Client: Commonwealth Edison

Calculation No. C-003

Title: HCLPF for Quad Cities Block Walls

Project: Quad Cities USI A-46 and IPEEE

Method: Appendix A of NP-6041

Acceptance Criteria: ACI 531-1979

Remarks:

REVISIONS

No.	Description	By	Date	Chk.	Date	App.	Date
0	Original Issue	Mingsong Li	11/2/96	WD	11/2/96	WD	11/2/96

S&A
Stevenson & Associates

CALCULATION COVER SHEET

FIGURE 1.3

CONTRACT NO.

93C2806.03

Introduction

This calculation documents the seismic screening spreadsheet for the two block walls in the Quad Cities Station part of the IPEEE evaluation. They are the Main Floor Partial Walls of Turbine Building and the Floor Partial Walls of 125 VDC Distribution Panel.

The basis of preliminary screening is to consider the block walls as a two-way slab or a one-way slab spent vertically. Reference 3 shows the details of screening basis and is attached in Appendix A.

In conclusion, the two masonry block walls in this calculation have been qualified to levels in excess of the RLE in-structure demand and may be screened out at the 0.3g, PGA HCLPF level.

References

1. Sargent & Lundy, Block Wall Capacities, Calculation 5570-31-TB-04, October, 1983.
2. Quad Cities Drawings of Turbine Building Main Floor Partial Walls, Drwgs. No. F-170, Rev. D, B-1772, Rev. G and B-1775, Rev. E.
3. S&A, "Block Wall Screening Spreadsheet", Cal. No. 95C2873-C001, Rev. 0, August 1995.
4. Jack R. Benjamin & Associates, et. al., A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Rev 1), EPRI NP-6041-SL, August 1991.
5. American Concrete Institute, ACI 531-1979 - ACI Manual of Building Code Requirements for Masonry Structures
6. Sargent & Lundy, "In-Structure Seismic Response Spectra for SMA Commonwealth Edison Company Quad Cities Nuclear Power Station Units 2 & 3, Quad Cities Nuclear Power Station, Units 1 & 2" , Project No. 09630-016, Report SL-8.11.6-2, Rev. 0, May, 1995
7. Robert Blevins, "Formulas for Natural Frequency and Mode Shape", 1979.

Block Wall Preliminary Screening Based on S&A Calculation 95C2873-C001:			
Wall Name:	125 VDC Distribution Panel - Block Wall Separation		
Reference Calculation:	S&L, Calc. No. 5570-31-TB04, pages 7 to 9		
User Input:			Remark
Height (H)	12.5	ft	Total unsupported height of block wall
Span (W)	15	ft	Unsupported horizontal span
Weight (q)	80	lb/ft^2	
Nominal Depth	8	in	
Sa Top	1.923	g	Top spectral acceleration
Sa Bottom	1.254	g	Bottom spectral acceleration
Sa	1.5885	g	Average spectral acceleration (5% damping)
Constant Fields:			
Cover Thickness	1.5	in	
Poisson's Ratio	0.2		
f'm	1270	psi	Mortar compressive strength
fy	60000	psi	Steel yield strength
Steel Area (As)	0.0375	in^2/in	#7 bar @ 16"
PGA	0.3	g	Peak Ground Acceleration for FRS
Em	952500	psi	750 * f'm
Es	29000000	psi	
n	30.45		
Calculated Fields:			
Actual Depth (D)	7.625	in	3/8" less than nominal
d	3.8125	in	
Ig	28.14	in^4/in	Section moment of inertia
Sg	7.38	in^3/in	Section modulus
fT	89.09	psi	Flexural strength
Mcr	0.66	k-in/in	Cracking moment
x	2.02	in	
It	6.42	in^4/in	
Ie	6.45	in^4/in	
Frequency (f)	7.89	Hz	Fundamental frequency
a	2.084	in	
Mv	5.61	k-in/in	
Mh	0.87	k-in/in	
Beta1	0.0411		Moment coefficient
My	1.18	k-in/in	Maximum vertical moment
Beta	0.0311		Moment coefficient
Mx	0.89	k-in/in	Maximum horizontal moment
HCLPF	0.295	g	

