ENCLOSURE 4

Presentation Slides "AP1000 Shield Building Design," Meeting with NRC Staff, May 17, 2011

(Non-Proprietary)

Westinghouse – NRC Meeting on AP1000 Shield Building

May 17, 2011

Purpose

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- Follow-up to our April 12th meeting where WEC and NRC discussed the WEC approach to combining seismic and thermal loading
- Present the results of calculations with the seismic and thermal loads combined for the AP1000 Enhanced Shield Building
- Demonstrate that the impact of the addition of discrete thermal loads to the load combination is small, and that the existing design of the shield building is technically acceptable
- Agree on the needed documentation of the new calculations and results in both the Shield Building Report and the DCD

Agenda for Proprietary Meeting

• Introduction	Mike Corletti
• Behavior of the AP1000 Shield Building	Amit Varma
• Justification for the Stiffness Reduction Factors for Thermal Calculations	Tod Baker
• Results of Calculations for the SC Cylindrical Wall	Keith Coogler
• Results of Calculations for the PCS Tank	Lee Tunon-Sanjur
• Plans to Docket Additional Information – DCD Rev 19 – SB Report	Don Lindgren
• Wrap-Up	All

Behavior of the AP1000 Shield Building

Dr. Amit Varma
Associate Professor
Purdue University
Civil Engineering

Shield Building Model for Global Analysis

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Shield Building Global Behavior

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Shield Building Global Behavior

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Evaluation of Shield Building Design for Thermal (operating) + SSE Loading Combination

Objectives

- To evaluate the effects of thermal demands on the seismic design of the SC shield building
- To demonstrate that ductile mechanisms govern the behavior of the shield building even in the presence of thermal + seismic loading (for both module 1 and 2)
- Demonstrate thermally induced forces do not reduce the plastic collapse strength of a structure that fails with ductile mechanisms.

Outline

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- Thermal Conditions (ambient)
- Force / Moment Demands Induced by Thermal Conditions and Seismic Loading
- Force / Moment Capacities of SC Shield Building Design
- Demand-to-Capacity Ratios and Governing Failure Modes
- Effects of Thermal Demands on Structure Failure Capacity – Relation with ACI 349.1R
- Conclusions

Thermal Conditions - Ambient

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Thermal Loads: Induced Demands

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Thermal Loads: Induced Demands

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Thermal Load: Induced Demands

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Seismic Demands: Induced Forces

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- In-plane axial forces and shear forces are shown as obtained from the analysis.

Seismic Demands: Induced Forces

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Thermal + Seismic: Combined Demands

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SC Shield Building Capacities

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SC Shield Building Capacities

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SC Shield Building Capacities

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SC Shield Building Capacities

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SC Shield Building Capacity

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SC Shield Building Evaluation

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SC Shield Building Evaluation

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SC Shield Building Evaluation Beyond Design Basis

