge method of analysis is used.

EXTERNAL EARTH PRESSURES

Effective δ angle (2/3 retained phi)	δ =22.7 deg
Coefficient of active earth pressure	ka =0.254
External failure plane	ρ = 58 deg
Effective Angle from horizontal	α =90.00 deg
Coefficient of passive earth pressure: kp = (1 + sin(φ)) / (1 - sin(φ))	kp =4.60

$$Ka := \frac{\cos(\phi_i + i)^2}{\cos(i)^2 \cdot \cos(\delta_i - i)\left(1 + \sqrt{\frac{\sin(\phi_i + \delta_i)\cdot\sin(\phi_i - \beta)}{\cos(\delta_i - i)\cdot\cos(i + \beta)}}\right)^2}$$

FORCES AND MOMENTS

The program resolves all the geometry into simple geometric shapes to make checking easier. All x and y coordinates are referenced to a zero point at the middle of the base block for eccentricity calculations.

LOADS FOR OVERTURNING ABOUT THE TOE

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	2538	--	2.05	--	--	5200
Soil Wedge(W2)	1.00	563	--	3.69	--	--	2077
Pa_h	1.00	--	330	--	1.58	522	--
Pa_v	1.00	138	--	4.92	--	--	677
Pq_h	1.00	--	324	--	2.38	770	--
Pq_v	1.00	135	--	4.92	--	--	666
Sum V / H	1.00	3375	654		Sum Mom	1292	8620

W0: stone within units

W1: facing units

W2: soil wedge behind the face

X-Len: is measured from the center of the base (+) Driving, (-) Resisting.

Pa_h: horizontal earth pressure

Pa_v: vertical earth pressure

Pq_h: horizontal surcharge pressure

Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	2538	--	0.41	--	1040	--
Soil Wedge(W2)	1.00	563	--	-1.23	--	--	-692
Pa_h	1.00	--	330	--	1.58	522	--
Pa_v	1.00	138	--	-2.46	--	--	-339
Pq_h	1.00	--	324	--	2.38	770	--
Pq_v	1.00	135	--	-2.46	--	--	-333
Sum V / H	1.00	3375	654		Sum Mom	2332	-1364

BASE SLIDING

Sliding at the base is checked at the block to leveling pad interface between the base block and the leveling pad.

Forces Resisting sliding = W1 + W2 + Pav + Pqv	
2538 + 563 + 138 + 135	N =3375ppf
Resisting force at pad = (N * 0.8 * tan(slope) + intercept x L)	
3375 x0.8 x tan(40.0) + 0.0	Rf =0
Passive resistance is calculated using kp = (1 + sin(40))/(1 - sin(40))	kp = 4.60
Force at top of resisting trapezoid, d1 = 0.50	Fp1 = 310.43
Force at base of resisting trapezoid, d2 = 1.00	Fp2 = 620.85
Depth of trapezoid	depth = 0.50
Pp = (Fp1 + Fp2) / 2 * depth	232.82
Friction angle = minimum of the leveling pad or Fnd	φ =40.00 deg
N1 includes N + leveling pad (LP)	
Where:	
LP = lvl pad thickness * 135pcf * (L + lvl pad thickness)	
L is the base block width	
3375 + 349	N1 = 3724ppf
Resisting force at fnd = (N1 tan(phi) + c L) + Pp	
3724 x tan(40) + 0 x 5.4 + 233	Rf1 = 0
Driving force is the horizontal component of	
Pah + Pqh	
330 + 324	Df =654
FSsl = (Rf / Df) and (Rf1 / Df)	FSsl =2.60 / 100.00

OVERTURNING ABOUT THE TOE

Overturning at the base is checked by assuming rotation about the front toe by the block mass and the soil retained on the blocks. Allowable overturning can be defined by eccentricity (e/L). For concrete leveling pads eccentricity is checked at the base of the pad.

