APP-1200-S3R-003
Revision 3

September 2010

Design Report for the AP1000 Enhanced Shield Building

Westinghouse

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September 30, 2010

This document contains sensitive unclassified non-safeguards information (SUNSI) related to the physical protection of an AP1000 Nuclear Plant. SUNSI information should be withheld from public disclosure pursuant to 10 CFR 2.390(d).

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
a/d	shear span ratio
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
ATR	adiabatic temperature rise
AWS	American Welding Society
BTU	British thermal unit
CDFM	conservative deterministic failure margin
CDP	concrete-damaged plasticity
CEF	concrete elastic fracture
CFR	Code of Federal Regulations
CFS	concrete-filled steel
CJP	couple joint penetration weld
CO	carbon monoxide
CSC	concrete-smeared cracking
CSDRS	Certified Seismic Design Response Spectra
CV	containment vessel
DCD	Design Control Document
DSER	Design Safety Evaluation Report
EEDM	earthquake energy dissipating mechanism
EPRI	Electric Power Research Institute
FME	foreign material exclusion
FFT	fast Fourier transform
FR	Federal Register
GD&T	geometric dimensioning and tolerance
GDC	General Design Criteria
GPR	ground penetrating radar
GRT	gamma radiography
HCLPF	high confidence of low probability of failure
HRHF	Hard Rock High Frequency
HVAC	heating, ventilating, and air conditioning
IAEA	International Atomic Energy Agency
ICC	International Code Council
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria
IEM	impact-echo method
IMI	Irving Materials, Inc.
IP	in plane
IR	impulse response
IRT	infrared thermal imaging
JEAG	Japanese Electric Association Nuclear Standards Committee

ACRONYMS AND ABBREVIATIONS (cont.)

kN	kilonewton
ksi	kips per square inch
LLL	Lawrence Livermore Laboratory
LS-DYNA	Livermore Software- Design Analysis
LVDT	linear variable differential transformer
MN	meganewton
MPa	megapascal
MSIV	main steam isolation valve
MTR	mill test report
MTS	materials testing system
NCHRP	National Cooperative Highway Research Program
NDE	nondestructive examination
NDT	nondestructive testing
NRC	U.S. Nuclear Regulatory Commission
NUREG	Nuclear Regulatory Commission report
OC	on center
OOP	out of plane
PCS	passive containment cooling system
PJP	partial joint penetration
PSF	pounds per square foot
PSI	pounds per square inch
QA	quality assurance
QC	quality control
RAI	request for additional information
RC	reinforced concrete
RLE	review level earthquake
RSA	response spectrum analyses
RT	radiography testing
SAFT	synthetic aperture focusing technique
SB	shield building
SBCEP	Shield Building Construction Execution Plan
SC	steel concrete composite
SCC	self-consolidating concrete
Sr	stress range
SRSS	square root of the sum of the squares
SSE	safe shutdown earthquake
USW	ultrasonic surface wave
UT	ultrasonic testing
VT	visual inspection
W/CM	water-to-cement ratio
WEC	Westinghouse Electric Company

EXECUTIVE SUMMARY

AP1000 Shield Building Function

The AP1000 Shield Building, a Seismic Category I structure, serves the following primary functions:

- Provides shielding for the Containment Vessel (CV) and the radioactive systems and components located in the Containment Building
- Protects the Containment Building from external events during normal operations
- Provides the required shielding for radioactive airborne materials that may be dispersed in the containment
- Provides support for the passive containment cooling water storage tank (PCCWST) for containment cooling
- Provides for natural air circulation cooling of the containment vessel

Enhanced AP1000 Shield Building Requirements

On June 12, 2009 the U.S. Nuclear Regulatory Commission (NRC) issued a new regulatory requirement (74 FR 28112) to address the beyond design basis aircraft impact events. Westinghouse developed the enhanced Shield Building design for the AP1000 to address these requirements.

The original certified Shield Building was of reinforced concrete (RC) design. In response to the new regulatory requirements, it was necessary to modify the AP1000 Shield Building design for the portion of the Shield Building above grade that is not protected from external hazards by the Auxiliary Building structure. The unprotected Shield Building structure was changed from an RC structure to an enhanced (strengthened) steel concrete composite (SC) structure.

In the initial Westinghouse design process for the SC Shield Building, Westinghouse relied on the conservative application of ACI 349 code provisions for RC nuclear structures and conservatively applied these provisions to the SC design of the Shield Building. This conservative application design process was consistent with design methodology that Westinghouse had developed for structural modules. This methodology was based on calculations and analyses where finite element (F/E) analyses of the structure are performed and the structural allowable limits are derived from the ACI 349 code. This methodology is supported by extensive international testing and is the basis for other international building codes for SC structures.

On October 15, 2009, the NRC provided a letter to Westinghouse summarizing their review of the AP1000 Enhanced Shield Building design and the Westinghouse design process. The NRC determined that the proposed design of the Shield Building would require modifications in some specific areas to provide its ability to perform its safety function under design basis loading conditions and to support a finding that it will meet applicable regulations.

