BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA:QA
2. Page 1

3. System	4. Document Identifier
Wet Handling Facility (WHF)	050-SYC-WH00-00400-000-00A

5. Title
WHF Pool Sloshing Evaluation

6. Group
Civil/Structural/ Architectural

7. Document Status Designation
☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

Disclaimer:
The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

Attachments	Total Number of Pages
ATTACHMENT A – FIGURES SHOWING THE SPENT FUEL POOL GEOMETRY	4

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial Issue	32	A4	John R. Bisset 02/23/2007	Sushil J. Kothari 02/23/2007	Michael S. Ruben 2/23/07	Raj Rajagopal 2/26/07

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FIGURES

TABLES

1. PURPOSE

The purpose of this calculation is to evaluate sloshing of water due to seismic events in the spent fuel pool of the Waste Handling Facility (WHF). This will include a determination of the water pressures that may act on the pool walls as a result of a seismic event and a determination of the amount of freeboard required to prevent spilling of spent fuel pool water on the WHF pool area floor during a seismic event.

2. REFERENCES

2.1 PROCEDURES/DIRECTIVES

2.1.1 BSC 2006. EG-DSK-3013, Rev. 0, *Using Calctrac.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20060130.0001.

2.1.2 BSC 2007. EG-PRO-3DP-G04B-00037, Rev. 07. *Calculations and Analyses.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG. 20070122.0010.

2.1.3 BSC 2006. IT-PRO-0011, Rev. 3. *Software Management.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20061221.0003.

2.1.4 BSC 2006. QA-DIR-10, Rev. 0. *Quality Management Directive.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20060906.0001. DIRS: 177655

2.1.5 ORD (Office of Repository Development) 2006. *Repository Project Management Automation Plan.* 000-PLN-MGR0-00200-000, Rev. 00D. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: ENG.20060703.0001.

2.2 DESIGN INPUTS

2.2.1 ACI 349-01. 2001. *Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-01).* Farmington Hills, Michigan: American Concrete Institute. TIC: 252732. DIRS: 158833

2.2.2 ACI 350.3/350.3R-1. 2001. *ACI 350.3, Seismic Design of Liquid-Containing Concrete Structures (ACI 350.3-01) and Commentary (350.3R-01)* [ACI 350.3-01/350.3R-01]. Farmington Hills, MI: American Concrete Institute (ACI). TIC 258510. DIRS: 177384

2.2.3 ASCE 4-98. 2000. *Seismic Analysis of Safety-Related Nuclear Structures and Commentary.* Reston, Virginia: American Society of Civil Engineers. TIC: 253158. DIRS: 159618

2.2.4 BSC (Bechtel SAIC Company) 2006. *Basis of Design for the TAD Canister-Based Repository Design Concept,* 000-3DR-MGR0-00300-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20061023.0002.

2.2.5 BSC 2006. *Project Design Criteria Document.* 000-3DR-MGR0-00100-000 REV 006. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20061201.0005.

2.2.6 MO0411SDSTMHIS.006. Seismic Design Spectra and Time Histories for the Surface Facilities Area (Point D/E) at 5E-4 Annual Exceedance Frequency. Submittal date: 11/16/2004. DIRS: 172426

2.2.7 MO0411WHBDE104.003. Seismic Design Spectra and Time Histories for the Surface Facilities Area (Point D/E) at 10-4 Annual Exceedance Frequency. Submittal date: 11/16/2004. DIRS: 172427

2.2.8 Biggs, J.M. 1964. *Introduction to Structural Dynamics*. New York, New York: McGraw-Hill. TIC: 240633. DIRS: 168427

2.2.9 ICC (International Code Council) 2003. *International Building Code 2000, with Errata to the 2000 International Building Code.* Falls Church, Virginia: International Code Council. TIC: 251054, 257198. DIRS 173525.

2.2.10 BSC 2006. *Seismic Analysis and Design Approach Document.* 000-30R-MGR0-02000-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20061214.0008.

2.2.11 BSC (Bechtel SAIC Company) 2007. *IED Seismic Data.* 800-IED-MGR0-00701-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070216.0003. DIRS 179278.

2.2.12 Gentry, C.A. and Sherman, W.C. 2006. *ACI One-Day Seminar, Seismic Design of Liquid - Containing Concrete Structures, Salt Lake City, Utah, May 24, 2006.* Farmington Hills, Michigan: American Concrete Institute. TIC: 259112. DIRS 179037.

2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

2.4.1 BSC, *Wet Handling Facility Subgrade Structure.* 050-SYC-WH00-00500-000-00A. Las Vegas, Nevada: Bechtel SAIC Company.

The results of this calculation may also be used in other future structural calculations associated with the design of the WHF pool structure.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 The figures in Attachment A provide the latest layout of the pool area. These are currently assumed as accurate. When committed or confirmed drawings that show the WHF spent fuel area are available, this calculation will be revised, if required.

Rationale: At this early stage of the design process, this is an adequate assumption. Since the figures associated with this calculation and shown in Appendix A are not based on committed or

confirmed drawings, this assumption has been entered into Calctrac (EG-DSK-3013 (ref. 2.1.1)) for tracking purposes as required by EG-PRO-3DP-G04B-00037 (ref. 2.1.2).

3.1.2 The current pool depth and freeboard are assumed acceptable with respect to the Beyond Design Basis Ground Motion (BDBGM).

Rationale: At this early stage of the design process, this is an adequate assumption. Seismic design requirements, as well as the spent fuel pool design are currently under development. Issues such as required freeboard for such very low probability events as the BDBGM are still being evaluated. This assumption has also been entered into Calctrac (EG-DSK-3013 (ref. 2.1.1)) for tracking purposes as required by EG-PRO-3DP-G04B-00037 (ref. 2.1.2).

3.1.3 The determination of the natural periods for the impulsive and convective modes and for the vertical seismic mode are not exact and the actual period can differ from the calculated value. To account for the uncertainties in the structural periods, the periods will be broadened by adjusting them 10% up or down in the direction of ascending accelerations to ensure the accelerations used in the calculations of forces and pressures bound the actual values. In effect the accelerations are assumed to be higher than what would be calculated without the 10% increase in periods.

Rationale: This is a reasonable assumption to ensure design data is conservative. The accelerations used in this calculation will be confirmed when the Tier 2 seismic analyses are complete. This assumption has also been entered into Calctrac (EG-DSK-3013 (ref. 2.1.1)) for tracking purposes as required by EG-PRO-3DP-G04B-00037 (ref. 2.1.2).

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 The pool structure is assumed to be a rigid structure.

Rationale: Given that the walls of the pool structure will be on the order of 8'-0" thick, this is a reasonable assumption. This is consistent with the criteria of Section 3.5.4.3 of ASCE 4-98 (ref. 2.2.3) (see also Section 4.3 below).

3.2.2 In developing the Hydrodynamic Forces due to seismic events, the formulas in ACI 350.3 (ref. 2.2.2) will be altered from what is given in this reference. Importance factors, I, and response modification factors, Rm, are assumed not to be appropriate.

Rationale: The formulas in ACI 350.3 (ref. 2.2.2) are consistent with a design to the seismic requirements of the International Building Code (IBC) (see Section 1615, ref. 2.2.9). The seismic design approach in the IBC is based on a design response spectra with a return period of about 500 years and a damping value of 5% (see Section 6.4.1 of the Seismic Analysis and Design Approach (SADA) document (ref. 2.2.10)). The IBC seismic design philosophy is based primarily on a static equivalent determination of the design seismic forces and includes importance factors, I, to increase the design base shear for important structures, and response modification factors, Rm, to reduce the design loads to account for damping and ductility.

The seismic design approach for ITS structures at the YMP is described in Sections 6.1 through 6.3 of the SADA document (ref. 2.2.10). This approach uses families of response spectra curves for different damping values for two seismic ground motions - one at a return period of 2000 years (Design Basis Ground Motion (DBGM)-2), which is the design basis, and one at a return period of 10000 years (Beyond Design Basis Ground Motion (BDBGM)), a beyond design basis event that is included to assure structural integrity and functionality. The importance of the structures is reflected in the much higher return periods to use for design and, thus, a separate importance factor is not applicable. Also, the WHF structure will be analyzed using dynamic response spectra and time history analyses and will employ various damping values that are appropriate to the structure and type of analysis. These analyses will consider seismic soil structure interaction and other non-linear effects. Thus damping and ductility effects are included in the analyses, a response modification factor, Rm, is, therefore, also not applicable for the design of ITS structures at the YMP. The importance factor, I, and the response modification factor, Rm, are therefore removed from the formulas used from ACI 350.3 (ref. 2.2.2) when used in the calculations herein.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses*, (Reference 2.1.2). The WHF building structure is classified as Important to Safety in Section 5.1.2 of the *Basis of Design for the TAD Canister-Based Repository Design Concept* (ref. 2.2.4). Therefore, this document is subject to the appropriate requirements of the BSC *Quality Management Directive* (ref. 2.1.4, Sections 2.1.C.1.1.a.i, and 17E), and the approved record version is designated as "QA:QA".