Moments Resisting Overturning = M1 + M2 + MPav + MPqv
5200 + 2077 + 677 + 666 Mr =8620ft-lbs

Moments causing Overturning = MPah + MPqh
522 + 770 Mo =1292ft-lbs

FSot = Mr / Mo
FSot =8620 / 1292 FSot =6.67

ECCENTRICITY AND BEARING

Eccentricity is the calculation of the distance of the resultant away from the centroid of mass. In wall design the eccentricity is used to calculate an effective footing width.

Calculation of Eccentricity

SumV = + W1 + W2 + Pav + Pqv

+ 2538 + 563 + 138 + 135 SumV = 3375

Moment Resisting Mr = -1364

Moment Driving Md = 2332

e = (SumMr + SumMd)/(SumV)

e = (968 /0.00) e =0.287ft

Calculation of Bearing Pressures

Qult = c * Nc + q * Nq + 0.5 * γ* (B') * Ng

where:

Nc =75.31

Nq =64.20

Ng =109.41

c =0.00psf

q = 135.00psf(soil weight above base of leveling pad)

B' = B - 2e + lvlpad = 4.84ft

Gamma =135pcf

Calculate Ultimate Bearing, Qult Qult =44432psf

Bearing Pressure = (SumVert / B') + (LP width * gamma) sigma = 768.88psf

Calculated Factors of Safety for Bearing Qult/sigma =57.79

SEISMIC CALCULATIONS

The loads considered under seismic loading are primarily inertial loadings. The wave passes the structure putting the mass into motion and then the mass will try to continue in the direction of the initial wave. In the calculations you see the one dynamic earth pressure from the wedge of the soil behind the reinforced mass, and then all the other forces come from inertia calculations of the face put into motion and then trying to be held in place.

Design Ground Acceleration	A =0.600
Horizontal Acceleration [kh = A/2]	kh =0.297
Vertical Acceleration	kv =0.000

INERTIA FORCES OF THE STRUCTURE

Face (Pif) = (W1)*kh(ext) = 2538.23 *0.297

Pif =753.65ppf

SEISMIC THRUST

Kae	Kae =0.498
D_Kae = Kae - Ka = (0.498 - 0.254)	D_Kae =0.244
Pae = 0.5*gamma*(H)^2*D_Kae	Pae =344.34ppf
Pae_h = Pae*cos(δ)	Pae_h =317.74ppf
Pae_v = Pae*sin(δ)	Pae_v =132.70ppf

TABLE OF RESULTS FOR SEISMIC REACTIONS

SEISMIC SLIDING

The target factor of safety for seismic is 75% of the static value. Live loads are ignored in these analysis based on the basic premise that the probability of the maximum acceleration occuring at the exact same instant as the maximum live load is small.

Details are only shown for sliding at the base of blocks, a check is made at the foundation level with the answer only shown.

The vertical resisting forces is W1 + W2 + Pav + Paev	
2538 + 563 + 138 + 133	SumVs = 3372
Resisting force = SumVs * tan(phi) + intercept x L	FRe =2264ppf
Driving force = Pa_h + Pae_h + Pif	
=330 +318 +754	FDr =1401ppf
FOS = FRe/FDr [leveling pad / foundation]	FoS =1.62 / 100.00

SEISMIC OVERTURNING

Overturning is rotation about the front toe of the wall. Eccentricity is also a check on overturning

Resisting Moment = M1 + M2 + MPav + MPaev	
5200 + 2077 + 677 + 652 +	SumMrS =8607ftppf
Driving Moment = MPah + MPaeh + MPif	
522 + 906 + 2148	SumMoS = 3575.81ftppf
Factor of Safety = SumMrS/SumMoS	FoS = 2.41

SEISMIC BEARING

Bearing is the ability of the foundation to support the mass of the structure.