Specifically, the design of the steel and concrete composite structural module (SC module) must demonstrate the ability to function as a unit during design basis events; the design of the connection of the SC module to the RC wall sections of the Shield Building must demonstrate the ability to function during design basis events; and the design of the Shield Building tension ring girder, which anchors the Shield Building roof to the wall, must be supported by either a confirmatory test or a validated (or benchmarked) analysis method.

As a result of the NRC review and findings of the enhanced Shield Building, Westinghouse is providing an integrated approach in the revisions to the design, analysis, and testing to demonstrate that the Shield Building structural components are integrated as a complete structure and act as a single unit to perform the intended safety function under design basis loads. In response to the NRC letter, Westinghouse has completed the following:

- Design changes were made to the Shield Building that improve its strength and ductility. With the inclusion of tie bars connecting the surface plates, it is demonstrated that the structure will act as a unit in response to design basis events.

- Design changes to the air inlets and tension ring region were made that improve its strength and ductility. The tension ring is designed as a steel structure in accordance with American National Standards Institute/American Institute of Steel Construction (ANSI/AISC) N690 and meets design basis loadings.

- Design changes to the RC/SC connections to use mechanical connectors that directly transfer the forces from the steel SC structure to the RC structure such that the connection will exhibit strength and ductility during seismic events.

- A series of confirmatory tests were performed that demonstrate that the Westinghouse design process that confirms that the ACI 349 code is conservatively applicable to the SC Shield Building structure.

- The design of the Shield Building confirms that the standard design process used for the design benchmarked nonlinear analyses demonstrate the overall strength and ductility of the AP1000 Shield Building. Specifically these analyses demonstrate that the AP1000 Shield Building is designed with adequate margin to withstand both the Safe Shutdown Earthquake (SSE) as well as the review-level earthquake in accordance with NRC regulations.

- Performance of additional analyses that demonstrate ductility beyond that of the review-level earthquake such that the SC Shield Building structure can be judged to be a safe and robust design.

- Westinghouse and The Shaw Group have performed constructability reviews of the Shield Building structure and have concluded that the design can be constructed such that the inherent performance requirements of the SC Shield Building as described in this report will be met. The design team has also identified inspection technologies that can be applied to SC.

This Executive Summary and the detail information within the Design Report depict a revised design process, revised design features, analysis, testing, construction, and inspection methodology that have resulted from the Westinghouse response to the NRC's findings, as outlined in their October 15, 2009 letter.

The acceptability of the Shield Building design relative to its role of protection against a malevolent aircraft crash is not addressed as part of this Design Report.

Process for Review and/or Revising the Design

Based on the NRC findings, Westinghouse supplemented its design team with additional outside industry experts that included members from The Shaw Group, Inc., Purdue University, URS Corporation, Obayashi Corporation, Ansaldo STS, NuStart and their consultants, Twining Laboratories, and Rutgers University Research. The expanded team led by Westinghouse has developed an overall integrated design process (see Figure ES-1) that includes consideration for civil/structural design, thermal/hydraulics and analysis, seismic margin, aircraft crash, durability, testing, construction, and inspection of the Shield Building. This integrated design process has resulted in Westinghouse incorporating design changes, performing additional tests at Purdue University, and performing extensive analysis that demonstrates the adequacy and safety of the AP1000 Enhanced Shield Building. The design, testing, and analysis are presented in this enclosed report.

