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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.

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

TABLE 1. GRAVITY BLOCK WALL DESIGN PARAMETERS

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)

Disclaimer: Any electronic form, facsimile or hard copy of the original document (email, text, table, and/or figure), if provided, and any attachments are only a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.







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

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.

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

 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.
 Only hand-operated compaction equipment shall be allowed within 5 feet behind the wall.

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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

Gravity Block Retaining Wall Section and Notes

Park Royal Apartments Bothell, Washington

GEOENGINEERS

Figure 1

UltraWall

Project: Location: Designer: Date: Section:	Park Roya Bothell, W CWM 6/30/2021 Shortest W	al Apartme 'A Vall	ents	
Design Method:) 3rd Ed	Ianore Vert	Force
Design Method.			ignore vert.	I UICE
Design Unit:	UltraBlock	ζ.		
Seismic Acc:	0.600			
SOIL PARAMETE	ERS	φ	coh	Y
Retained Soil	:	34 deg	0psf	125pcf
Foundation S	oil:	40 deg	0psf	135pcf

40 deg

0psf

135pcf

Crushed Stone



25

GEOMETRY

Leveling Pad:

	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:	Oft
	Slope Toe Offset:	0.0ft	Leveling Pad Width:	3.46ft
	Vert δ on Single Dpth			
FAC	CTORS OF SAFETY (Sta	atic / Seismic)		
	Sliding:	1.50 / 1.125	Overturning:	1.50 / 1 .1
	Bearing:	2.00 / 1.5		



RESULTS (Static / S	eismic)

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(IvI 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		
Dis als Maintet (Eans a su	$\langle D _{2} = 1 \langle M _{2} \rangle = 1 \langle D _{2} \langle D _{2} \rangle = 1 \langle D _{2} \langle D _{2} \rangle$	6 V Amer - 1 00ft	

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: $kp = (1 + sin(\phi)) / (1 - sin(\phi))$	kp =4.60

$$K_{a} := \frac{\cos(\varphi_{i} + i)^{2}}{\cos(i)^{2} \cdot \cos(\delta_{i} - i) \left(1 + \sqrt{\frac{\sin(\varphi_{i} + \delta_{i}) \cdot \sin(\varphi_{i} - \beta)}{\cos(\delta_{i} - i) \cdot \cos(i + \beta)}}\right)^{2}}$$

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.

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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

LOADS FOR OVERTURNING ABOUT THE TOE

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

Pq_h: horizontal surcharge pressure

Pa v: vertical earth pressure

Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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)) Force at top of resisting trapezoid, d1 = 0.50 Force at base of resisting trapezoid, d2 = 1.00 Depth of trapezoid Pp = (Fp1 + Fp2) / 2 * depth	kp = 4.60 Fp1 = 310.43 Fp2 = 620.85 depth = 0.50 232.82
Friction angle = minimum of the leveling pad or Fnd N1 includes N + leveling pad (LP) Where: LP = IvI pad thickness * 135pcf * (L + IvI pad thickness) L is the base block width	φ =40.00 deg
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
FSsI = (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 Horizontal Acceleration [kh = A/2] Vertical Acceleration	A =0.600 kh =0.297 kv =0.000
INERTIA FORCES OF THE STRUCTURE Face (Pif) = (W1)*kb(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
$Pae_h = Pae^*cos(\delta)$	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')*Ngwhere: Nc = 75.31 Nq = 64.20 Ng =109.41 c = 0.00psf q = 135.00psf

Qult = 21155.13psf
e =0.943
B' =1ft
sigma =620psf
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	Y
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:	Oft
	Slope Toe Offset:	0.0ft	Leveling Pad Width:	5.92ft
	Vert δ on Single Dpth			
FAG	CTORS OF SAFETY (Sta	atic / Seismic)		
	Sliding:	1.50 / 1.125	Overturning:	1.50 / 1.125
	Bearing:	2.00 / 1.5		



RESULTS (Static / Seismic)	
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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(IvI 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 = 358ppfPa_h (Force H) = Pa cos(δ - batter) = $358 \times cos(22.7 - (0.0)) = 330ppf$ 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: $kp = (1 + sin(\phi)) / (1 - sin(\phi))$	kp =4.60

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

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.