4.2 USE OF SOFTWARE

The originator used the following computer programs to prepare this calculation; all the software used resides on a Personal Computer:

TABLE 4-1 – SOFTWARE USAGE

Program[2]	Version	Use	Software Tracking Number
Word[1,4]	Office 2000	Word Processing	003743-E[4]
Mathcad[1,3]	13	Calculations	611161

Notes:

1. Usage of the above software in this calculation constitutes Level 2 software usage as defined in IT-PRO-0011, (ref. 2.1.3). This software is listed in the current Controlled Software Report (see http://connect.ymp.gov/artman/uploads/software_report.pdf), as well as the Repository Project Management Automation Plan (ref. 2.1.5).

2. The software is operated on a PC system using the Windows 2000 operating system.

3. Checking of calculations prepared using Mathcad was done using hand calculations and visual inspection.

4. Word is part of the Office 2000 Professional suite of programs.

4.3 EVALUATION METHODOLGY

Section 5.2.3.1.6, "Structure Seismic Loads," of the *Basis of Design for the TAD Canister-Based Repository Design Concept* (ref. 2.2.4) identifies that the WHF structure shall be designed for loading conditions associated with a Design Basis Ground Motion (DBGM)-2 seismic event. In addition, an analysis shall demonstrate that the WHF structure has sufficient design margin to ensure that a no structural collapse safety function is maintained for loading conditions associated with a Beyond Design Basis Ground Motion (BDBGM) seismic event. Therefore, hydrodynamic forces and pressures due to both the DBGM-2 and the BDBGM are determined in this calculation.

Section 4.2.11.3.11, "Fluid Load, F," of the *Project Design Criteria Document* (ref. 2.2.5) requires that fluid loads include the effects of horizontal sloshing in accordance with Section 3.5.4.3 of ASCE 4-98 (ref. 2.2.3).

Section 3.5.4.3, "Horizontal Sloshing (Convective Mode)," of ASCE 4-98 (ref. 2.2.3) identifies the following criteria that are important to this evaluation:

3.5.4.3.1 Effective weight of fluid - Sloshing mode
The effective fluid weight acting in the horizontal sloshing mode may be determined on the basis of an assumed rigid tank (see Assumption 3.2.1).

3.5.4.3.2 Spectral acceleration - Sloshing mode
In determining the spectral acceleration in the horizontal sloshing mode, the fluid damping shall be taken as *0.5%* of critical damping unless a higher value can be substantiated. The fundamental circular natural frequency in the sloshing mode may be determined on the basis of an assumed rigid tank shell (see Assumption 3.2.1). The horizontal sloshing mode spectral acceleration shall be determined using the sloshing mode fundamental frequency and damping ratio.

3.5.4.3.4 Hydrodynamic pressure on tank shell - Sloshing mode
The hydrodynamic pressure on the tank shell resulting from the horizontal sloshing fluid mode may be determined on the basis of an assumed rigid tank shell (see Assumption 3.2.1).

3.5.4.3.5 Fluid slosh height - Fundamental sloshing mode
The fluid slosh height may be determined based upon the assumption of a rigid tank shell (see Assumption 3.2.1).

The fluid pressures and required freeboard will be determined using the procedures and formulae given in ACI 350.3 (ref. 2.2.2). The software Mathcad is used to perform the calculations. As identified in the Information Exchange Document 800-IED-MGR0-00701-000 (ref. 2.2.11), DTN: MO0411SDSTMHIS.006 is the source of response spectra information for the DBGM-2 (2000 yr. return

period) event, while DTN: MO0411WHBDE104.003 provides the response spectra information for the BDBGM (10000 yr. return period) event.

5. LIST OF ATTACHMENTS

	Number of Pages
Attachment A – Figures Showing Spent Fuel Pool Geometry	4

6.0 BODY OF CALCULATION

6.1 DETERMINATION OF WATER PRESSURES

A water retaining structure will be subjected to a number of loads by the water. These include the hydrostatic pressures, impulsive pressures, convective pressures, and hydrodynamic pressures due to the vertical seismic acceleration. These are illustrated in the figure 6-1 on page 18. Each of the different pressures are determined in subsequent subsections.

6.1.1 Pool Geometry and Total Weight of Stored Water

Pool Geometry:

The figures in Attachment A show the pool to have the following dimensions:

Wall Height = $H_w := 52 \cdot ft$

Design Depth of Stored Liquid = $H_L := 48 \cdot ft$

Length of Pool = $L_P := 75 \cdot ft$

Width of Pool = $B_P := 61 \cdot ft$

Other Parameters:

Weight Density of Water = $\gamma_w := 62.43 \cdot pcf$ See pg. 9 of ACI 350.3 (ref. 2.2.2)

Mass Density of Water = $\rho_w := \frac{\gamma_w}{g}$ $\rho_w = 1.94 \frac{lbf \cdot sec^2}{ft^4}$ See pg. 9 of ACI 350.3 (ref. 2.2.2)

Total Weight of Water = $W_L := H_L \cdot B_P \cdot L_P \cdot \gamma_w$ $W_L = 1.371 \times 10^7 lbf$

6.1.2 Equivalent weights of Accelerated Water and Heights to Centers of Gravity:

a. North South Direction:

Pool Dimension Parallel to Earthquake = $L_a := B_P$ $L_a = 61\ ft$

$LH := \frac{L_a}{H_L}$ $LH = 1.271$

Impulsive Weight of Water = $W_{ia} := \left(\frac{\tanh(0.866 \cdot LH)}{0.866 \cdot LH}\right) \cdot W_L$ Formula 9-1 of ACI 350.3 (ref. 2.2.2)

$W_{ia} = 9.974 \times 10^6$ lbf

$h_{ia} := (0.5 - 0.09375 \cdot LH) \cdot H_L$, $h_{ia} = 18.281$ ft Formula 9-3 of ACI 350.3 (ref. 2.2.2)

Convective Weight of Water = $W_{ca} := 0.264 \cdot LH \cdot \tanh\left(3.16 \cdot LH^{-1}\right) \cdot W_L$ Formula 9-2 of ACI 350.3 (ref. 2.2.2)

$W_{ca} = 4.536 \times 10^6$ lbf

$$h_{ca} := \left[1 - \frac{\cosh\left[3.16 \cdot \left(LH^{-1}\right)\right] - 1}{3.16 \cdot \left(LH^{-1}\right) \cdot \sinh\left[3.16 \cdot \left(LH^{-1}\right)\right]}\right] \cdot H_L \quad , \quad h_{ca} = 31.661 \text{ ft}$$

Formula 9-5 of ACI 350.3 (ref. 2.2.2)

b. East West Direction:

Pool Dimension Parallel to Earthquake: $L_b := L_P$ $L_b = 75$ ft

$LH := \frac{L_b}{H_L}$ $LH = 1.562$

Impulsive Weight of Water = $W_{ib} := \left(\frac{\tanh(0.866 \cdot LH)}{0.866 \cdot LH}\right) \cdot W_L$ Formula 9-1 of ACI 350.3 (ref. 2.2.2)

$W_{ib} = 8.863 \times 10^6$ lbf

$h_{ib} := 0.375 \cdot H_L$ $h_{ib} = 18$ ft Formula 9-4 of ACI 350.3 (ref. 2.2.2)

Convective Weight of Water = $W_{cb} := 0.264 \cdot LH \cdot \tanh\left(3.16 \cdot LH^{-1}\right) \cdot W_L$ Formula 9-2 of ACI 350.3 (ref. 2.2.2)

$W_{cb} = 5.461 \times 10^6$ lbf

$$h_{cb} := \left[1 - \frac{\cosh\left[3.16 \cdot \left(LH^{-1}\right)\right] - 1}{3.16 \cdot \left(LH^{-1}\right) \cdot \sinh\left[3.16 \cdot \left(LH^{-1}\right)\right]}\right] \cdot H_L \quad , \quad h_{cb} = 29.813 \text{ ft}$$

Formula 9-5 of ACI 350.3 (ref. 2.2.2)

6.1.3 Dynamic Properties:

Determination of the dynamic properties pertinent to the calculation of the hydrodynamic forces depends on the concrete wall mass and stiffness. Since the wall design is not complete, mass and stiffness values are determined for three wall thicknesses - 4'-0", 6'-0", and 8'-0":

Mass per unit width of wall:

$$t_w := \begin{pmatrix} 48 \\ 72 \\ 96 \end{pmatrix} \text{ in} \quad w_c := 150 \cdot \text{pcf}$$ Standard Weight of Reinforced Concrete

Mass per unit width of wall = $m_w := H_w \cdot \frac{t_w \cdot ft}{12} \cdot \frac{w_c}{g}$ Section R9.2.4 of ACI 350.3 (ref. 2.2.2)

$$m_w = \begin{pmatrix} 970 \\ 1455 \\ 1939 \end{pmatrix} \frac{1}{ft^2} \text{lbf} \cdot \text{sec}^2$$