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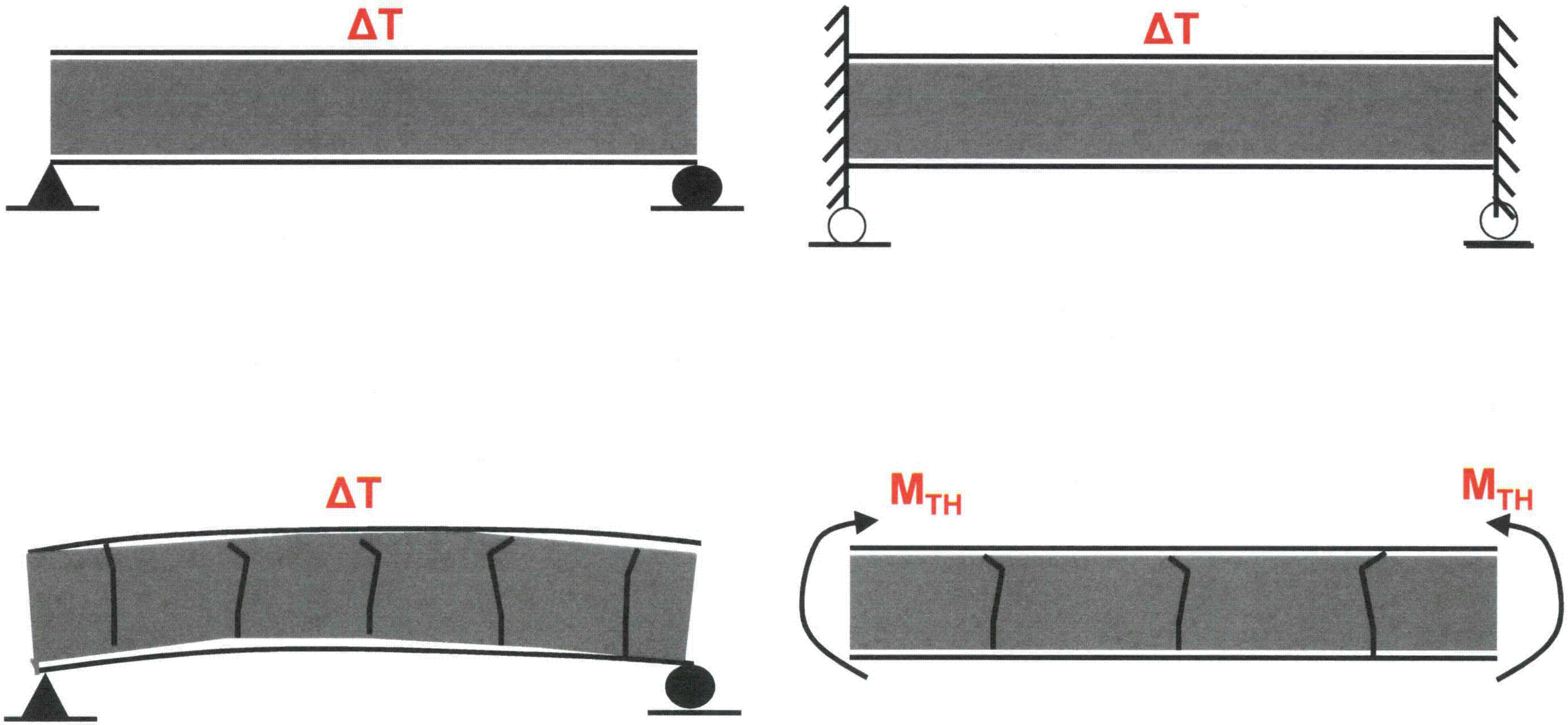
Thermal + Loading



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Thermal + Loading

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Example of Thermal + Loading

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Example of Thermal + Loading

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Example of Thermal + Loading

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Thermal + SSE Loading Summary and Conclusions

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- Thermally induced forces do not reduce the plastic collapse strength of the structure ... However, this requires a ductile failure mode to govern the collapse strength of the structure.
- Due to this understanding, the ambient thermal demands are often not included with the SSE demands during design of structures. It is expected to initiate yielding first, but the overall structure strength will be the same.
- As demonstrated earlier, the ductile flexural yielding mode governs for the shield building when Thermal + SSE is evaluated.
- However, if SSE is increased for more extreme earthquake loads, the ductile failure modes or overall collapse govern even more.

Justification for the Stiffness Reduction Factors for Thermal Calculations

Tod H. Baker, P.E.

Westinghouse Fellow Engineer

Stiffness Reduction Ratio

- The purpose of this presentation is to provide justification for the stiffness reduction ratio used in the Shield Building calculations where Westinghouse has combined SSE + Thermal
- Westinghouse has applied a stiffness reduction ratio to thermal loadings in all Shield Building thermal load combinations
- The forces and moments from the linear thermal analysis are multiplied by a stiffness reduction ratio in order to account for concrete cracking

Stiffness Reduction Ratio

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- The linear elastic FEA (i.e. NI05 model) has been performed using $0.8E_m$ as described in the Shield Building report and as recommended in FEMA 356 Table 6.5

Table 6-5 Effective Stiffness Values

Component	Flexural Rigidity	Shear Rigidity	Axial Rigidity
Beams—nonprestressed	$0.5E_cI_g$	$0.4E_cA_w$	—
Beams—prestressed	E_cI_g	$0.4E_cA_w$	—
Columns with compression due to design gravity loads $\geq 0.5\ A_gf'_c$	$0.7E_cI_g$	$0.4E_cA_w$	E_cA_g
Columns with compression due to design gravity loads $\leq 0.3\ A_gf'_c$ or with tension	$0.5E_cI_g$	$0.4E_cA_w$	E_sA_s
Walls—uncracked (on inspection)	$0.8E_cI_g$	$0.4E_cA_w$	E_cA_g
Walls—cracked	$0.5E_cI_g$	$0.4E_cA_w$	E_cA_g
Flat Slabs—nonprestressed	See Section 6.5.4.2	$0.4E_cA_g$	—
Flat Slabs—prestressed	See Section 6.5.4.2	$0.4E_cA_g$	—

Note: It shall be permitted to take I_g for T-beams as twice the value of I_g of the web alone. Otherwise, I_g shall be based on the effective width as defined in Section 6.4.1.3. For columns with axial compression falling between the limits provided, linear interpolation shall be permitted. Alternatively, the more conservative effective stiffnesses shall be used.