Block Wall Preliminary Screening capacity based on one way slab spanned vertically			
Continuation on Wall:	125 VDC Distribution Panel - Block Wall Separation		
			Remark
L	150.0	in	
Weight (q)	0.556	lb/in^2	
Mv	5.61	k-in/in	Vertical Moment Capacity
Shear Capacity	0.14	k/in	2 rows of 3/8" CEA @2'-3" c.c. staggered
Calculated Fields:			
Frequency	4.56	Hz	Fundamental frequency
Sa	1.275	g	Average spectral acceleration (5% damping and 10% uncertainty)
My	1.99	k-in/in	Maximum vertical moment
Shear	0.05	k/in	@ top and bottom of wall
HCLPF of My	0.845	g	
HCLPF of shear	0.782	g	
HCLPF	0.782	g	

Block Wall Preliminary Screening Based on S&A Calculation 95C2873-C001:			
Wall Name:	Turbine Building Main Floor Partial Walls		
Reference Drwgs:	F-170, Rev. D, B-1772, Rev. G and B-1775, Rev. E		
User Input:			Remark
Height (H)	20	ft	Total unsupported height of block wall
Span (W)	30	ft	Unsupported horizontal span
Weight (q)	100	lb/ft^2	Weight per unit area (assume 2/3 grouted and density = 125 pcf) = 50.7+2/3*(121.1-50.7) = 98 psf
Nominal Depth	12	in	
Sa Top	1.07	g	Top spectral acceleration
Sa Bottom	1.07	g	Bottom spectral acceleration
Sa	1.07	g	Average spectral acceleration (5% damping)
Constant Fields:			
Cover Thickness	1.5	in	
Poisson's Ratio	0.2		
f'm	1350	psi	Mortar compressive strength
fy	60000	psi	Steel yield strength
Steel Area (As)	0.0375	in^2/in	#7 bar @ 16"
PGA	0.3	g	Peak Ground Acceleration for FRS
Em	1012500	psi	750 * f'm
Es	29000000	psi	
n	28.64		
Calculated Fields:			
Actual Depth (D)	11.625	in	3/8" less than nominal
d	5.8125	in	
Ig	76.89	in^4/in	Section moment of inertia
Sg	13.23	in^3/in	Section modulus
fT	91.86	psi	Flexural strength
Mcr	1.22	k-in/in	Cracking moment
x	2.62	in	
It	16.94	in^4/in	
Ie	17.06	in^4/in	
Frequency (f)	3.94	Hz	Fundamental frequency
a	1.961	in	
Mv	9.79	k-in/in	
Mh	1.62	k-in/in	
Beta1	0.0348		Moment coefficient
My	3.35	k-in/in	Maximum vertical moment
Beta	0.0189		Moment coefficient
Mx	1.82	k-in/in	Maximum horizontal moment
HCLPF	0.266	g	

Block Wall Preliminary Screening capacity based on one way slab spanned vertically			
Continuation on Wall:	Turbine Building Main Floor Partial Walls		
			Remark
L	240.0	in	
Weight (q)	0.694	lb/in^2	
Mv	9.79	k-in/in	Vertical Moment Capacity
Shear Capacity	0.42	k/in	2 rows of 3/8" CEA @ 9" c.c.
Calculated Fields:			
Frequency	2.67	Hz	Fundamental frequency
Sa	0.864	g	Spectral acceleration (5% damping)
My	4.32	k-in/in	Maximum vertical moment
Shear	0.07	k/in	@ top and bottom of wall
HCLPF of My	0.680	g	
HCLPF of shear	1.731	g	
HCLPF	0.680	g	

ATTACHMENT C
"HCLPF for Quad Cities Block Walls"
Calculation 93C2806.03
Revision 0
SVP-98-286

Appendix A: S&A, "Block Wall Screening Spreadsheet", Cal. No. 95C2873-C001, Rev. 0, August 1995.

Background

This calculation documents the seismic screening spreadsheet for the block walls in the Nine Mile Point 1 stationas part of the IPEEE evaluation. Page 1 of the spreadsheet provides the basis for preliminary screening. If the block walls do not pass the preliminary screening, page 2 can be used which allows the wall to drift during an earthquake.

The block walls in NMP1 are typically made of 8" and 12" hollow blocks reinforced by #4 bars @32" [4]. The reinforced cell is filled with concrete. Wall bottom is reinforced with existing dowels @ 16" spacing. The walls are reinforced horizontally by Dur-O-Wall, or 3/16" deformed side rods at 16" spacing [4]. The sides of the walls are tied in to precast concrete with two 1/4" threaded rods into inserts.