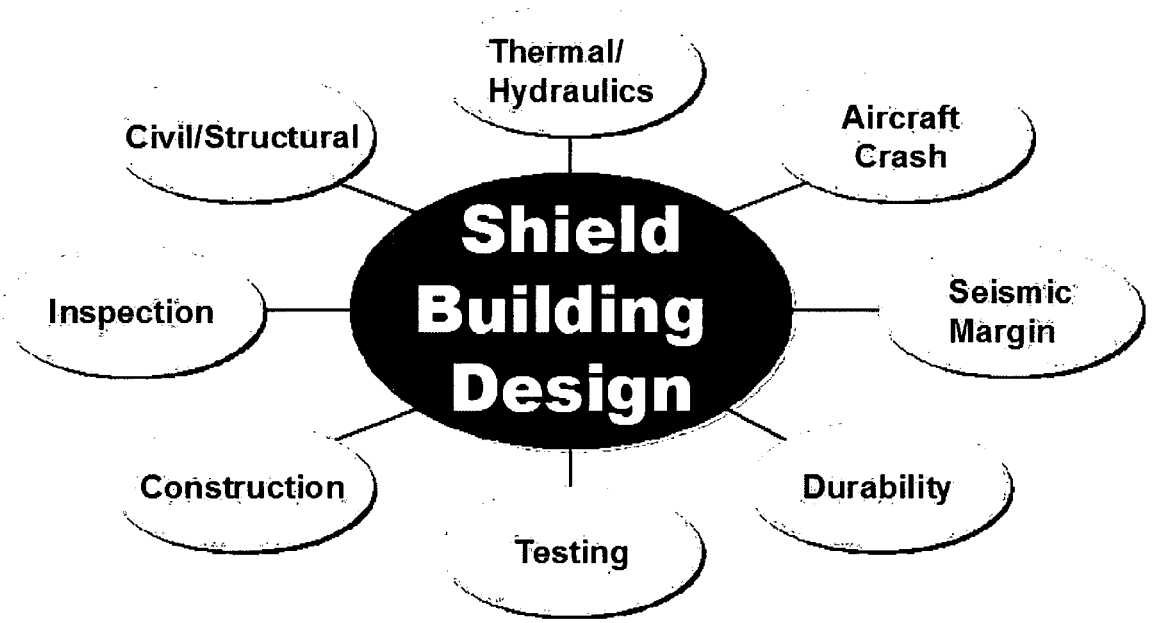


Figure ES-1 Shield Building Design Process

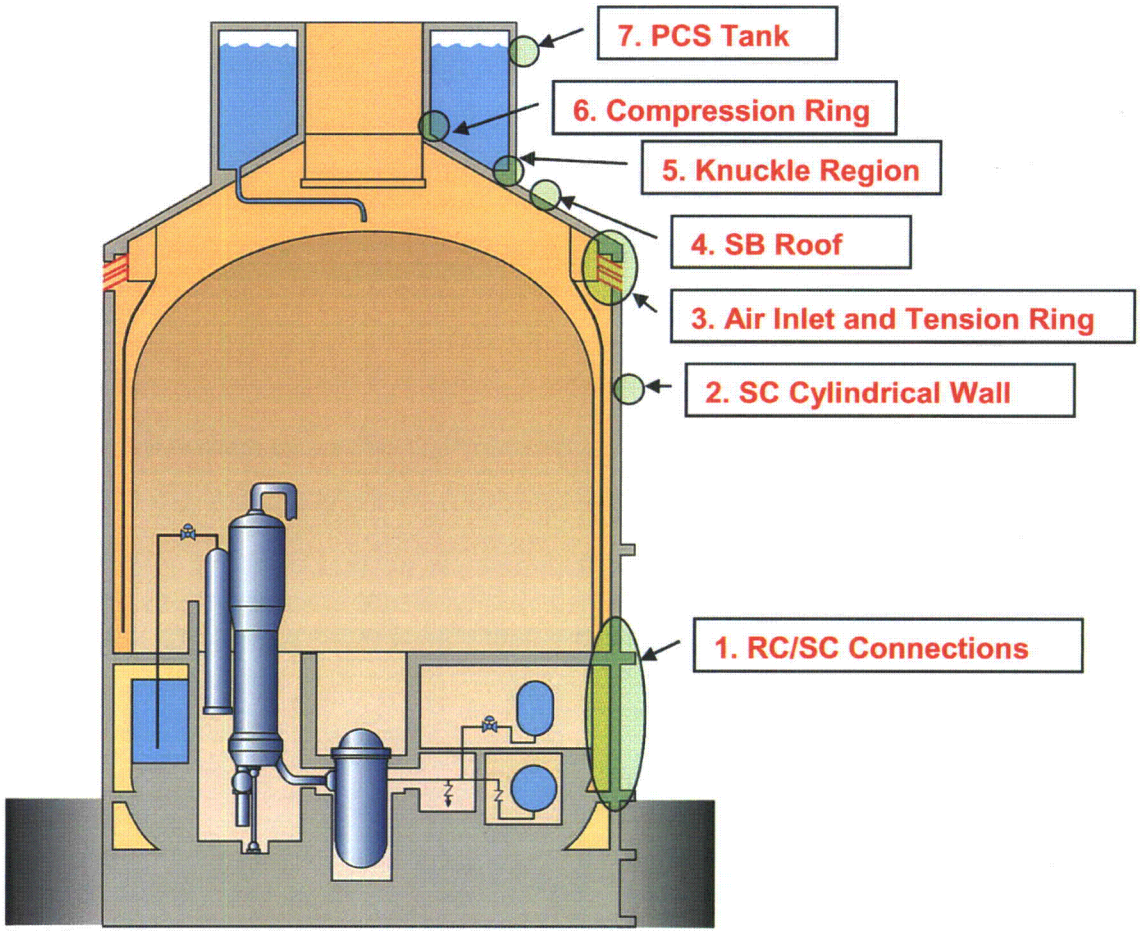


Figure ES-2 Shield Building Structure Key Areas

Modified Design Features

The integrated engineering team evaluated the seven key areas comprising the Shield Building structure as noted in Figure ES-2. The design modifications were identified for three key areas. These include Area 1, the RC/SC vertical and horizontal connections; Area 2, the SC cylindrical wall; and Area 3, the air inlets/tension ring. The purpose of the design modifications was threefold: to allow these portions of the structure to act as a unit; to provide more ductility; and to add more conservatism to the SC design. A decision was made to limit the use of self-consolidating concrete (SCC) to selected regions, including the knuckle region of the roof, the air inlets, and the tension ring. The remainder of the Shield Building will be constructed using standard concrete with a strength of 6000 psi in the SC and 4000 psi in the RC areas. Key areas 4, 5, 6, and 7 are designed as a RC structure in accordance with the ACI and ANSI/AISC codes.