Total mass per unit width of wall (concrete mass plus impulsive mass):

Vector of the impulsive water weight = $W_i := \begin{pmatrix} W_{ia} \\ W_{ib} \end{pmatrix} \quad W_i = \begin{pmatrix} 9.974 \times 10^6 \\ 8.863 \times 10^6 \end{pmatrix} \text{lbf}$

$$L := \begin{pmatrix} L_a \\ L_b \end{pmatrix} \quad L = \begin{pmatrix} 61 \\ 75 \end{pmatrix} \text{ft} \quad k := 1..2$$

Mass per unit width of wall = $m_{i_k} := \left(\frac{W_{i_k}}{W_L}\right) \cdot \left(\frac{L_k}{2}\right) \cdot H_L \cdot \rho_w$ Section R9.2.4 of ACI 350.3 (ref. 2.2.2)

$$m_i = \begin{pmatrix} 2067 \\ 2258 \end{pmatrix} \frac{1}{ft} \text{lbf} \cdot \frac{\text{sec}^2}{ft}$$

Stiffness of wall:

Concrete compressive strength that will be used for the WHF = $f_c := 5000 \cdot \text{psi}$ Sect. 4.2.11.6.2 of the PDC (ref. 2.2.5)

Young's modulus for concrete = $E_c := \left(w_c \cdot pcf^{-1}\right)^{1.5} \cdot 33 \cdot \sqrt{f_c \cdot psi^{-1}} \cdot psi$ Section 8.5.1 of ACI 349 (ref. 2.2.1)

$E_c = 4.287 \times 10^6 psi$

Height to centroid of wall = $h_w := \frac{H_w}{2}$ $h_w = 26$ ft

Heights to center of gravity of impulsive forces $h_i := \begin{pmatrix} h_{ia} \\ h_{ib} \end{pmatrix}$ $h_i = \begin{pmatrix} 18.281 \\ 18 \end{pmatrix}$ ft

Weighted average height to centroids of wall and impulsive force = h

$m := 1..3$ $n := 1..2$

$$h_{m,n} := \frac{h_w \cdot m_{w_m} + h_{i_n} \cdot m_{i_n}}{m_{w_m} + m_{i_n}}$$

$$h = \begin{array}{c} \begin{array}{cc} \text{N-S} & \text{E-W} \end{array} \\ \begin{pmatrix} 20.746 & 20.403 \\ 21.47 & 21.134 \\ 22.018 & 21.696 \end{pmatrix} \end{array} ft \quad \begin{array}{l} t_{w_1} = 48 \\ t_{w_2} = 72 \\ t_{w_3} = 96 \end{array}$$

Section R9.2.4 of ACI 350.3 (ref. 2.2.2)

$$k_{m,n} := \frac{\frac{E_c \cdot psi^{-1}}{12} \cdot \left(\frac{t_{w_m} \cdot H_w \cdot ft^{-1}}{h_{m,n} \cdot ft^{-1}}\right)^3}{\left(H_w \cdot ft^{-1} - h_{m,n} \cdot ft^{-1}\right)^2 \cdot \left(4 \cdot H_w \cdot ft^{-1} - h_{m,n} \cdot ft^{-1}\right)} \cdot \frac{lbf}{ft^2}$$

Used stiffness formula for a rectangular tank with a roof to simulate confining effects of the WHF slab at the top of the pool structure; see the formula on page 40 (slide 80) of the Seminar Notes (ref. 2.2.12)

$$k = \begin{array}{c} \begin{array}{cc} \text{N-S} & \text{E-W} \end{array} \\ \begin{pmatrix} 3.401 \times 10^6 & 3.492 \times 10^6 \\ 1.09 \times 10^7 & 1.116 \times 10^7 \\ 2.49 \times 10^7 & 2.543 \times 10^7 \end{pmatrix} \end{array} \frac{lbf}{ft^2} \quad \begin{array}{l} t_{w_1} = 48 \\ t_{w_2} = 72 \\ t_{w_3} = 96 \end{array}$$

Total mass associated with the impulsive mode:

$l := 1..3$ $n := 1..2$

$m_{l,n} := m_{w_l} + m_{i_n}$

$$m = \begin{pmatrix} 3036 & 3228 \\ 3521 & 3713 \\ 4006 & 4197 \end{pmatrix} \frac{1}{ft} lbf \cdot \frac{sec^2}{ft}$$

Formula 9-10 of ACI 350.3 (ref. 2.2.2)

Circular frequency of the impulsive mode:

$$\omega_{i_{l,n}} := \sqrt{\frac{k_{l,n}}{m_{l,n}}} \qquad \omega_i = \begin{pmatrix} 33.468 & 32.892 \\ 55.627 & 54.817 \\ 78.842 & 77.841 \end{pmatrix} \text{Hz}$$

Formula 9-9 of ACI 350.3 (ref. 2.2.2)

Periods of the impulsive mode:

$$T_i := \frac{2\cdot\pi}{\omega_i} \qquad T_i = \begin{array}{c} \begin{array}{cc} \text{N-S} & \text{E-W} \end{array} \\ \begin{pmatrix} 0.188 & 0.191 \\ 0.113 & 0.115 \\ 0.08 & 0.081 \end{pmatrix} \end{array} \text{s} \qquad \begin{array}{l} t_{w_1} = 48 \\ t_{w_2} = 72 \\ t_{w_3} = 96 \end{array}$$

Formula 9-14, ACI 350.3 (ref. 2.2.2)

Circular Frequency of the convective mode:

$$\omega_c = \frac{\lambda}{\sqrt{L}}$$

Formula 9-12 of ACI 350.3 (ref. 2.2.2)

$$\lambda := \sqrt{3.16\cdot g\cdot \tanh\left[3.16\cdot\left(\frac{H_L}{L}\right)\right]} \qquad \lambda = \begin{pmatrix} 10.014 \\ 9.908 \end{pmatrix} \frac{ft^{0.5}}{s}$$

Formula 9-13 of ACI 350.3 (ref. 2.2.2)

$$\omega_c := \frac{\lambda}{\sqrt{L}} \qquad \omega_c = \begin{pmatrix} 1.282 \\ 1.144 \end{pmatrix} \text{Hz}$$

Periods of the convective mode:

$$T_c := \frac{2\cdot\pi}{\omega_c} \qquad T_c = \begin{pmatrix} 4.901 \\ 5.492 \end{pmatrix} \text{s} \qquad \begin{array}{l} \text{N-S} \\ \text{E-W} \end{array}$$

Periods for vertical response spectra:

$$T_v = 2\cdot\pi\cdot\sqrt{\frac{m_v}{kv}}$$

Formula 9-11, ACI 350.3 (ref. 2.2.2)

$$\text{Vertical mass of water} = m_v := \frac{L_P\cdot B_P\cdot H_L\cdot\gamma_w}{g} \qquad m_v = 4.261\times 10^5\,\text{lbf}\cdot\frac{\text{sec}^2}{\text{ft}}$$

Vertical stiffness = $k_v = \dfrac{A_c \cdot E_c}{L}$

(Stiffness of a Column = (Cross-Sectional Area x Young's Modulus)/length) (standard formula)

$j := 1..3$

$$k_{v_j} := \frac{2\cdot\left[L_P + B_P + \frac{(2t_w)_j \cdot ft}{12}\right]\cdot\frac{t_{w_j}\cdot ft}{12}\cdot E_c\cdot psi^{-1}\cdot 144\cdot psf}{H_L} \qquad k_v = \begin{pmatrix} 1.482\times10^{10} \\ 2.284\times10^{10} \\ 3.128\times10^{10} \end{pmatrix}\frac{lbf}{ft}$$

$$T_v := 2\cdot\pi\cdot\sqrt{\frac{m_v}{k_v}} \qquad T_v = \begin{pmatrix} 0.034 \\ 0.027 \\ 0.023 \end{pmatrix} s \qquad \begin{matrix} t_{w_1} = 48 \\ t_{w_2} = 72 \\ t_{w_3} = 96 \end{matrix}$$

Determine the design accelerations based on the site specific response spectra and the above calculated periods. The accelerations are interpolated from DTN: MO0411SDSTMHIS.006 (ref. 2.2.6) for the DBGM-2 event, and DTN: MO0411WHBDE104.003 (ref. 2.2.7) for the BDBGM event. Since the determination of the above periods is not an exact science and the actual period can differ from the calculated value, the periods will be broadened by adjusting them 10% up or down in the direction of increasing accelerations to ensure the maximum applicable acceleration is determined. See assumption 3.1.3

The accelerations are determined by interpolation as follows:

$A_i = A_1 + (A_2 - A_1)((T_1 - \beta T_i)/(T_1 - T_2))$ if the response spectra curve is descending, or

$A_i = A_1 - (A_1 - A_2)((T_1 - \beta T_i)/(T_1 - T_2))$ if the response spectra curve is ascending.