Qult = c*Nc + q*Nq + 0.5*gamma*(B')*Ng

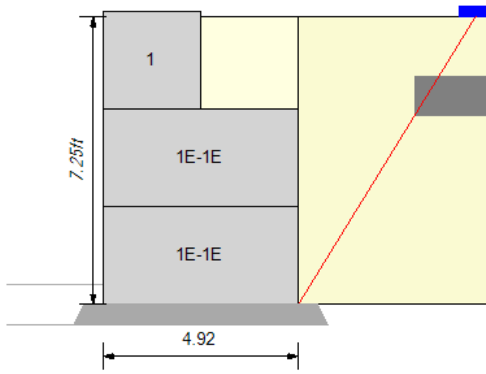
where:

Nc = 75.31
Nq = 64.20
Ng =109.41
c = 0.00psf
q = 135.00psf

Calculate Ultimate Bearing, Qult (seismic)	Qult = 42074.09psf
eccentricity (e)	e =0.966
Equivalent Footing Width, B' = L - 2e + lvl pad	B' =3ft
Bearing Pressure = sumVs/B'	sigma =768psf
Factor of Safety for Bearing = Qult/Bearing	FoS =55

UltraWall

Project: Park Royal Apartments
Location: Bothell, WA
Designer: CWM
Date: 6/30/2021
Section: Tallest Wall Height
Design Method: NCMA_09_3rd_Ed, Ignore Vert. Force
Design Unit: UltraBlock



Seismic Acc: 0.600

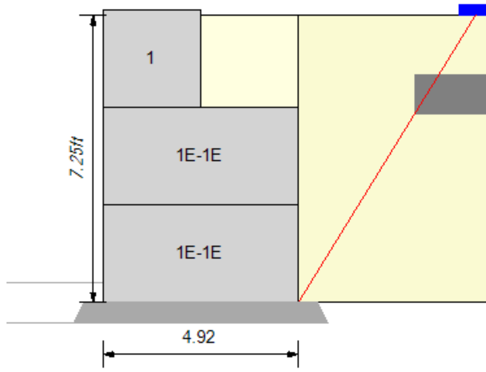
SOIL PARAMETERS	φ	coh	γ	
Retained Soil:	34 deg	0psf	125pcf	
Foundation Soil:	40 deg	0psf	135pcf	
Leveling Pad:	40 deg	0psf	135pcf	Crushed Stone

GEOMETRY

Design Height:	7.25ft	Live Load:	80psf
Wall Batter/Tilt:	0.00/ 0.00 deg	Live Load Offset:	6.50ft
Embedment:	0.50ft	Live Load Width:	20ft
Leveling Pad Depth:	0.50ft	Dead Load:	1500psf
Slope Angle:	0.0 deg	Dead Load Offset:	5.4ft
Slope Length:	0.0ft	Dead Load Width:	2ft
Slope Toe Offset:	0.0ft	Leveling Pad Width:	5.92ft
Vert δ on Single Dpth			

FACTORS OF SAFETY (Static / Seismic)

Sliding:	1.50 / 1.125	Overturning:	1.50 / 1.125
Bearing:	2.00 / 1.5		



RESULTS (Static / Seismic)

FoS Sliding:	2.28 (lvlpd) / 1.13	FoS Overturning:	4.85 / 1.31
Bearing:	1268.26 / 1300.20	FoS Bearing:	32.73 / 30.04

Name	Elev.	ka	kae	Pa	Pae	Pir	Paq	Paqd	PaT	FSsl	FoS OT	siesFSsl	FoS SeisOT
1	4.92	0.254	0.498	87	169	251	0	0	87	231.75	18.07	45.46	2.30
1E-1E	2.46	0.254	0.498	365	714	754	0	0	365	60.59	14.89	14.52	2.39
1E-1E	0.00	0.220	0.498	724	1635	1256	49	494	1266	2.28[100.00]	4.85	1.13[100.00]	1.31

Column Descriptions:

ka: active earth pressure coefficient
kae: active seismic earth pressure coefficient
Pa: active earth pressure
Pae: dynamic earth pressure
Pir: inertia force
Paq: live surcharge earth pressure
Paq2: live load 2 surcharge earth pressure
Paqd: dead surcharge earth pressure
(PaC): reduction in load due to cohesion
PaT: sum of all earth pressures
FSsl(lvl Pad): factor of safety for sliding at each layer. (FS sliding below the leveling pad)
FSot: factor of safety of overturning about the toe.