RC/SC Horizontal and Vertical Connections (Key Area #1)

The RC/SC connection has been redesigned. The steel plate modules are anchored to the RC basemat and walls of the Shield Building by mechanical rebar connections. The connectors provide for the direct transfer of forces from the RC reinforcing steel to the SC liner plates.

At the horizontal connection at the interface with the RC structure that occurs on the bottom of the lowest SC wall module, each vertical reinforcing bar in the RC basemat wall is connected to a mechanical coupler. A similar vertical connection occurs on the vertical edges of SC wall modules that interface with the RC portion of the Shield Building wall. In the vertical connection, each hoop reinforcing bar in the RC wall is connected to a mechanical coupler, and forces are transferred directly from the hoop bars to the SC liner plate. The mechanical connection is designed to the allowable working stress limits of ANSI/AISC N690 for loads in the reinforcing bars equivalent to 125 percent of the yield strength of the reinforcing bars and are proven components used in existing structures. This connection improves the overall ductility of the RC/SC connection.

SB Cylindrical Wall (Key Area #2)

The cylindrical wall has been redesigned. The Shield Building surrounds the CV and shares a common basemat with the CV and the Auxiliary Building. The cylindrical shield wall has an outside radius of 72.5 feet and a thickness of 36 inches. The cylindrical wall section that is below the Auxiliary Building roof line is a reinforced concrete structure. The section that is not protected by the Auxiliary Building is a steel concrete composite structure, where two 0.75-inch plates act compositely with 34.5 inches of concrete via tie bars and shear studs. The steel plate modules are connected to the reinforced concrete basemat and walls by mechanical connectors as described above.

A typical configuration of the SC wall is shown in Figure ES-3. The overall thickness of 36 inches is the same as the RC wall below. The concrete for the SC portion is standard concrete with compressive strength of 6000 psi. The SC portion is constructed with American Society for Testing and Materials (ASTM) A572 Grade 50 steel surface plates which act as concrete reinforcement. The nominal thickness of the steel faceplates is 0.75 inches. In each module, 0.75-inch tie bars are welded to the outside faces of the steel faceplates to develop composite behavior of the steel faceplates and concrete. The 0.75-inch shear studs are at nominal 8.375-inch circumferential spacing and nominal 8.5-inch vertical spacing, and are welded to the inside surface of the steel plate. The tie bar reinforcing bars are at 6-inch centers in the higher stress regions. The reinforcement detailing incorporates both American Concrete Institute (ACI) 349 R1.4 and ACI 318-08 requirements.

The use of tie bars and mechanical connections at the RC/SC interfaces addresses the issues raised in the NRC letter (dated October 15, 2009) that the AP1000 Shield Building must act as a unit. Westinghouse has performed testing and analysis that demonstrates this behavior. Use of 0.75 inch steel plate also addresses issues raised in the NRC letter with respect to ductility and the effects of creep. Figure ES-3 illustrates this design.