Where:

A_i = Acceleration corresponding to the natural period T_i

A_1 = Acceleration corresponding to the period T_1

A_2 = Acceleration corresponding to the period T_2

T_i = Natural period of interest of spent fuel pool structure

T_1 = First period from the tables of the above referenced DTN's that is greater than βT_i

T_2 = Period from the tables of the above referenced DTNs that preceeds T_1 and thus, with T_1, brackets βT_i

β = Broadening factor as discussed above; = 0.9 if the response spectra curve is descending; = 1.1 if the response spectra curve is ascending

Impulsive mode accelerations in g's (based on 5% damping results per Section R4.2.2 of ACI 350.3 (ref. 2.2.2)):

DBGM-2 (2000 yr. return period) Seismic Event:

$$A_{i_{1,1}} := 1.1779 + (1.2106 - 1.1779)\cdot\left(\frac{0.201 - 0.9\cdot 0.188}{0.201 - 0.167}\right) \quad A_{i_{1,1}} = 1.208 \quad \text{NS, } t_w = 48''$$

$$A_{i_{1,2}} := 1.1779 + (1.2106 - 1.1779)\cdot\left(\frac{0.201 - 0.9\cdot 0.191}{0.201 - 0.167}\right) \quad A_{i_{1,2}} = 1.2059 \quad \text{EW, } t_w = 48''$$

$$A_{i_{2,1}} := 1.2453 + (1.2453 - 1.2512)\cdot\left(\frac{0.110 - 0.9\cdot 0.113}{0.110 - 0.100}\right) \quad A_{i_{2,1}} = 1.2404 \quad \text{NS, } t_w = 72''$$

$$A_{i_{2,2}} := 1.2453 + (1.2453 - 1.2512)\cdot\left(\frac{0.110 - 0.9\cdot 0.115}{0.110 - 0.100}\right) \quad A_{i_{2,2}} = 1.2415 \quad \text{EW, } t_w = 72''$$

Governs

$$A_{i_{3,1}} := 1.2512 - (1.2512 - 1.0897)\cdot\left(\frac{0.100 - 1.1\cdot 0.080}{0.100 - 0.050}\right) \quad A_{i_{3,1}} = 1.2124 \quad \text{NS, } t_w = 96''$$

$$A_{i_{3,2}} := 1.2512 - (1.2512 - 1.0897)\cdot\left(\frac{0.100 - 1.1\cdot 0.081}{0.100 - 0.050}\right) \quad A_{i_{3,2}} = 1.216 \quad \text{EW, } t_w = 96''$$

BDBGM (10000 yr. return period) Seismic Event:

$$A_{10i_{1,1}} := 2.4746 + (2.4990 - 2.4746)\cdot\left(\frac{0.201 - 0.9\cdot 0.188}{0.201 - 0.167}\right) \quad A_{10i_{1,1}} = 2.497 \quad \text{NS, } t_w = 48''$$

$$A_{10i_{1,2}} := 2.4746 + (2.4990 - 2.4746)\cdot\left(\frac{0.201 - 0.9\cdot 0.191}{0.201 - 0.167}\right) \quad A_{10i_{1,2}} = 2.4955 \quad \text{EW, } t_w = 48''$$

$$A_{10i_{2,1}} := 2.5446 + (2.5548 - 2.5446)\cdot\left(\frac{0.110 - 0.9\cdot 0.113}{0.110 - 0.100}\right) \quad A_{10i_{2,1}} = 2.5531 \quad \text{NS, } t_w = 72''$$

Governs

$$A_{10i_{2,4}} := 2.5446 + (2.5548 - 2.5446)\cdot\left(\frac{0.110 - 0.9\cdot 0.115}{0.110 - 0.100}\right) \quad A_{10i_{2,4}} = 2.5512 \quad \text{EW, } t_w = 72''$$

$$A_{10i_{3,1}} := 2.5548 - (2.5548 - 2.2732)\cdot\left(\frac{0.100 - 1.1\cdot 0.080}{0.100 - 0.050}\right) \quad A_{10i_{3,1}} = 2.4872 \quad \text{NS, } t_w = 96''$$

$$A_{10i_{3,2}} := 2.5548 - (2.5548 - 2.2732)\cdot\left(\frac{0.100 - 1.1\cdot 0.081}{0.100 - 0.050}\right) \quad A_{10i_{3,2}} = 2.493 \quad \text{EW, } t_w = 96''$$

Convective mode accelerations in g's (based on 0.5% damping results per Section R4.2.2 of ACI 350.3 (ref. 2.2.2)):

DBGM-2 (2000 yr. return period) Seismic Event:

$$A_{c_1} := 0.0614 + (0.1215 - 0.0614)\cdot\left(\frac{4.978 - 0.9\cdot 4.901}{4.978 - 3.351}\right) \qquad A_{c_1} = 0.0823 \qquad \text{NS}$$

$$A_{c_2} := 0.0126 + (0.0614 - 0.0126)\cdot\left(\frac{10.000 - 0.9\cdot 5.492}{10.000 - 4.978}\right) \qquad A_{c_2} = 0.0617 \qquad \text{EW}$$

BDBGM (10000 yr. return period) Seismic Event:

$$A_{10c_1} := 0.1813 + (0.3401 - 0.1813)\cdot\left(\frac{4.978 - 0.9\cdot 4.901}{4.978 - 3.351}\right) \qquad A_{10c_1} = 0.2367 \qquad \text{NS}$$

$$A_{10c_2} := 0.0395 + (0.1813 - 0.0395)\cdot\left(\frac{10.000 - 0.9\cdot 5.492}{10.000 - 4.978}\right) \qquad A_{10c_2} = 0.1823 \qquad \text{EW}$$

Vertical mode accelerations in g's (based on 5% damping results per Section R4.2.2 of ACI 350.3 (ref. 2.2.2)):

DBGM-2 (2000 yr. return period) Seismic Event:

$$A_{v_1} := 0.9842 - (0.9842 - 0.8745)\cdot\left(\frac{0.050 - 1.1\cdot 0.034}{0.050 - 0.034}\right) \qquad A_{v_1} = 0.898 \quad t_w = 48'' \quad \text{Governs}$$

$$A_{v_2} := 0.8745 - (0.8745 - 0.7768)\cdot\left(\frac{0.034 - 1.1\cdot 0.027}{0.034 - 0.025}\right) \qquad A_{v_2} = 0.8278 \qquad t_w = 72''$$

$$A_{v_3} := 0.8745 - (0.8745 - 0.7768)\cdot\left(\frac{0.034 - 1.1\cdot 0.023}{0.034 - 0.025}\right) \qquad A_{v_3} = 0.7801 \qquad t_w = 96''$$

BDBGM (10000 yr. return period) Seismic Event:

$$A_{10v_1} := 2.7433 - (2.7433 - 2.4641)\cdot\left(\frac{0.050 - 1.1\cdot 0.034}{0.050 - 0.034}\right) \qquad A_{10v_1} = 2.523 \quad t_w = 48\text{" Governs}$$

$$A_{10v_2} := 2.4641 - (2.4641 - 2.2386)\cdot\left(\frac{0.034 - 1.1\cdot 0.027}{0.034 - 0.025}\right) \qquad A_{10v_2} = 2.3564 \quad t_w = 72\text{"}$$

$$A_{10v_3} := 2.4641 - (2.4641 - 2.2386)\cdot\left(\frac{0.034 - 1.1\cdot 0.023}{0.034 - 0.025}\right) \qquad A_{10v_3} = 2.2461 \quad t_w = 96\text{"}$$