Stiffness Reduction Ratio

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- The stiffness reduction ratio compares the un-cracked stiffness to the cracked stiffness
- Ratios are calculated for out-of-plane flexure and axial loadings
- The stiffness reduction ratio used in the SSE+Thermal load combination for the Shield Building is 0.5 times the un-cracked stiffness based on the elastic modulus defined in the ACI 349 Code

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Stiffness Reduction Ratio for Axial and Flexure

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Stiffness Reduction Ratio for Flexure

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Stiffness Reduction Ratio for Flexure

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Stiffness Reduction Ratio for Axial Tension

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Stiffness Reduction Ratio for Axial Tension plus Flexure

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Stiffness Reduction Ratio

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- A summary of the calculated axial and flexural stiffness parameters is tabulated below

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Stiffness Reduction Ratio

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- A value of 0.5 is chosen as a representative effective stiffness
- This value agrees well with FEMA 356 Table 6.5
- This value also agrees well with Table 3-1 of ASCE/SEI 43-05, “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”

Stiffness Reduction Ratio

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- ASCE/SEI 43-05

TABLE 3-1. Effective Stiffness of Reinforced Concrete Members

Member	Flexural Rigidity	Shear Rigidity	Axial Rigidity
Beams—Nonprestressed	$0.5\ E_cI_g$	G_cA_W	
Beams—Prestressed	E_cI_g	G_cA_W	
Columns in compression	$0.7\ E_cI_g$	G_cA_W	E_cA_g
Columns in tension	$0.5\ E_cI_g$	G_cA_W	E_sA_s
Walls and diaphragms—Uncracked	E_cI_g ($f_b < f_{cr}$)	G_cA_W ($V < V_c$)	E_cA_g
Walls and diaphragms—Cracked	$0.5\ E_cI_g$ ($f_b > f_{cr}$)	$0.5\ G_cA_W$ ($V > V_c$)	E_cA_g

Notes:

A_g = Gross area of the concrete section

A_s = Gross area of the reinforcing steel

A_w = Web area

E_c = Concrete compressive modulus, from ACI-349 $57{,}000(f'_c)^{1/2}$

E_s = Steel modulus

f_b = Bending stress

f_{cr} = Cracking stress

G_c = Concrete shear modulus = $0.4\ E_c$

I_g = Gross moment of inertia

V = Wall shear

V_c = Nominal concrete shear capacity

Stiffness Reduction Ratio

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- A value of 0.5 is also consistent with ACI 349.1R-07, "Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures," Section 1.4.2

  "*Elastic FEAs can be used with a reduced elastic modulus for concrete to account in a very simple manner for the various effects of cracking, creep, and yield. Values of 0.50Ec have been used in past practice.*"

- Therefore, a stiffness reduction factor of 0.5 has been applied to the forces and moments resulting from the linear elastic thermal analysis of the Shield Building

Stiffness Reduction Ratio for RC Regions

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- The stiffness reduction ratio for the RC portion of the shield building is calculated in a similar manner
- A stiffness reduction ratio of 0.5 is used for RC

Connections, Air Inlet Structure, Tension Ring, and RC Roof

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- A capacity design approach has been used to design the SC to RC connections

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- Therefore, the SC to RC connection design is not affected by SSE + Thermal load combinations
- The Air Inlet Structure, Tension Ring, and RC Roof have no significant thermal demand

Results of Calculations for the SC Cylindrical Wall

Keith Coogler
Westinghouse Senior Engineer

Shield Building Cylinder Rollout

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Load Combinations

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Summary of Results Presented

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Simplified Applied Temperatures

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Updated Thermal Analysis

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Out of Plane Shear Capacities

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SC Shield Building Capacities

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Element Averaging at the Annulus Seal

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LC1-17 Shear Area Required (SHEAR, $0.21 in^2/ft^2$ provided)

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LC18-41 Shear Area Required (SHEAR, 0.21in²/ft² provided)

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LC18-41(HT) Shear Area Required (SHEAR, $0.21 in^2/ft^2$ provided)

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LC1-17 Plate Area Required (AYSUM, 9in²/ft provided)

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LC1-17 Plate Area Required (AXSUM, 9in²/ft provided)

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LC18-41 Plate Area Required (AYSUM, 9in²/ft provided)