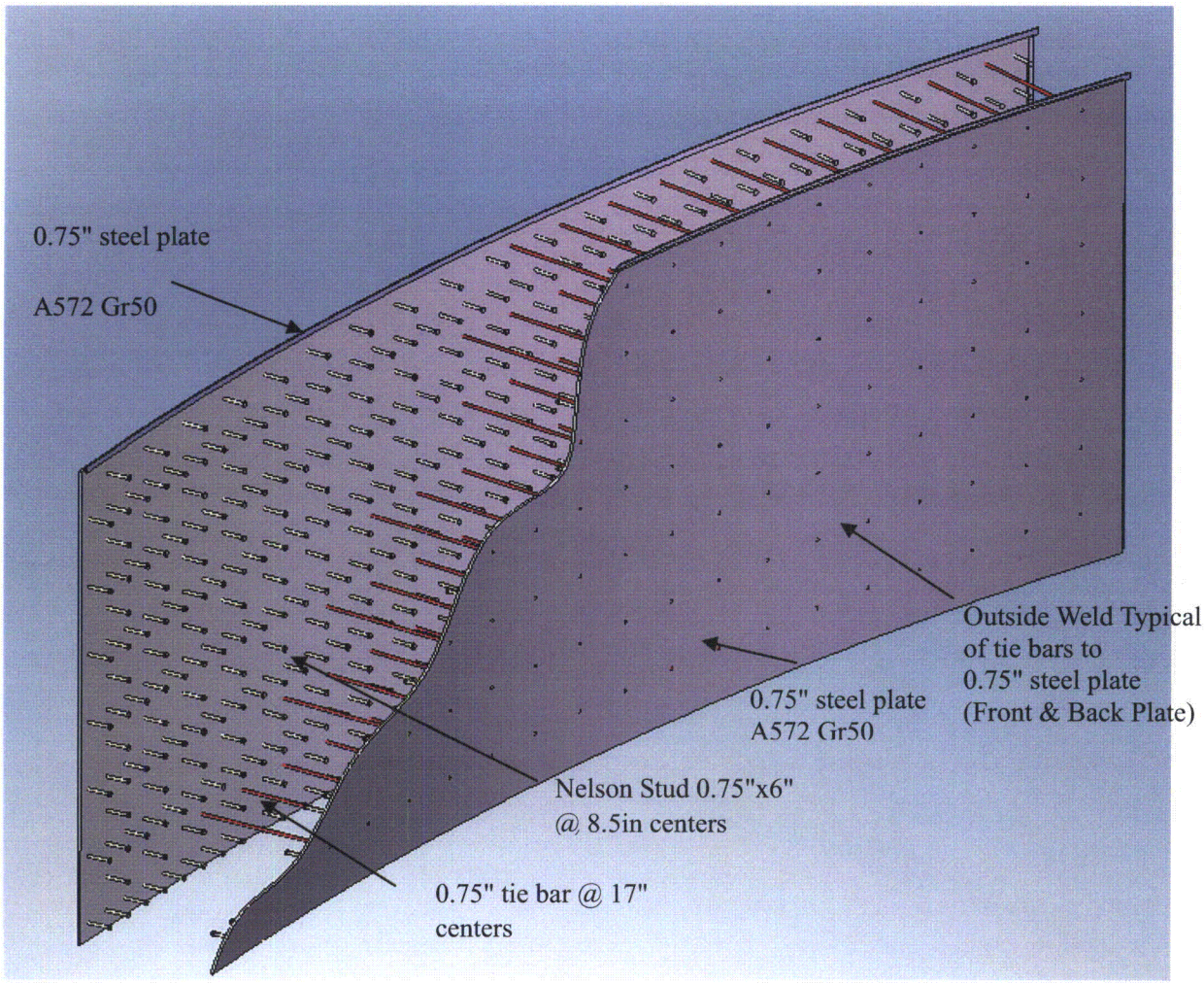


Figure ES-3 Enhanced Shield Building Wall Panel Layout

Air Inlets and Tension Ring (Key Area #3)

The air inlets and tension ring region have been redesigned. The configuration and plate size of the air inlets have been changed to enhance its structural performance. The air inlets structure (as shown on Figure ES-4) is located at the top of the cylindrical wall portion of the Shield Building, beginning at approximately Elevation 251 feet and rising to approximately Elevation 266 feet. The air inlets serve as the intake for air as part of the passive containment cooling system (PCS).