To simplify the design calculations, and since one value is not significantly different from the other values, use the following acceleration values for the impulsive and vertical seismic accelerations:

$$A_i := 1.24 \qquad A_v := 0.90 \qquad A_{10i} := 2.55 \quad A_{10v} := 2.52$$

6.1.4 Hydrostatic and Hydrodynamic Forces and Pressures:

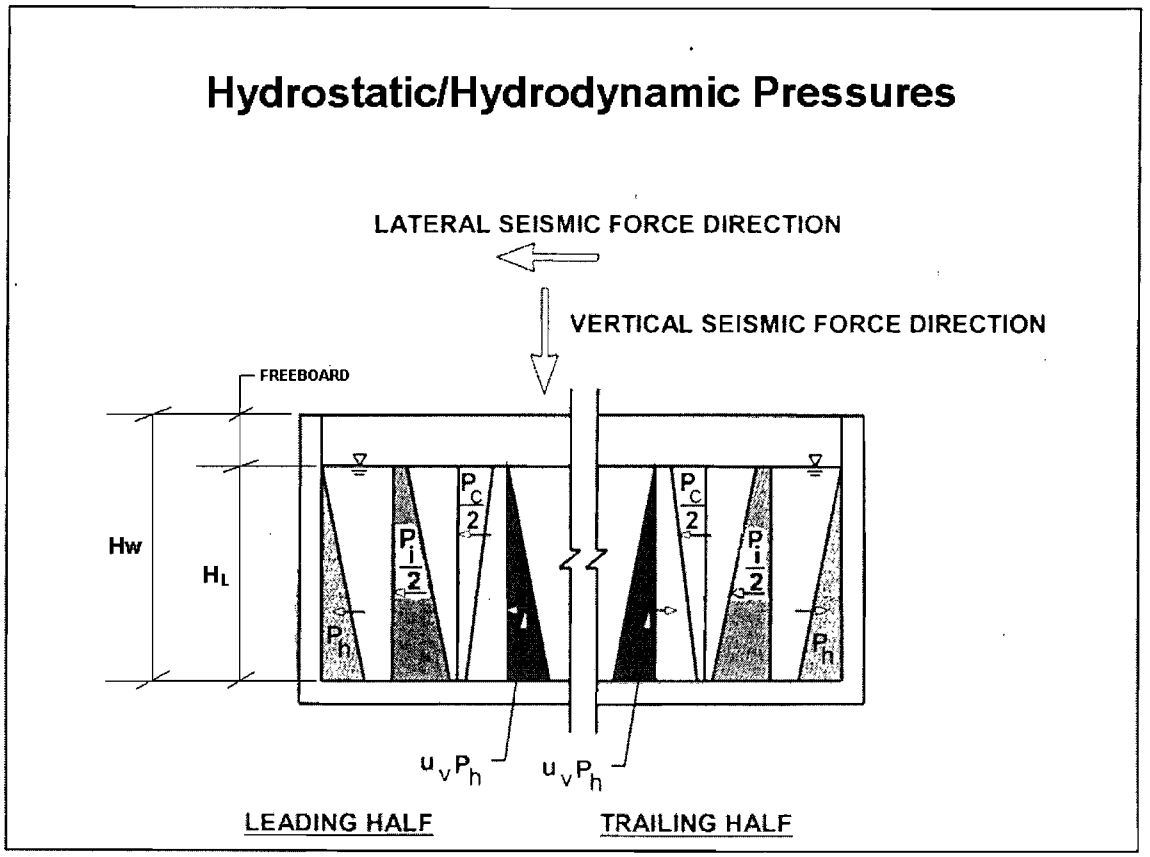


FIGURE 6-1 - WATER PRESSURES
(based on definitions of forces and pressures given in ACI 350.3, ref. 2.2.2; linear approximations of pressure distributions are used; see figures R.5.3 and R5.5 of ACI 350.3)

Where:

P_h = force due to hydrostatic pressure
P_i = impulsive hydrodynamic force
P_c = convective hydrodynamic force
u_vP_h = hydrodynamic force due to vertical seismic acceleration

In developing the Hydrodynamic Forces due to seismic events, the formulas in ACI 350.3 (ref. 2.2.2) will be altered from what is given in this reference. Importance factors and response modification factors will not be used. See Assumption 3.2.2.

Hydrostatic Pressure:

$p_h = \gamma_w \cdot z \quad @\, z = H_L \quad p_h := \gamma_w \cdot H_L \qquad p_h = 2997\,psf$

$P_h := 0.5 \cdot p_h \cdot H_L \quad P_h = 71.9\,klf$ (per ft of width of wall) Acting at $\frac{H_L}{3} = 16$ ft

Hydrodynamic Forces and Pressures:
DBGM-2 (2000 yr. Return Period) Seismic Event:

Impulsive Hydrodynamic Pressure (see formula 4-3 as modified by Section 4.2.2 of ACI 350.3 (ref. 2.2.2) and without I and Rm factors as discussed in Assumption 3.2.2):

North- South Direction:

$P_{ia} := A_i \cdot \frac{W_{ia}}{L_P} \qquad P_{ia} = 164.9 \frac{kip}{ft}$ Acting at $h_{ia} = 18.281$ ft

The impulsive pressure distribution is trapezoidal. The pressure at the top, p_{iat}, and the pressure at the bottom, p_{iab}, are determined by determining the forces and moments at the base due to the pressures and equating these to the forces and moments produced by the above force. One half the total impulsive force is used because the impulsive pressures consist of a pressure acting on the walls of the leading half of the structure and a suction acting on the trailing half of the structure(see figure 6-1). This process is shown below. The same process applies to the convective node pressures.

$\Sigma F = 0$:

$$\frac{P_{ia}}{2} = \left(p_{iat} \cdot H_L\right) + \left(p_{iab} - p_{iat}\right) \cdot \frac{H_L}{2} \qquad \text{Equation 1}$$

Simplifying yields:

$$\frac{P_{ia}}{2} = \left(p_{iat} + p_{iab}\right) \cdot \frac{H_L}{2} \qquad \text{Equation 1a}$$

Transposing yields the following equation for p_{iab}:

$$p_{iab} = \frac{P_{ia}}{H_L} - p_{iat} \qquad \text{Equation 1b}$$

$\Sigma M = 0$:

$$\frac{P_{ia}}{2} \cdot h_{ia} = \left(p_{iat} \cdot \frac{H_L^2}{2}\right) + \left(p_{iab} - p_{iat}\right) \cdot \frac{H_L^2}{6} \qquad \text{Equation 2}$$

Simplifying yields:

$$\frac{P_{ia}}{2}\cdot h_{ia} = \frac{2p_{iat} + p_{iab}}{6}\cdot H_L^{\,2} \qquad \text{Equation 2a}$$

Multiplying equation 1a by $H_L/3$ and subtracting from equation 2a, simplifying and transposing yields the following results for p_{iat}:

$$p_{iat} := \frac{P_{ia}}{2}\cdot\left(\frac{6\cdot h_{ia}}{H_L^{\,2}} - \frac{2}{H_L}\right), \qquad p_{iat} = 490\,\text{psf}$$

Inserting this value into equation 1b gives the following result for p_{iab}:

$$p_{iab} := \frac{P_{ia}}{H_L} - p_{iat} \qquad p_{iab} = 2946\,\text{psf}$$

East- West
Direction:

$$P_{ib} := A_i\cdot\frac{W_{ib}}{B_P} \qquad P_{ib} = 180.2\,\text{klf} \quad \text{Acting at } h_{ib} = 18\ \text{ft}$$

$$p_{ibt} := \frac{P_{ib}}{2}\cdot\left(\frac{6\cdot h_{ib}}{H_L^{\,2}} - \frac{2}{H_L}\right) \qquad p_{ibt} = 469\,\text{psf}$$

See calculations above for the North-South direction for the derivations of these pressure formulas.

$$p_{ibb} := \frac{P_{ib}}{H_L} - p_{ibt} \qquad p_{ibb} = 3284\,\text{psf}$$

Convective Hydrodynamic Forces(see formula 4-4 as modified by Section 4.2.2 of ACI 350.3 (ref. 2.2.2) and without I and Rm factors as discussed in Assumption 3.2.2 of this calculation):

North- South Direction:

$$P_{ca} := A_{c_1}\cdot\frac{W_{ca}}{L_P} \qquad P_{ca} = 4.98\,\text{klf} \quad \text{(per ft of width of wall)Acting at} \quad h_{ca} = 31.661\ \text{ft}$$

$$p_{cat} := \frac{P_{ca}}{2} \cdot \left(\frac{6 \cdot h_{ca}}{H_L^{\,2}} - \frac{2}{H_L} \right)$$ $p_{cat} = 102\,psf$ (per ft of width of wall)

$$p_{cab} := \frac{P_{ca}}{H_L} - p_{cat}$$ $p_{cab} = 2\,psf$ (per ft of width of wall)

See the calculations above on pages 18 and 19 for the pressures in the North-South direction due to impulsive forces for the derivations of these pressure formulas.

East-West Direction:

$$P_{cb} := A_{c_2} \cdot \frac{W_{cb}}{B_P}$$ $P_{cb} = 5.5 \frac{kip}{ft}$ (per ft of width of wall) Acting at $h_{cb} = 29.813$ ft

$$p_{cbt} := \frac{P_{cb}}{2} \cdot \left(\frac{6 \cdot h_{cb}}{H_L^{\,2}} - \frac{2}{H_L} \right)$$ $p_{cbt} = 99\,psf$ (per ft of width of wall)

$$p_{cbb} := \frac{P_{cb}}{H_L} - p_{cbt}$$ $p_{cbb} = 16\,psf$ (per ft of width of wall)

See the calculations above on pages 18 and 19 for the pressures in the North-South direction due to impulsive forces for the derivations of these pressure formulas.