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LC18-41 Plate Area Required (AXSUM, $9 in^2/ft$ provided)

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LC18-41(HT) Plate Area Required (AYSUM, $9 in^2/ft$ provided)

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LC18-41(HT) Plate Area Required (AXSUM, $9 in^2/ft$ provided)

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Summary

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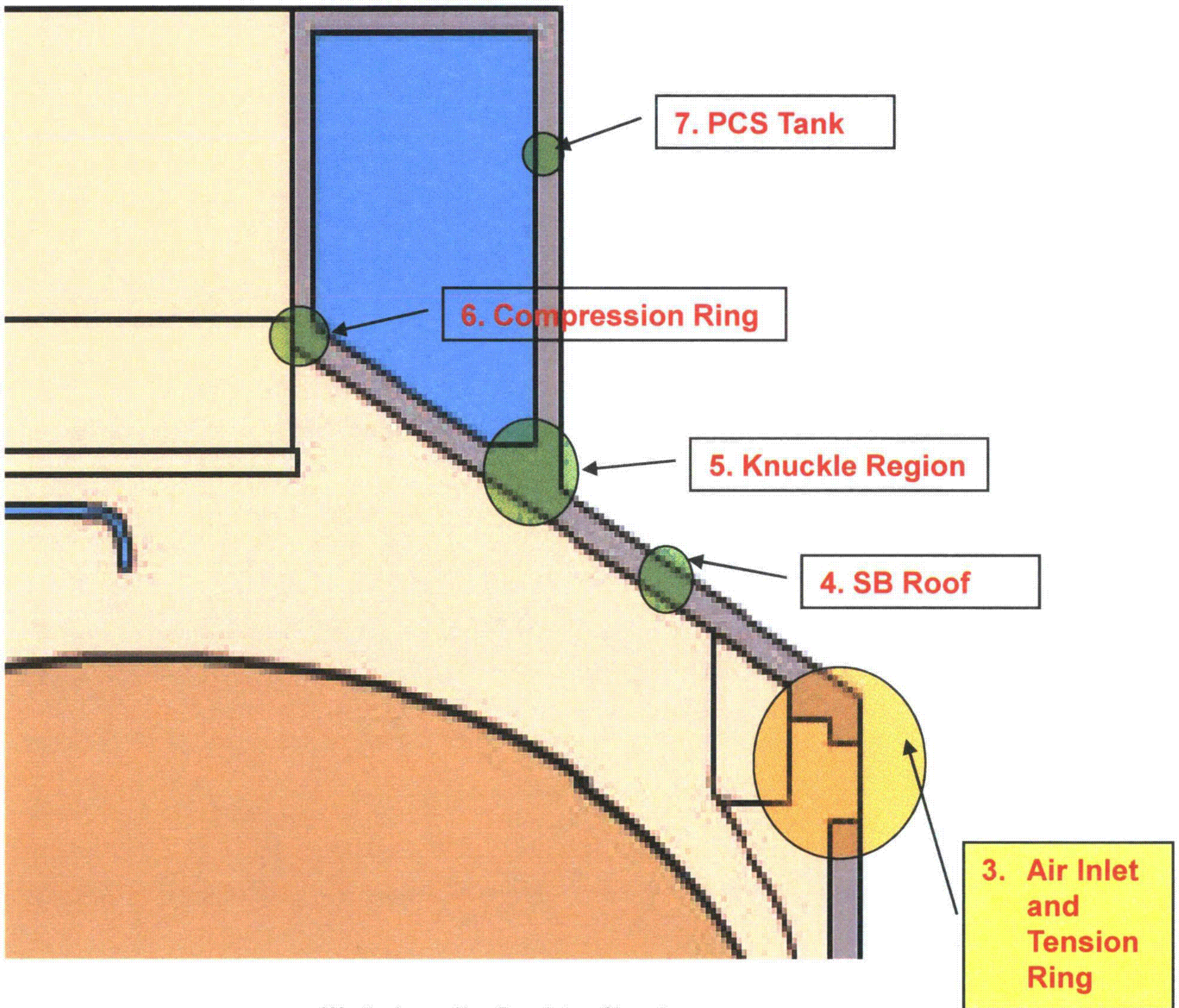
Results of Calculations for the PCS Tank

Lee Tunon-Sanjur

Westinghouse Civil Structural Design Analysis Manager

Shield Building Roof



PCS Tank Design DCD Rev 15

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PCS Tank Design DCD Rev 18

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Review of Seismic Member Forces for PCS Tank using NI05