The walls are considered well anchored at the ends. In the pre-screening, only the out-of-plane bending moment at the center of the wall is checked. The in-plane loading is neglected. The slight beneficial effect due to the gravity is also ignored.

Solution Methodology

The solution is mainly based on EPRI NP-6041 [1] Appendix R without taking advantage of the permissible drift. In addition to the methodology of [1], two-way plate action is considered in both the frequency estimation and the maximum moment estimation.

Elastic Frequency

Instead using the formula in [1], the two-way rectangular plate frequency formular from [3], p. 258 will be used. The wall is assumed to be simply-supported on all four sides,

$$f = \frac{\lambda^2}{2\pi W^2}\sqrt{\frac{E_m I_e g}{q(1-\nu^2)}}$$

where

$$\lambda^2 = \pi^2\left[1+\left(\frac{W}{H}\right)^2\right]$$

W = Width of the wall
H = Height of the wall
q = Weight per unit wall area
ν = Poisson's ratio
E_m = elastic modulus of masonry $\approx 750\ f_m'$ (psi)
I_e = Effective moment of inertia

$$= I_T + \left(\frac{M_{CR}}{M_{CDFM}}\right)^3 \left(I_g - I_T\right) \le I_g$$

I_g = Gross moment of inertia
I_T = Cracked section transformed moment of inertia

M_{CR} = Cracking moment = $f_T S_g$
f_T = Cracking tension in flexure $\approx 2.5\sqrt{f'_m}$ (psi)
S_g = Gross section modulus = $2I_g / D$

Since the walls are hollow, it is grouted only at the reinforcement, the moment of inertia will calculated using the concrete block cover only.

$$I_g = bt(D-t)^2/2$$

where b = unt width of the wall, and t = thickness of cover. For the cracked section, the location of the neutral axis from the compression face can be estimated by solving

$$x\left(\frac{x}{2}\right) - nA_s(d-x) = 0$$

where

$$n = \frac{E_s}{E_m}$$

E_S = elastic modulus for rebars

assuming x does not exceed t, the cracked section moment of inertia

$$I_T = \frac{bx^3}{3} + nA_s(d-x)^2$$

<u>Vertical Moment Capacity</u>

$$M_V = 0.9\,M_U = 0.9\,A_s f_y\left[d - \frac{a}{2}\right]$$

where

A_S = steel area per unit width
f_y = yield strength of rebar
d = depth from the compressive face to the center of steel = $D/2$
D = Depth of wall

$$a = \frac{A_s f_y}{0.85 f'_m}$$

f'_m = specified compressive strength of masonry (psi)

The vertical moment capacity is defined as the larger of the M_V or the cracking moment M_{CR} defined in the previous section.

Horizontal Moment Capacity

Since the Dur-O-Wall horizontal reinforcement has only 0.028 in^2 every 16", in addition the splice is only 6", which will not be able to sustain the yield strength of the bars, the bending in the horizontal direction will be governed by the cracking moment of the blocks.

According to [7], Table 6.3.1.1, the allowable flexural tension parallel to bed joint is at least 133% of the tensile strength when stressed normal to bed joints.

$$M_H = 1.33 M_{CR}$$

Maximum Moment

The maximum moment in the wall will be determined by the close form solutions presented in [2], Section 30, pp. 113-119 assuming all edges of the wall are simply-supported. The maximum moment occurs at the center of the wall

$$(M_x)_{y=0} = \frac{qx(W-x)}{2} - qW^2\pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2\nu B_m - (1-\nu)A_m\right]\sin\frac{m\pi x}{W}$$

$$(M_y)_{y=0} = \nu\frac{qx(W-x)}{2} - qW^2\pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2B_m + (1-\nu)A_m\right]\sin\frac{m\pi x}{W}$$

$$\begin{aligned}(M_x)_{max} = (M_x)_{y=0,x=W/2} &= \frac{qW^2}{8} - qW^2\pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2\nu B_m - (1-\nu)A_m\right]\sin\frac{m\pi}{2} \\ &= \left(\frac{1}{8} - \pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2\nu B_m - (1-\nu)A_m\right]\sin\frac{m\pi}{2}\right)qW^2 \\ &= \beta q W^2\end{aligned}$$