Vertical Seismic:

$uvP_h := A_v \cdot P_h$ $uvP_h = 64.7\,klf$ (per ft of width of wall) Acting at $\frac{H_L}{3} = 16$ ft

$uvp_h := A_v \cdot p_h$ $uvp_h = 2697\,psf$

BDBGM (10000 yr. Return Period) Seismic Event:

Impulsive Hydrodynamic Pressure:

North- South Direction (see formula 4-3 as modified by Section 4.2.2 of ACI 350.3 (ref. 2.2.2) and without I and Rm factors as discussed at the beginning of this section):

$$P_{10ia} := A_{10i} \cdot \frac{W_{ia}}{L_P}$$ $P_{10ia} = 339.1\,klf$ Acting at $h_{ia} = 18.281$ ft

The impulsive pressure distribution is trapezoidal. The pressure at the top, p_{10iat}, and the pressure at the bottom, p_{10iab}, are determined using the same formulas as used in the DBGM-2 case above.

$$p_{10iat} := \frac{P_{10ia}}{2} \cdot \left(\frac{6 \cdot h_{ia}}{H_L^{\,2}} - \frac{2}{H_L} \right)$$ $p_{10iat} = 1007\,psf$

$$p_{10iab} := \frac{P_{10ia}}{H_L} - p_{10iat} \qquad p_{10iab} = 6058\,psf$$

East- West Direction:

$$P_{10ib} := A_{10i} \cdot \frac{W_{ib}}{B_P} \qquad P_{10ib} = 370.5\,klf \qquad \text{Acting at } h_{ib} = 18\ ft$$

$$p_{10ibt} := \frac{P_{10ib}}{2} \cdot \left(\frac{6 \cdot h_{ib}}{H_L^{\,2}} - \frac{2}{H_L} \right) \qquad p_{10ibt} = 965\,psf$$

$$p_{10ibb} := \frac{P_{10ib}}{H_L} - p_{10ibt} \qquad p_{10ibb} = 6754\,psf$$

Convective Hydrodynamic Forces:

North- South Direction:

$$P_{10ca} := A_{10c_1} \cdot \frac{W_{ca}}{L_P} \qquad P_{10ca} = 14.3\,klf \quad \text{(per ft of width of wall)Acting at } h_{ca} = 31.661\ ft$$

$$p_{10cat} := \frac{P_{10ca}}{2} \cdot \left(\frac{6 \cdot h_{ca}}{H_L^{\,2}} - \frac{2}{H_L} \right) \qquad p_{10cat} = 292\,psf \quad \text{(per ft of width of wall)}$$

$$p_{10cab} := \frac{P_{10ca}}{H_L} - p_{10cat} \qquad p_{10cab} = 6\,psf \quad \text{(per ft of width of wall)}$$

East-West Direction:

$$P_{10cb} := A_{10c_2} \cdot \frac{W_{cb}}{B_P} \qquad P_{10cb} = 16.3\,klf \quad \text{(per ft of width of wall)Acting at } h_{cb} = 29.813\ ft$$

$$p_{10cbt} := \frac{P_{10cb}}{2} \cdot \left(\frac{6 \cdot h_{cb}}{H_L^{\,2}} - \frac{2}{H_L} \right) \qquad p_{10cbt} = 294\,psf \quad \text{(per ft of width of wall)}$$

$p_{10cbb} := \frac{P_{10cb}}{H_L} - p_{10cbt}$ $p_{10cbb} = 46\,psf$ (per ft of width of wall)

Vertical Seismic:

$uvP_{10h} := A_{10v} \cdot P_h$ $uvP_{10h} = 181.2\,klf$ (per ft of width of wall) Acting at $\frac{H_L}{3} = 16$ ft

$uvp_{10h} := A_{10v} \cdot p_h$ $uvp_{10h} = 7552\,psf$

6.2 DETERMINATION OF REQUIRED FREEBOARD

Determine the amount of sloshing due to the convective mode (see Chapter 7 and Section R4.2.2 of ACI 350.3 (ref. 2.2.2)):

Convective acceleration for sloshing height $A_{cd} = \eta_c \cdot \frac{S_D}{g} \cdot \left(\frac{2 \cdot \pi}{T_c}\right)^2$

Damping factor $= \eta_c := 1.0$ for 0.5% damping (see Section R4.2.2 of ACI 350.3 (ref. 2.2.2))

Based on a discussion on response spectra in Section 6.2 in Biggs (1964) (ref. 2.2.8), spectral acceleration and spectral displacement are related as shown below:

$S_a = \omega^2 \cdot S_d$ Based on formula 6.3 of Biggs (ref. 2.2.8).

Where:

S_a = Spectral acceleration

ω = Natural circular frequency

S_d = Spectral displacement

Natural periods of convective mode = $T_c = \begin{pmatrix} 4.901 \\ 5.492 \end{pmatrix} s \begin{matrix} N\text{-}S \\ E\text{-}W \end{matrix}$ (see pg. 12)

6.2.1 DBGM-2 (2000 yr. Return Period) Seismic Event:

The accelerations corresponding to these values of Tc are determined by linear interpolation from MO0411SDSTMHIS.006 (ref 2.2.6) at 0.5% damping; the periods are "broadened" by 10% per Assumption 3.1.3:

$i := 1..2$

$$S_{A2_1} := \left[0.0614 + (0.1215 - 0.0614)\cdot\frac{4.978 - 0.9\cdot 4.901}{4.978 - 3.351}\right]\cdot g \qquad S_{A2_1} = 2.649\ \frac{ft}{s^2}$$

$$S_{A2_2} := \left[0.0614 + (0.1215 - 0.0614)\cdot\frac{4.978 - 0.9\cdot 5.492}{4.978 - 3.351}\right]\cdot g \qquad S_{A2_2} = 2.017\ \frac{ft}{s^2}$$

$$\omega_2 := \frac{2\cdot\pi}{T_c} \qquad \omega_2 = \begin{pmatrix}1.282\\1.144\end{pmatrix} Hz$$ See formula 2.6 of Biggs 1964 (ref. 2.2.8).

$$S_{D2} := \frac{S_{A2}}{\omega_2^{\ 2}} \qquad S_{D2} = \begin{pmatrix}19.342\\18.494\end{pmatrix} in$$ See formula above in introduction to this section.

$$A_{cd2_i} := \eta_c\cdot\frac{S_{D2_i}}{g}\cdot\left(\frac{2\cdot\pi}{T_{c_i}}\right)^2 \qquad A_{cd2} = \begin{pmatrix}0.082\\0.063\end{pmatrix}$$

Maximum vertical displacements:

North - South Earthquake:

$$d_{ma2_1} := \left(\frac{L_a}{2}\right)\cdot A_{cd2_1} \qquad d_{ma2_1} = 30.139\,in$$

Sect. R7.1, ACI 350.3 (ref. 2.2.2); importance factor, I, not used; see Assumption 3.2.2 of this calculation.

East - West Earthquake

$$d_{ma2_2} := \left(\frac{L_b}{2}\right)\cdot A_{cd2_2} \qquad d_{ma2_2} = 28.215\,in$$

Sect. R7.1, ACI 350.3 (ref. 2.2.2); importance factor, I, not used; see Assumption 3.2.2 of this calculation.

$Free2 := \max(d_{ma2})$ $\qquad Free2 = 2.512\ ft$ $\quad <$ 4'-0" Provided, OK

6.2.2 BDBGM (10000 yr. Return Period) Seismic Event:

The accelerations corresponding to the above values of Tc are determined by linear interpolation from MO0411WHBDE104.003 (ref. 2.2.7) at 0.5% damping; the periods are "broadened" by 10% per Assumption 3.1.3:

$i := 1..2$

$$S_{A10_1} := \left[0.1813 + (0.3401 - 0.1813)\cdot\frac{4.978 - 0.9\cdot 4.901}{4.978 - 3.351}\right]\cdot g \qquad S_{A10_1} = 7.614\ \frac{ft}{s^2}$$

$$S_{A10_2} := \left[0.1813 + (0.3401 - 0.1813)\cdot\frac{4.978 - 0.9\cdot 5.492}{4.978 - 3.351}\right]\cdot g \qquad S_{A10_2} = 5.944\ \frac{ft}{s^2}$$

$$\omega_{10} := \frac{2\cdot\pi}{T_c} \qquad \omega_{10} = \begin{pmatrix}1.282\\1.144\end{pmatrix} Hz$$ See formula 2.6 of Biggs 1964 (ref. 2.2.8).

$$S_{D10} := \frac{S_{A10}}{\omega_{10}^{\ 2}} \qquad S_{D10} = \begin{pmatrix}55.583\\54.49\end{pmatrix} in$$ See formula above in introduction to this section.

$$A_{cd10_i} := \eta_c\cdot\frac{S_{D10_i}}{g}\cdot\left(\frac{2\cdot\pi}{T_{c_i}}\right)^2 \qquad A_{cd10} = \begin{pmatrix}0.237\\0.185\end{pmatrix}$$

Maximum vertical displacements:

North - South Earthquake:

$$d_{ma10_1} := \left(\frac{L_a}{2}\right)\cdot A_{cd10_1} \qquad d_{ma10_1} = 86.614\,in$$

Sect. R7.1, ACI 350.3 (ref. 2.2.2); importance factor, I, not used; see Assumption 3.2.2 of this calculation.