RETAINING WALL UNITS

STRUCTURAL PROPERTIES:

N is the normal force [or factored normal load] on the base unit

The default leveling pad to base unit shear is 0.8 tan(φ) [AASHTO 10.6.3.4] or may be the manufacturer supplied data. φ is assumed to be 40 degrees for a stone leveling pad.

FORCE DETAILS

The details below shown how the forces are calculated for each force component. The values shown are not factored. All loads are based on a unit width (ppf / kNpm).

Layer	Block Wt	Soil Fill Wt	Soil Wt
1	846		574
2	1692		0
3	1692		

Block Weight (Force v (Block Wt + Infill Soil)) = 4230ppf X-Arm = 2.21ft
Soils Block Weight (Force v) = 574ppf X-Arm = 3.69ft

Active Earth Pressure Pa = 724ppf

Pa_h (Force H) = Pa cos(δ - batter) = 724 x cos(22.7 - (0.0)) = 668ppf

Y-Arm = 2.42ft

Pa_v (Force V) = Pa sin(δ - batter) = 724 x sin(22.7 - (0.0)) = 279ppf

X-Arm = 4.92ft

Live Load Pq = 49ppf

Pq_h (Force H) = Pq cos(δ - batter) = 49 x cos(22.7 - 0.0) = 45ppf

Y-Arm = 3.63ft

Pq_v (Force V) = Pq sin(δ - batter) = 49 x sin(22.7 - 0.0) = 19ppf

X-Arm = 4.92ft

Dead Load Pqd = 494ppf

Pqd_h (Force H) = Pqd cos(δ - batter) = 494 x cos(22.7 - (0.0)) = 456ppf

Y-Arm = 2.37ft

Pqd_v (Force V) = Pqd sin(δ - batter) = 494 x sin(0.0 + 22.7) = 190ppf

X-Arm = 4.92ft

CALCULATION RESULTS

OVERVIEW

UltraWall calculates stability assuming the wall is a rigid body. Forces and moments are calculated about the base and the front toe of the wall. The base block width is used in the calculations. The concrete units and granular fill over the blocks are used as resisting forces.

EARTH PRESSURES

The method of analysis uses the Coulomb Earth Pressure equation (below) to calculate active earth pressures. Wall friction is assumed to act at the back of the wall face. The component of earth pressure is assumed to act perpendicular to the boundary surface. The effective δ angle is δ minus the wall batter at the back face. If the slope breaks within the failure zone, a trial wedge method of analysis is used.

EXTERNAL EARTH PRESSURES

Effective δ angle (2/3 retained phi)	δ =22.7 deg
Coefficient of active earth pressure	ka =0.220
External failure plane	ρ = 58 deg
Effective Angle from horizontal	α =90.00 deg
Coefficient of passive earth pressure: kp = (1 + sin(φ)) / (1 - sin(φ))	kp =4.60

$$Ka := \frac{\cos(\phi_i + i)^2}{\cos(i)^2 \cdot \cos(\delta_i - i)\left(1 + \sqrt{\frac{\sin(\phi_i + \delta_i)\cdot\sin(\phi_i - \beta)}{\cos(\delta_i - i)\cdot\cos(i + \beta)}}\right)^2}$$

FORCES AND MOMENTS

The program resolves all the geometry into simple geometric shapes to make checking easier. All x and y coordinates are referenced to a zero point at the middle of the base block for eccentricity calculations.