$$\begin{aligned}(M_y)_{max} = (M_y)_{y=0,x=W/2} &= \nu\frac{qW^2}{8} - qW^2\pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2B_m + (1-\nu)A_m\right]\sin\frac{m\pi}{2} \\ &= \left(\frac{\nu}{8} - \pi^2 \sum_{m=1,3,5,\ldots}^{\infty} m^2\left[2B_m + (1-\nu)A_m\right]\sin\frac{m\pi}{2}\right)qW^2 \\ &= \beta_1 q W^2\end{aligned}$$

where

$$A_m = -\frac{2(\alpha_m \tanh\alpha_m + 2)}{\pi^5 m^5 \cosh\alpha_m}$$

$$B_m = \frac{2}{\pi^5 m^5 \cosh\alpha_m}$$

Spectral Acceleration

The spectral acceleration will be extracted from the corresponding Floor Response Spectrum at the bottom and the top of the block wall. The average of the top and bottom acceleration will be used in the spreadsheet.

HCLPF

The *HCLPF* will be estimated by the minimum of

$$HCLPF_V = \frac{(M_y)_{max}}{M_V}(PGA)$$

and

$$HCLPF_H = \frac{(M_x)_{max}}{M_H}(PGA)$$

Pre-Screening Implementation

The above procedure is implemented in an Excel spreadsheet, BWSCREEN.XLS, sheet BLOCK.

Block Wall Compression Strength f_m'

Based on test results in Ref. [5] and [6], the average compressive strength is 2,920 psi with a standard deviation of 400 psi. Following the guideline of [1], the SMA strength capacity for non-ductile materials should be set the 99% level, therefore, it is recommended that

$$f_m' = 2{,}920 - 2.3 * 400 = 2{,}000 \text{ psi}$$

Weight

Lacking detailed information, the following weight may be used [8] for hollow walls

Wall thickness	Unit Weight
6"	43 lb/ft^2
8"	55
12"	80

Any attached weight on the wall, including electrical boxes, conduits, etc. should be added to the total weight.

Response Spectra Damping
When retrieving spectral values, 7% damping similar to reinforced concrete structures may be used for the preliminary screening.

HCLPF Based on NP-6041, Appendix R

Alternative to the above elastic solution, the following calculation allowing the block wall to drift based on Appendix R of [1] is presented in a spreadsheet.

Based on the above parameters, the CDFM permissible drift limit is determined by

$$\left(\frac{\Delta_u}{H}\right)_{CDFM} = \frac{0.005}{c/d} F_c \leq 0.04$$

where

$$F_c = \frac{H/d}{30} \leq 1.0$$

Seismic Capacity
Based on Ref. [1], for a simply supported uniformly loaded non-load bearing masonry wall, the seismic spectral acceleration capacity is

$$\frac{S_{A_C}}{g} = \left\{\frac{8M_{CDFM}}{qH^2} - 4\left(\frac{\Delta_u}{H}\right)\right\}$$

Secant Frequency
In determining the seismic demand using the equivalent linear elastic procedure, an effective frequency is required. According to Ref. [1], the secant frequency corresponding to an ultimate nonlinear displacement Δ_u is

$$f_s = \frac{1}{2\pi}\sqrt{\frac{1.5S_{A_C}}{\Delta_u}}$$

The effective nonlinear seismic demand can be approximated by treating the walls as pseudo-elastic with an effective frequency equals f_S and effective damping β_e at about 6% [1]. Therefore

$$S_{A_D} = S_A(f_s,\ 6\%)$$

The scale factor to be applied to a reference input spectrum is

$$F_{S_I} = \frac{S_{A_C}}{S_{A_{DR}}}$$

The HCLPF can then be obtained by

$$\text{HCLPF} = F_{S_I}\,(\text{PGA})$$

The computation has been implemented in the spreadsheet file BWSCREEN.XLS, sheet DRIFT.

Note that the elastic frequency is lower than that of the pre-screening spreadsheet, because Appendix R of NP-6041 assumes the wall to span one way vertically while in the pre-screening, two-way action is used. The final HCLPF is the maximum within the drift limits in the sheet. In some cases with large drift, the seismic capacity may turn negative. These limiting cases should be ignored.