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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

LOADS FOR OVERTURNING ABOUT THE TOE

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

Pq_h: horizontal surcharge pressure

Pa_v: vertical earth pressure Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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)) Force at top of resisting trapezoid, d1 = 0.50 Force at base of resisting trapezoid, d2 = 1.00 Depth of trapezoid Pp = (Fp1 + Fp2) / 2 * depth	kp = 4.60 Fp1 = 310.43 Fp2 = 620.85 depth = 0.50 232.82
Friction angle = minimum of the leveling pad or Fnd N1 includes N + leveling pad (LP) Where: LP = IvI pad thickness * 135pcf * (L + IvI pad thickness) L is the base block width	φ =40.00 deg
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
FSsI = (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-Ibs
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 = $\pm W(1 \pm W(2 \pm Pay) \pm Pay$	
+ 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 Horizontal Acceleration [kh = A/2] Vertical Acceleration	A =0.600 kh =0.297 kv =0.000
INERTIA FORCES OF THE STRUCTURE Face (Pif) = (W1)*kb(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')*Ngwhere: Nc = 75.31 Nq = 64.20 Ng =109.41 c = 0.00psf q = 135.00psf

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

UltraWall

Project: Location:	Park Royal Apartments 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	Y
Retained Soil:	34 deg	0psf	125pcf
Foundation Soil:	40 deg	0psf	135pcf
Leveling Pad:	40 deg	0psf	135pcf

Crushed Stone



25

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			
FAG	CTORS OF SAFETY (Sta	atic / Seismic)		
	Sliding:	1.50 / 1.125	Overturning:	1.50 / 1.1
	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(IvI 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							
3lock Weight (Force v (Block Wt + Infill Soil)) = 4230ppf X-Arm = 2.21ft								
Soils Block Weight (Fo	prce v) = 574ppf	X-Arm = 3.69ft						
Active Earth Pressure Pa_h (Force H) =	Pa = 724ppf Pa cos(δ - batter) = 724 x cos(22	2.7 - (0.0)) = 668ppf						
Y-Arm = 2.42f	t							
Pa_v (Force V) = X-Arm = 4.921	Pa sin(δ - batter) = 724 x sin(22. τ	7 - (0.0)) = 279ppf						
Live Load Pq = 49ppf								
Pq_h (Force H) = Y-Arm = 3.63f	Pq $cos(\delta - batter) = 49 x cos(22)$ t	.7 - 0.0) = 45ppf						
Pq_v (Force V) = X-Arm = 4.921	Pq sin(δ - batter) = 49 x sin(22.7 t	7 - 0.0) = 19ppf						
Dead Load Pod = 494	ppf							
Pqd_h (Force H) = Y-Arm = 2.37f	- Pqd cos(δ - batter) = 494 x cos(t	(22.7 - (0.0)) = 456ppf						
Pqd_v (Force V) = X-Arm = 4.921	፡ Pqd sin(δ - batter) = 494 x sin((τ	0.0 + 22.7) = 190ppf						

4

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: $kp = (1 + sin(\phi)) / (1 - sin(\phi))$	kp =4.60

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

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.

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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

LOADS FOR OVERTURNING ABOUT THE TOE

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

Pq_h: horizontal surcharge pressure

Pa_v: vertical earth pressure Pq_v: vertical surcharge pressure

BEARING LOADS: NCMA

Name	Factor y	Force (V)	Force (H)	X-len	Y-len	Мо	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)) Force at top of resisting trapezoid, d1 = 0.50 Force at base of resisting trapezoid, d2 = 1.00 Depth of trapezoid Pp = (Fp1 + Fp2) / 2 * depth	kp = 4.60 Fp1 = 310.43 Fp2 = 620.85 depth = 0.50 232.82
Friction angle = minimum of the leveling pad or Fnd N1 includes N + leveling pad (LP) Where: LP = IvI pad thickness * 135pcf * (L + IvI pad thickness) L is the base block width	φ =40.00 deg
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
FSsI = (Rf / Df) and (Rf1 / Df)	FSsI =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 + Pgv + Pgdv	
+ 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 + Ivlpad = 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 Horizontal Acceleration [kh = A/2] Vertical Acceleration	A =0.600 kh =0.297 kv =0.000
INERTIA FORCES OF THE STRUCTURE Face (Pif) = (W1)*kh(ext) = 4230.38 *0.297	Pif =1256.09ppf
SEISMIC THRUST Kae D_Kae = Kae - Ka = (0.498 - 0.220) Pae = 0.5^{*} gamma [*] (H) ^A 2 [*] D_Kae Pae_h = Pae [*] cos(δ) Pae_v = Pae [*] sin(δ)	Kae =0.498 D_Kae =0.277 Pae =911.19ppf Pae_h =840.81ppf 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')*Ngwhere: Nc = 75.31 Nq = 64.20 Ng =109.41 c = 0.00psf q = 135.00psf

Qult = 39058.54psf
e =1.970
B' =1ft
sigma =1300psf
FoS =30