LOADS FOR OVERTURNING ABOUT THE TOE

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	4230	--	2.21	--	--	9360
Soil Wedge(W2)	1.00	574	--	3.69	--	--	2115
Pa_h	1.00	--	668	--	2.42	1614	--
Pa_v	1.00	279	--	4.92	--	--	1372
Pq_h	1.00	--	45	--	3.63	163	--
Pq_v	1.00	19	--	4.92	--	--	92
Pqd_h	1.00	--	456	--	2.37	1082	--
Pqd_v	1.00	190	--	4.92	--	--	936
Sum V / H	1.00	5292	1169		Sum Mom	2859	13874

W0: stone within units
W1: facing units
W2: soil wedge behind the face
X-Len: is measured from the center of the base (+) Driving, (-) Resisting.
Pa_h: horizontal earth pressure
Pa_v: vertical earth pressure
Pq_h: horizontal surcharge pressure
Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor γ	Force (V)	Force (H)	X-len	Y-len	Mo	Mr
Face Blocks(W1)	1.00	4230	--	0.25	--	1040	--
Soil Wedge(W2)	1.00	574	--	-1.23	--	--	-705
Pa_h	1.00	--	668	--	2.42	1614	--
Pa_v	1.00	279	--	-2.46	--	--	-686
Pq_h	1.00	--	45	--	3.63	163	--
Pq_v	1.00	19	--	-2.46	--	--	-46
Pqd_h	1.00	--	456	--	3.63	1652	--
Pqd_v	1.00	190	--	-2.46	--	--	-468
Sum V / H	1.00	5292	1169		Sum Mom	4469	-1905

BASE SLIDING

Sliding at the base is checked at the block to leveling pad interface between the base block and the leveling pad.

Forces Resisting sliding = W1 + W2 + Pav + Pqv + Pqdv	
4230 + 574 + 279 + 19 + 190	N =5292ppf
Resisting force at pad = (N * 0.8 * tan(slope) + intercept x L)	
5292 x0.8 x tan(40.0) + 0.0	Rf =0
Passive resistance is calculated using kp = (1 + sin(40))/(1 - sin(40))	kp = 4.60
Force at top of resisting trapezoid, d1 = 0.50	Fp1 = 310.43
Force at base of resisting trapezoid, d2 = 1.00	Fp2 = 620.85
Depth of trapezoid	depth = 0.50
Pp = (Fp1 + Fp2) / 2 * depth	232.82
Friction angle = minimum of the leveling pad or Fnd	φ =40.00 deg
N1 includes N + leveling pad (LP)	
Where:	
LP = lvl pad thickness * 135pcf * (L + lvl pad thickness)	
L is the base block width	
5292 + 349	N1 = 5641ppf
Resisting force at fnd = (N1 tan(phi) + c L) + Pp	
5641 x tan(40) + 0 x 5.4 + 233	Rf1 = 0
Driving force is the horizontal component of	
Pah + Pqh + Pqdh	
668 + 45 + 456	Df =1,169
FSsl = (Rf / Df) and (Rf1 / Df)	FSsl =2.28 / 100.00

OVERTURNING ABOUT THE TOE

Overturning at the base is checked by assuming rotation about the front toe by the block mass and the soil retained on the blocks. Allowable overturning can be defined by eccentricity (e/L). For concrete leveling pads eccentricity is checked at the base of the pad.

Moments Resisting Overturning = M1 + M2 + MPav + MPqv + MPqdv)
9360 + 2115 + 1372 + 92 + 936 — Mr =13874ft-lbs

Moments causing Overturning = MPah + MPqh + MPqdh
1614 + 163 + 1082 — Mo =2859ft-lbs

FSot = Mr / Mo
FSot =13874 / 2859 — FSot =4.85

ECCENTRICITY AND BEARING

Eccentricity is the calculation of the distance of the resultant away from the centroid of mass. In wall design the eccentricity is used to calculate an effective footing width.