References

1. EPRI NP-6041, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," Revision 1, Final Report, August 1991.

2. Tomoshenko and Woinowsky-Krieger, "Theory of Plate and Shells," 2nd Edition, McGraw-Hill, 1959.

3. Blevins, "Formulas for Natural Frequency and Mode Shape," Van Nostrand Reinhold, 1979.

4. 1P1 Drawing C-18801-C, Rev. 6, Turbine Building Battery Board Room at El. 261'-1", Plane Sections and De. ls.

5. NMP1 Calculation S6-IE8011-MWR1, Masonry Wall Ref. 1. 1987.

6. NMP1 Calculation S6-IE8011-MW, Masonry Walls, 1987.

7. ACI 530-92/ASCE 5-92/TMS 402-92, Building Code Requirements for Masonry Structures, 1992.

8. AISC, Steel Construction Manual, 8th Edition.

Block Wall Preliminary Screnning Based on S&A Calculation 95C2873-C001:

Wall Name:	Diesel Generator Area Block Wall #29 (Example)		
User Input:			Remark
Height (H)	36.8	ft	Total unsupported height of block wall
Span (W)	40	ft	Unsupported horizontal span
Weight (q)	79	lb/ft^2	Weight per unit area
Nominal Depth	12	in	
Sa Top	0.41	g	Top spectral acceleration
Sa Bottom	0.36	g	Bottom spectral acceleration
Sa	0.385	g	Average spectral acceleration (7% damping)
Constant Fields:			
Cover Thickness	1.25	in	
Poisson's Ratio	0.15		
f'm	2000	psi	Mortar compressive strength
fy	40000	psi	Steel yield strength
Steel Area (As)	0.00625	in^2/in	#4 bar @ 32"
PGA	0.13	g	Peak Ground Accleration for FRS
Em	1500000	psi	750 * f'm
Es	29000000	psi	
n	19.33		
Calculated Fields:			
Actual Depth (D)	11.625	in	3/8" less than nominal
d	5.8125	in	
Ig	67.28	in^4/in	Section moment of inertia
Sg	11.57	in^3/in	Section modulus
fT	111.80	psi	Flexural strength
Mcr	1.29	k-in/in	Cracking coment
x	1.07	in	
It	3.13	in^4/in	
Ie	67.28	in^4/in	
Frequency (f)	4.01	Hz	Fundamental frequency
a	0.147	in	
Mv	1.29	k-in/in	
Mh	1.72	k-in/in	
Beta1	0.0416		Moment coefficient
My	2.02	k-in/in	Maximum horizontal moment
Beta	0.0361		Moment coefficient
Mx	1.76	k-in/in	Maximum vertical moment
HCLPF	0.083	g	

S&A	JOB NO. 95C2873-C001 SUBJECT NMP1 IPEEE	SHEET # 9 OF 9
STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	Block Wall Screening Spreadsheet	Revision By TMT 7/26/95 Chk. MSL 8/23/95

Drift Calculation Based on EPRI NP-6041, Appendix R						
Cotinuation on Wall:	Diesel Generator Area Block Wall #29 (Example)					
As	0.00625	in^2				
d	5.81	in				
ρ	0.00108					
a	0.147	in				
c	0.173	in				
c/d	0.030					
L	441.6	in				
F_c	1		NP-6041 Eq. R-14			
Δ_u / L	0.040		NP-6041 Eq. R-15			
Δ_u	17.66	in	CDFM Permissible Drift Limit			
W	0.549	lb/in^2				
$M_{P\Delta}$	2.14	k-in/in				
M_{CDFM}	1.29	k-in/in				
Drift Ratio	Drift	Frequency	Reference Demand	Capacity	Scale Factor	HCPLF
Δ_u / L	Δ_u (in)	f (Hz)	S_{ADR} (g)	S_{AC} (g)	F_{SI}	g
Elastic	0.00	2.158	0.281	0.097	0.34	0.045
0.005	2.21	0.713	0.092	0.077	0.84	0.109
0.01	4.42	0.434	0.057	0.057	0.99	0.129
0.02	8.83	0.166	0.025	0.017	0.68	0.088
0.03	13.25	#NUM!		-0.023	#DIV/0!	
0.04	17.66	#NUM!		-0.063	#DIV/0!	
HCLPF	0.129	g				