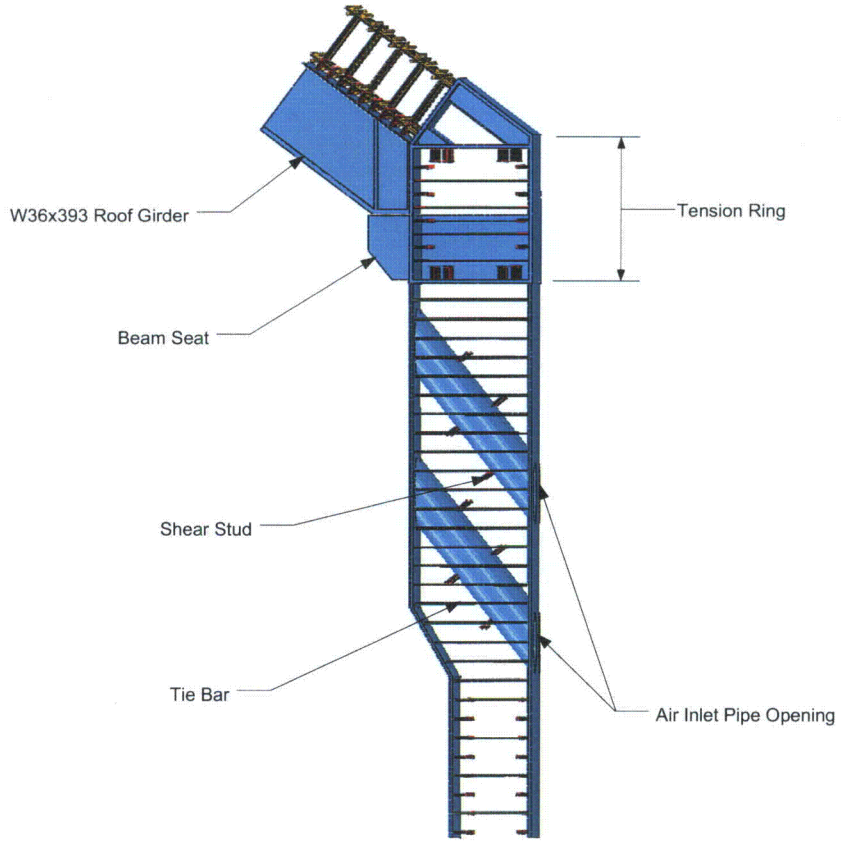


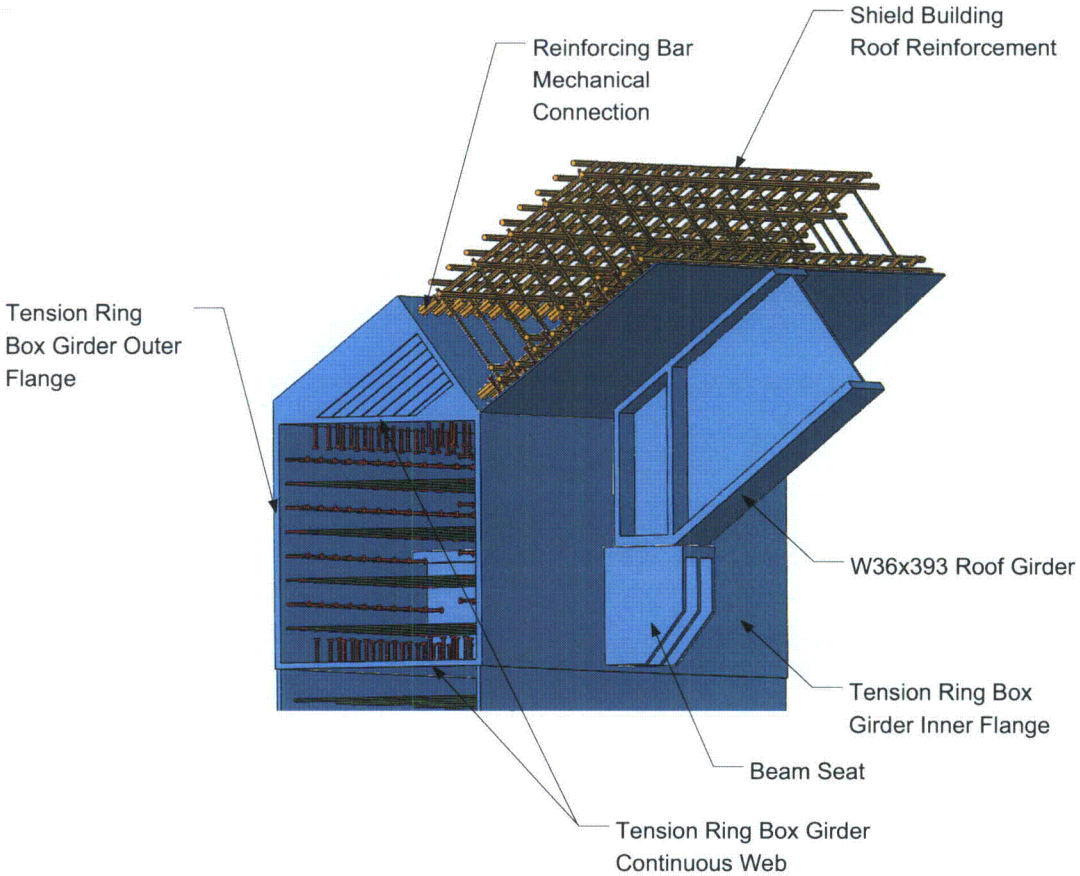
Figure ES-4 Elevation View of Tension Ring and Air Inlets

Above the air inlets, at approximately Elevation 266 feet, is the connection designated as the tension ring that connects and supports the conical roof. The tension ring also contains 32 radial beam seat connections where the W36 x 393 radial beams for the conical roof are connected.

The air inlets region is 4.5-feet thick with 1-inch plates on each face as the primary reinforcement, which are connected using 0.75-inch tie bars. The number, size, and spacing of the air inlet openings has been modified to enhance structural performance. The 236 air inlet openings are formed using 18-inch diameter, Schedule 40 pipe at a downward inclination of 38 degrees from the vertical. The pipe spacing is approximately 2.81 degrees circumferentially with shear studs welded to the outside surface of the pipes. The 18-inch diameter air inlet pipes are welded to the faceplates and tie the faceplates together.

Air flow calculations were completed as a result of changing the air inlet numbers and sizing of the Shield Building. The path for the air circulation continues to meet the safety requirements for the PCS for the Shield Building. The assessment of the impact on the containment cooling was submitted to the NRC in a letter report and is not included in this Shield Building Design Report.

The tension ring has been redesigned as a structural steel box structure with concrete infill and shear studs. Also the connection of the RC conical roof to the tension ring has been redesigned to a mechanical connection. The air inlets and tension ring design methodology is supported by linear analysis and benchmarked nonlinear analysis as presented in this report. The tension ring is designed to ANSI/AISC N690 and is a concrete-filled box girder, with two continuous 1.5-inch thick steel plates top and bottom that connect the inner liner plate to the outer liner plate, as shown in Figure ES-5.



ES-5 Shield Building Tension Ring

SB Roof, Compression Ring, Knuckle Region, and PCS Tank (Key Areas #4, #5, #6, and #7)

The other areas of the Shield Building have been designed to existing industry code requirements, and include the conical roof, the PCS tank, the compression ring, the knuckle region, and their related attachments. Linear analysis was previously performed on these areas and no additional design modifications, analysis, benchmarking, or testing is required. These areas are designed as RC structures in accordance with ACI 349. The steel frame for the roof is designed for the applicable building code ANSI/AISC N690. The concrete roof is designed to ACI 349 requirements without credit for the steel plate on the bottom of the concrete.

Structural Analysis

Benchmarked structural analyses using detailed finite element model are used to demonstrate structural adequacy for the critical areas of the Shield Building. For the Shield Building cylindrical wall and the related connection regions to the roof, the Auxiliary Building, and the basemat, a combination of testing and benchmarked analysis is used to confirm the structural adequacy of the design.