East - West Earthquake

$$d_{ma10_2} := \left(\frac{L_b}{2}\right)\cdot A_{cd10_2} \qquad d_{ma10_2} = 83.131\,in$$

Sect. R7.1, ACI 350.3 (ref. 2.2.2); importance factor, I, not used; see Assumption of this calculation.

$Free10 := \max(d_{ma10})$ $\qquad Free10 = 7.218\ ft$ > 4'-0" Provided, may not be OK

7. RESULTS AND CONCLUSIONS

7.1 RESULTS

The resulting hydrostatic and hydrodynamic pressures and required freeboard are summarized in the following table (see Figure 6-1 for force and pressure designations and pressure shapes):

TABLE 7-1 - RESULTS

HYDROSTATIC AND HYDRODYNAMIC FORCES AND PRESSURES AND REQUIRED FREEBOARD

PARAMETER	VALUE		NOTES
HYDROSTATIC FORCE AND PRESSURE			
HYDROSTATIC FORCE	P_h = 71.9 klf @ h_h = 16 ft		
HYDROSTATIC PRESSURE	p_h = 2997 psf @ base		Triangular Pressure Shape
HYDRODYNAMIC FORCES AND PRESSURES			
	DBGM-2 SEISMIC EVENT	BDBGM SEISMIC EVENT	
IMPULSIVE FORCE (earthquake in N-S direction)	P_{ia} = 164.9 klf acting @ 18.281 ft	P_{10ia} = 339.1 klf acting @ 18.281 ft	Total Force – Leading Half plus Trailing Half
IMPULSIVE PRESSURE (TOP) (earthquake in N-S direction)	p_{iat} = 490 psf	p_{10iat} = 1007 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; suction on Trailing Half)
IMPULSIVE PRESSURE (BOTTOM) (earthquake in N-S direction)	p_{iab} = 2946 psf	p_{10iab} = 6058 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing half)
IMPULSIVE FORCE (earthquake in E-W direction)	P_{ib} = 180.2 klf acting @ 18.0 ft	P_{10ib} = 370.5 klf acting @ 18.0 ft	Total Force – Leading Half plus Trailing Half
IMPULSIVE PRESSURE (TOP) (earthquake in E-W direction)	p_{ibt} = 469 psf	p_{10ibt} = 965 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing Half)
IMPULSIVE PRESSURE (BOTTOM) (earthquake in E-W direction)	p_{ibb} = 3284 psf	p_{10ibb} = 6754 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing Half)

HYDROSTATIC AND HYDRODYNAMIC FORCES AND PRESSURES AND REQUIRED FREEBOARD

PARAMETER	VALUE		NOTES
HYDRODYNAMIC FORCES AND PRESSURES (CONT'D)			
	DBGM-2 SEISMIC EVENT	BDBGM SEISMIC EVENT	
CONVECTIVE FORCE (earthquake in N-S direction)	P_{ca} = 5 klf @ h_{ca} = 31.661 ft	P_{10ca} = 14.3 klf @ h_{ca} = 31.661 ft	Total Force – Leading Half plus Trailing Half
CONVECTIVE PRESSURE (TOP) (earthquake in N-S direction)	p_{cat} = 102 psf	p_{10cat} = 292 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing Half)
CONVECTIVE PRESSURE (BOTTOM) (earthquake in N-S direction)	p_{cab} = 2 psf	p_{10cab} = 6 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing Half)
CONVECTIVE FORCE (earthquake in E-W direction)	P_{cb} = 5.5 klf @ h_{cb} = 29.813 ft	P_{10cb} = 16.3 klf @ h_{cb} = 29.813 ft	Total Force – Leading Half plus Trailing Half
CONVECTIVE PRESSURE (TOP) (earthquake in E-W direction)	p_{cbt} = 99 psf	p_{10cbt} = 294 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing half)
CONVECTIVE PRESSURE (BOTTOM) (earthquake in E-W direction)	p_{cbb} = 16 psf	p_{10cbb} = 46 psf	Trapezoidal Pressure Shape (Pressure on Leading Half; Suction on Trailing half)
VERTICAL SEISMIC FORCE	uvP_h = 64.7 klf @ h_v = 16 ft	uvP_{10h} = 181.2 klf @ h_v = 16 ft	Horizontal Force Acting on Walls due to Vertical Seismic Acceleration
VERTICAL SEISMIC PRESSURE	uvp_h = 2697 psf	uvp_{10h} = 7552 psf	Triangular Pressure Shape
REQUIRED FREEBOARD	Free2 = 2.5 ft	Free10 = 7.2 ft	Actual Freeboard = 4'-0"

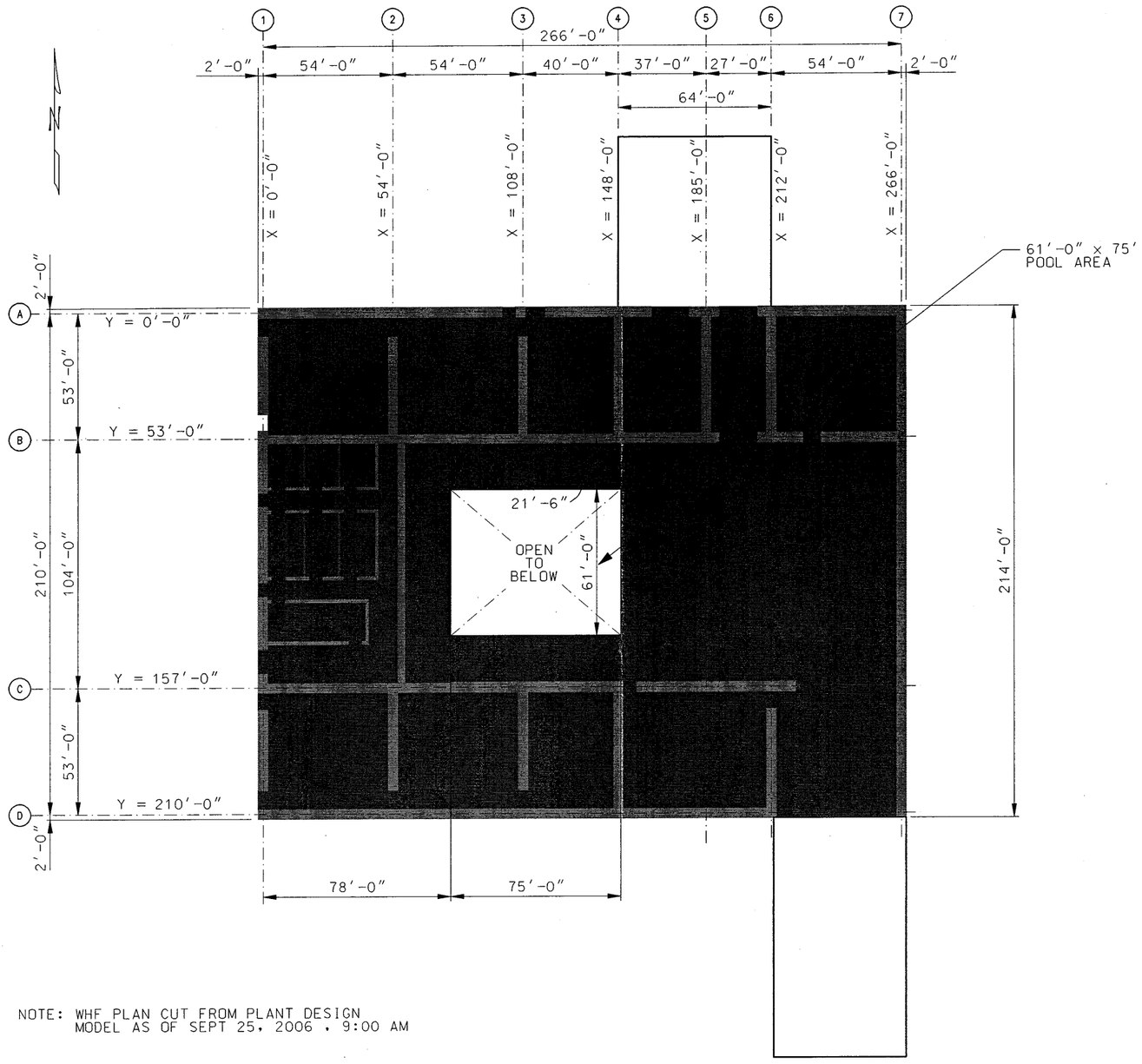
7.2 CONCLUSIONS

The analytical results are reasonable and suitable for their intended use; namely as input into the design and analysis of the WHF pool structure.

The results indicate that the actual freeboard of 4'-0" provided by the WHF spent fuel structure is acceptable for the DBGM-2 seismic event (2.5' required vs. 4.0' provided), but the WHF spent fuel pool structure is overtopped for a BDBGM seismic event (7.2' required vs. 4.0' provided).