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PRELIMINARY

PCS Exterior Wall Comparison of demand vs capacity

Wall Segment	**Location (Figure 3H.5-11)**	**Required for seismic LC**	**Required for non-seismic LC**	**Required SSE + Thermal**	**Provided DCD Rev 19**
Bottom	Vertical	0.91	1.62	**1.69**	1.72
	Hoop	1.23	**1.89**	1.65	2.00
	Shear	0.14	0.0	0.14	0.48
Mid-height	Vertical	1.17	**1.53**	1.18	1.72
	Hoop	1.16	**1.94**	1.40	2.00
Top	Vertical	**1.18**	0.71	1.17	1.72
	Hoop	0.88	**1.72**	1.18	2.00

Notes:

1. Response spectrum analysis uses NI05 model with only three elements vertically.
2. All of water horizontal mass is lumped on exterior wall in NI05.
3. Response spectrum analysis combines direction by SRSS method and does not look at all possible sign combinations of member forces.

Review of Seismic Member Forces for PCS Tank using NI05

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- Thermal load combinations govern in most of the PCS tank because of the conservatisms in the thermal analyses previously performed
- Thermal + SSE governs the vertical and shear reinforcement at the base of the PCS exterior wall but the design is still adequate
- SB Action Item 21 committed Westinghouse to evaluate the PCS tank for hydrodynamic loads using an equivalent static analysis
- WEC has recognized that the design results for the PCS exterior wall provided in the DCD was obtained from the NI05 model and not the equivalent static model as committed in our response to SB Action Item 21

Next Steps

- Westinghouse has demonstrated using the NI05 the effects of combining SSE + thermal does not impact the design of the PCS Tank
- Westinghouse will provide an equivalent static analysis of the hydrodynamic loads in accordance with our response to Action Item 21 from SB Report
- This analysis will combine seismic plus thermal and can be included in both the DCD and the Updated Shield Building Report

Plans to Docket Additional Information

- DCD Rev 19
- SB Report

Don Lindgren, PE

AP1000 Licensing

Submittals to NRC

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- Planned submittals to NRC include:
  - DCD Revision 19
  - APP-GW-GLR-602 Rev 1
  - Shield Building Report Revision 4
- DCD Mark-ups were sent to NRC and we are prepared to discuss
- Technical Reports are not being revised

Submittals to NRC

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- DCD Revision 19
  - Text changes in 3.8.4 to identify Shield Building approach
  - Note is changed in Table 3.8.4-2 to refer to additional shield building information
  - Additional load combination including thermal and seismic added in Table 3H.5-14 for Shield Building cylinder wall critical sections
  - Results included in Table 3H.5-14 for load combination and required reinforcement are being finalized

Submittals to NRC

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- APP-GW-GLR-602 Revision 1 to be submitted with DCD Rev. 19
  - Revision 1 includes changes to address confirmatory questions
- GLR-602 Table 2, Shield Building roof reinforcement is impacted by load combination questions.
  - Includes PCS tank
- Draft mark-ups for DCD and GLR 602 provided May 11
- Results included in tables are being finalized to support a May 31 submittal

Submittals to NRC

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- Technical reports supporting the structural design are not revised
- The results and methodology included in TR-03 are not altered by the combination of seismic and thermal loads
  - SSI results are not affected by thermal loads
  - Development of the seismic response spectra is not changed by consideration of thermal loads
  - Design seismic response spectra are not changed
- Analysis of the shield building for the thermal and seismic load combination uses response spectra method consistent with TR-03 approach

Submittals to NRC

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- The basemat design and information included in TR-85 are not impacted by thermal loads
- TR-09 containment penetration analysis is not impacted by the load combination questions because it uses ASME B&PV Code approach not ACI methods

Submittals to NRC

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- Shield Building Report
  - New appendix is added to address combination of seismic and thermal loads
    - Describe approach
    - Results from calculations
  - Selected tables from Revision 3 are being revised as needed to address confirmatory issues
  - Results in report are consistent with final DCD Revision 19 tables
  - Revised WEC Action 21 response

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Wrap-Up

Mike Corletti

Director, AP1000 Plant Engineering

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Conclusions

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- Westinghouse has demonstrated the Shield Building capacity is not significantly affected by the combination of thermal and seismic loads
- Preliminary calculations performed for the shield building cylinder demonstrate that the design can accommodate the combination of SSE + thermal within the ACI code limits
- Ongoing analysis of the PCS tank are showing that the combination of seismic and thermal do not have a significant impact on overall margin
- Westinghouse will provide an equivalent static analysis of the hydrodynamic loads in accordance with our response to Action Item 21 from SB Report