Load combinations for seismic Category I concrete and steel structures were used for the design of the Shield Building. Loads for the design of each structural element were based on the conditions to which the particular structural element is potentially subjected and on the applicable U.S. Nuclear Regulatory Commission Standard Review Plan NUREG 0800. The governing loads and evaluations for various locations were considered. Linear elastic analyses and nonlinear analyses, and load distribution using analysis tools such as SASSI, ANSYS, and LS-DYNA and ABAQUS were performed to confirm that cracking is not significant for load distribution; to confirm that regions of the Shield Building act as a unit; and to show margin for beyond design basis review-level earthquakes.

The Shield Building design has reserve strength that provides seismic margin above the review-level earthquake. The analyses show that the seismic high confidence of low probability of failure (HCLPF) value is above the review-level earthquake value of 0.5g. The standard seismic margin calculations are based on conservative design loads. The linear elastic analyses calculation that shows margin between the capacity of the structure and the design basis loading.

Benchmarked nonlinear analyses were performed on the Shield Building anchorage, cylindrical wall, tension ring, and roof anchorage connections. The benchmarked nonlinear analyses demonstrate significant margin over and above that demonstrated in the linear elastic analyses. Benchmarked Level 2 and Level 3 analyses were performed to demonstrate the system strength and ductility, both at the global level (Level 2) and at the component level (Level 3). In all cases the analyses demonstrate large margin to regulatory safety limits and demonstrate sufficient ductility in the AP1000 Shield Building.

The design life of the Shield Building is 60 years. Nonlinear analyses were performed to assess that buckling, creep, and shrinkage were not significant factors in the design. Concrete material and placement testing was conducted as part of the overall comprehensive test program. Thermal analysis was performed to quantify the effect of daily and seasonal thermal cycles on the cylindrical wall and the effect of cracking due to thermal gradients.

Confirmatory Testing

A confirmatory test program was developed and conducted as part of the Shield Building design process to demonstrate the adequacy of the design modifications and to address NRC comments. The testing program, in conjunction with Purdue University and under the direction of Dr. Amit Varma, included anchorage, out-of-plane shear (with and without tension), and in-plane shear tests. The goal of the testing was to demonstrate the behavior and adequacy of the Shield Building based on the AP1000 design process assumption that the ACI 349 code provisions for RC nuclear structures are conservatively applicable to the SC design of the Shield Building.

Each of the test program elements also included variations of specimen plots to determine their fundamental behavior. A summary of the key test program elements is as follows:

1. Out-of-plane (OOP) shear without tension to demonstrate that the OOP shear strength of the AP1000 SC design can be estimated using ACI code provisions for the shear strength of RC beams

2. OOP shear with tension to demonstrate that axial tension will not significantly affect the ACI strength prediction

3. OOP shear cyclic to demonstrate ductility

4. Pushout to demonstrate the general behavior of SC structures

5. Weld fatigue to determine if the fatigue specimens can support a minimum of 73000 cycles

6. Cyclic in-plane shear to demonstrate that shear strength of SC can be conservatively estimated using ACI code provisions for RC walls as well as ductility

7. Anchorage to demonstrate the strength of the RC/SC connection in tension

8. The in-plane shear strength is greater than that calculated using ACI 349 code

All tests demonstrate the robust behavior of the AP1000 SC structural components. The test program confirms the Westinghouse design approach that the ACI 349 code can conservatively be used to design the SC AP1000 Shield Building. These tests are also used to by Westinghouse in the benchmarking of the nonlinear analyses presented in this report.

Construction and Inspection

Good construction practice starts early by integrating constructability and inspection reviews into the design process.

For the AP1000 design, including the Shield Building, parallel integrated construction and inspection reviews have been proactive and have been included in the design process for the purposes of identifying and accessing engineering information to enhance the design certification process and the development of the overall constructability plan.

These reviews are based on using current available construction and inspection technologies, practices, and procedures.

The objectives of the review are to:

- Validate constructability processes and techniques

- Develop construction interfaces, tolerances, and complete construction sequencing

- Incorporate logic ties for material take-offs, module identification, fabrication, manpower estimates, installation sequences, and inspection

- Detail the structural and architectural critical areas of construction for required mockups and procedures such as concrete placement, welding, and quality assurance

- Analyze the material requirements and establish the required procedures for concrete placement, mix requirements, welding procedures, and inspection techniques according to industry codes and qualification requirements

When critical areas are analyzed and established such as the RC/SC basemat connection and air inlets regions of the Shield Building, they are identified as challenging areas of construction which are then included in the construction mockup plan. The mockups will be fabricated and constructed as a physical representation of the structure for craft, Quality Control inspectors, and construction supervisors.

Post-mockup activities include visual inspections of the mockup surfaces by disassembling the mockup and examining surfaces for verification of strength and/or defects. When defects are found, the procedures will be revised and the mockups repeated until the required results are obtained.

Constructability reviews performed on the Shield Building have yielded improvements and design changes that offer the assurance that the end product of the engineering design will result in a well-constructed plant.