Calculation of Eccentricity

SumV = + W1 + W2 + Pav + Pqv + Pqdv

+ 4230 + 574 + 279 + 19 + 190 SumV = 5292

Moment Resisting Mr = -1905

Moment Driving Md = 4469

e = (SumMr + SumMd)/(SumV)

e = (2564 /0.00) e =0.485ft

Calculation of Bearing Pressures

Qult = c * Nc + q * Nq + 0.5 * γ* (B') * Ng

where:

Nc =75.31

Nq =64.20

Ng =109.41

c =0.00psf

q = 135.00psf(soil weight above base of leveling pad)

B' = B - 2e + lvlpad = 4.45ft

Gamma =135pcf

Calculate Ultimate Bearing, Qult Qult =41513psf

Bearing Pressure = (SumVert / B') + (LP width * gamma) sigma =1268.26psf

Calculated Factors of Safety for Bearing Qult/sigma =32.73

SEISMIC CALCULATIONS

The loads considered under seismic loading are primarily inertial loadings. The wave passes the structure putting the mass into motion and then the mass will try to continue in the direction of the initial wave. In the calculations you see the one dynamic earth pressure from the wedge of the soil behind the reinforced mass, and then all the other forces come from inertia calculations of the face put into motion and then trying to be held in place.

Design Ground Acceleration	A =0.600
Horizontal Acceleration [kh = A/2]	kh =0.297
Vertical Acceleration	kv =0.000

INERTIA FORCES OF THE STRUCTURE

Face (Pif) = (W1)*kh(ext) = 4230.38 *0.297

Pif =1256.09ppf

SEISMIC THRUST

Kae	Kae =0.498
D_Kae = Kae - Ka = (0.498 - 0.220)	D_Kae =0.277
Pae = 0.5*gamma*(H)^2*D_Kae	Pae =911.19ppf
Pae_h = Pae*cos(δ)	Pae_h =840.81ppf
Pae_v = Pae*sin(δ)	Pae_v =351.14ppf

TABLE OF RESULTS FOR SEISMIC REACTIONS

SEISMIC SLIDING

The target factor of safety for seismic is 75% of the static value. Live loads are ignored in these analysis based on the basic premise that the probability of the maximum acceleration occuring at the exact same instant as the maximum live load is small.

Details are only shown for sliding at the base of blocks, a check is made at the foundation level with the answer only shown.

The vertical resisting forces is W1 + W2 + Pav + Paev	
4230 + 574 + 279 + 351	SumVs = 5434
Resisting force = SumVs * tan(phi) + intercept x L	FRe =3648ppf
Driving force = Pa_h + Pae_h + Pif	
=668 +841 +1256	FDr =3221ppf
FOS = FRe/FDr [leveling pad / foundation]	FoS =1.13 / 100.00

SEISMIC OVERTURNING

Overturning is rotation about the front toe of the wall. Eccentricity is also a check on overturning

Resisting Moment = M1 + M2 + MPav + MPaev	
9360 + 2115 + 1372 + 1726 +	SumMrS =15509ftppf
Driving Moment = MPah + MPaeh + MPif	
1614 + 3658 + 5464	SumMoS = 11817.93ftppf
Factor of Safety = SumMrS/SumMoS	FoS = 1.31

SEISMIC BEARING

Bearing is the ability of the foundation to support the mass of the structure.

Qult = c*Nc + q*Nq + 0.5*gamma*(B')*Ng

where:

Nc = 75.31

Nq = 64.20

Ng =109.41

c = 0.00psf

q = 135.00psf

Calculate Ultimate Bearing, Qult (seismic)	Qult = 39058.54psf
eccentricity (e)	e =1.970
Equivalent Footing Width, B' = L - 2e + lvl pad	B' =1ft
Bearing Pressure = sumVs/B'	sigma =1300psf
Factor of Safety for Bearing = Qult/Bearing	FoS =30