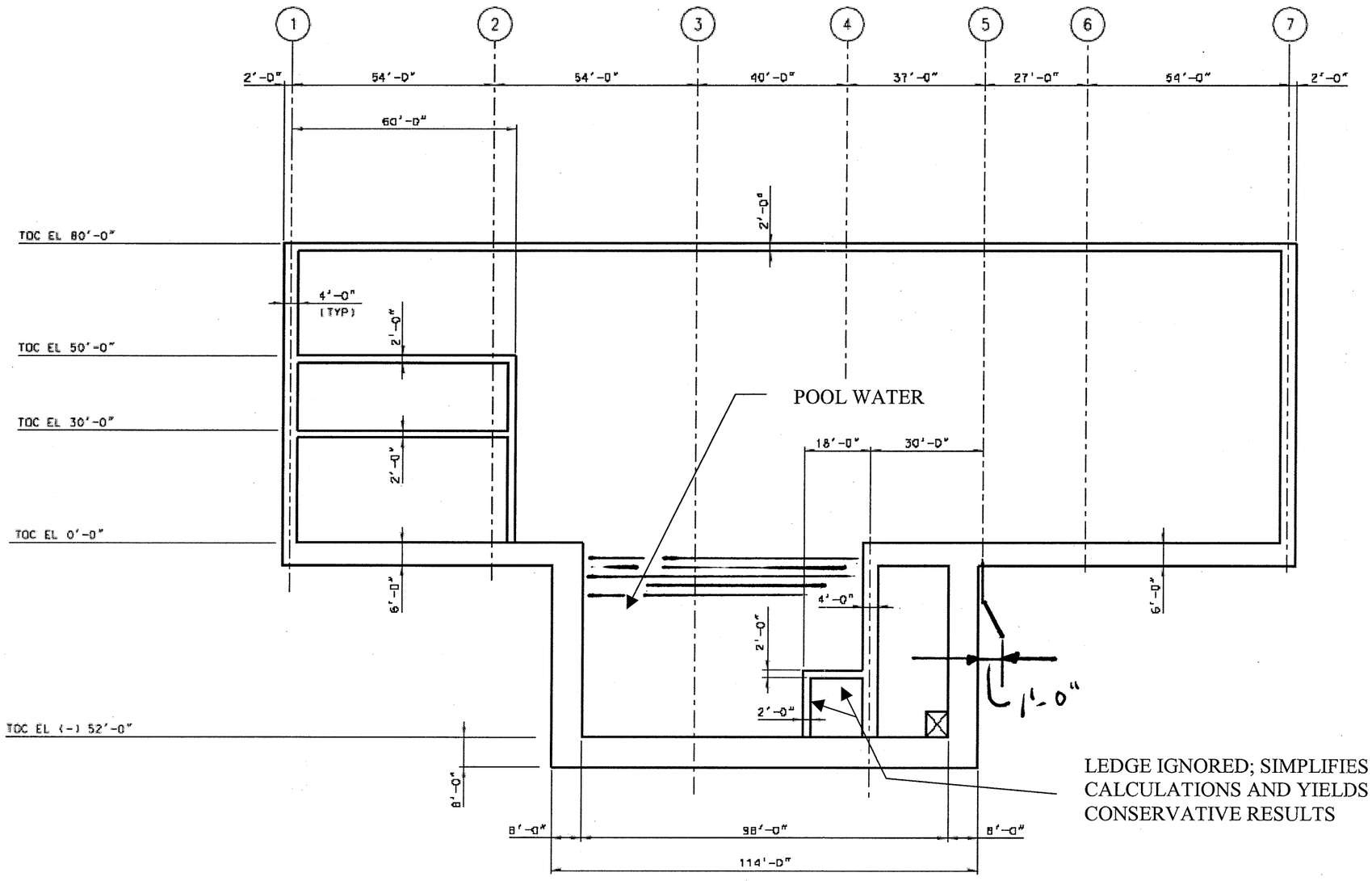
However, there is not currently any set acceptance criteria for freeboard under a very low probability event like the BDBGM. It is not likely that additional freeboard will be provided given this low probability, however sloped floors and curbs will be provided to contain within the WHF any fluid that sloshes out of the pool. In addition, ample water should remain in the pool to provide the necessary shielding. Under conditions when fuel elements are not being handled a minimum of 21'-0" of water will cover the casks and related fuel elements (see sheet A4 of this calculation). The occurrence of a BDBGM event at the same time fuel rods are being moved will be of extremely low probability. This issue will be evaluated further as the WHF design progresses. Assumption 3.1.2 documents that the current pool depth and freeboard are assumed acceptable with respect to the BDBGM.

ATTACHMENT A – FIGURES SHOWING THE SPENT FUEL POOL GEOMETRY

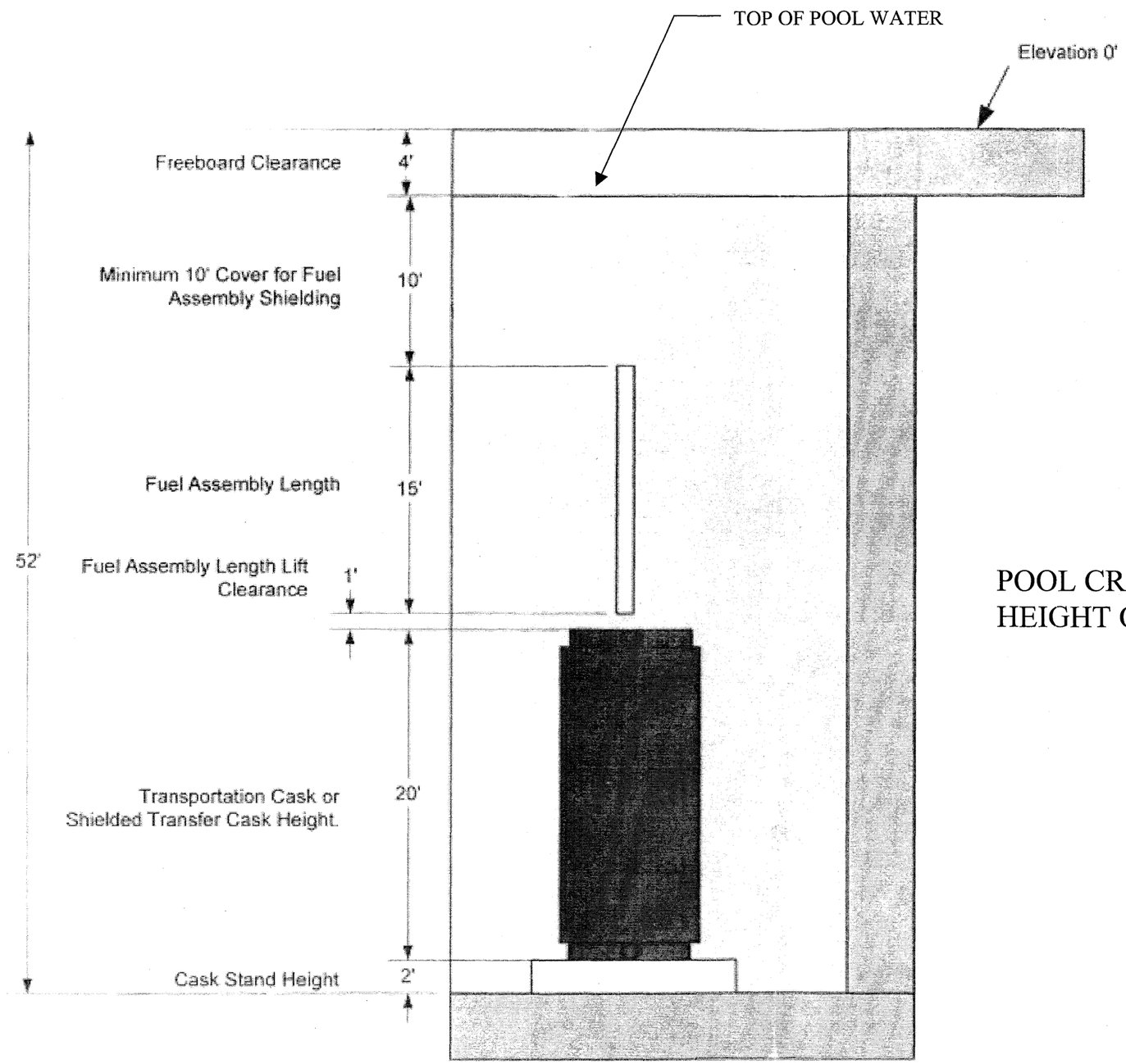


NOTE: WHF PLAN CUT FROM PLANT DESIGN
MODEL AS OF SEPT 25, 2006 , 9:00 AM

GROUND FLOOR PLAN AT EL 0'-0"



LONGITUDINAL SECTION BETWEEN COL 'B' & 'C'
LOOKING NORTH



POOL CROSS-SECTION SHOWING THE HEIGHT OF THE POOL WATER