In addition to these constructability practices, additional insights on nondestructive examination (NDE) programs are applied regarding NDE technology in the inspection of post-placement concrete.

Summary

The foregoing claims revised the design process, and the revised design features, analyses, testing, construction, and inspection have resulted in an AP1000 Shield Building revised design that is safe and conservative. This is substantiated by the details of conformance as shown in a detailed compliance matrix. The compliance matrix was developed from the October 15, 2009, NRC letter concerning the original enhanced Shield Building Design Report and is provided as the Executive Summary and Chapter 12 to the report.

Table ES-1 Compliance Matrix

NRC Identified Key Issue	Westinghouse Actions
10 CFR 50.55a	Westinghouse design approach on how it demonstrates that the Shield Building SC design is safe and conservative and meets NRC regulations has been outlined in Section 2 of the report. The Shield Building is a hybrid structure. There are areas of the Shield Building that fall within established codes. For those structures safety is demonstrated by showing margin against code allowable. There are other areas that are considered special structures in accordance with ACI 349, Section 1.4. For those special structures, in addition to meeting Code requirements, safety and margin are demonstrated by testing or benchmarked analyses.
10 CFR 50, Appendix A General Design Criterion (GDC) 1 Quality Standards and Records: insufficient information regarding detail, design analysis, construction, inspection, and testing.	This revision of Shield Building Design Report has been structured to outline the design criteria utilized; the justification as to why the design criteria is adequate; and how the Westinghouse enhanced Shield Building design is meeting the criteria. Specifically the Shield Building design attributes are addressed in the following sections: - Detail Design Sections 1.2, 3.1, 3.4, 4.1, and 6.1 - Design Analysis Section 2 - Construction Section 9 - Inspection Sections 9.7 and 9.8 - Testing Section 7 In addressing general design criteria as defined, Westinghouse has modified and revised its design, analysis, testing, construction, and inspection as previously identified in the report submittal.
General Design Criterion (GDC) 2 Design Bases for protection against natural phenomena; requires safety-related structures to withstand the most severe natural phenomena such as winds, tornadoes, floods, earthquakes, and the appropriate combination of loads.	Westinghouse has revised the design of the cylindrical wall steel concrete composite (SC) and connection designs, where the reinforced concrete (RC) structures and SC structures interact, to function as an integrated unit. Three criteria were utilized to demonstrate compliance: 1) Adequate strength margins to industry and regulatory codes and standards 2) Adequate ductility margin 3) Adequate building durability Specifically these criteria are demonstrated in the following report Sections: - Strength and Ductility Sections 4.2, 3.2, 5.2, 6.2 and Section 10 - Durability Section 3

Table ES-1 Compliance Matrix (cont.)

NRC Identified Key Issue	Westinghouse Actions
Detailing, Design, and Analysis	
1. Westinghouse (WEC) has not demonstrated that it adequately designed and detailed the steel concrete composite (SC) module to function as a fully composite unit as assumed in the WEC design/analysis. In addition, WEC has not demonstrated that the SC module has sufficient ductility to survive severe earthquakes or tornado winds.	Sections 3, 4, 5, 6, and 10, provide the design feature descriptions, methodology, and demonstration of margin for compliance for the revised Shield Building design. The modified cylindrical wall and connection designs, specifically address the adequacy of the structure to act as an integrated unit, providing adequate ductility and durability in severe earthquakes or other natural disasters. With respect to comments made regarding the discontinuity of the six-inch studs, as described in the general description of the Shield Building, Section 1.2, the new tie bars included in the Westinghouse design now employ tie bars spaced on six-inch centers in the higher stressed regions. There are six-inch studs also spaced between the tie bars at 17-inch centers in the lower stressed regions. This creates a maximum spacing between stud and/or tie bar of 8.5 inches.
2. The SC module wall to reinforced concrete (RC) wall connection lacks design and detailing for the RC portion of the connection. Thus, it cannot be determined whether the connection will carry the SB design loads.	The design and detailing for the RC portion of the connection has been added to the Shield Building design report. Inclusion of the RC support structures provides a thorough demonstration of the interaction between the two types of structures. The finite element models utilized to analyze these details provide an overall analysis of the interaction, demonstrating the integration of the building structures.

Table ES-1 Compliance Matrix (cont.)

NRC Identified Key Issue	Westinghouse Actions
3. The design and analysis of the shield building tension ring (i.e., ring girder) and the air inlet region is not supported by a validated design/analysis method (i.e., benchmarked to experimental data), or by confirmatory model tests.	The tension ring and air inlet has been designed to take full advantage of the steel structure (i.e., the exterior and interior steel plates, the steel air tubes, and the rebar in the structure). The tension ring has been designed in accordance to AISC/ANSI N690. Very detailed finite element models of the air inlets and tension ring were used to demonstrate the adequacy of this design. Consistent with the analysis approach outlined in the report, a Level 3 analysis of the tension ring and air inlets was performed. This analysis model takes into account the details of the design, which uses the loads/deformations from the Level 2 analyses. Both Level 2 and Level 3 analyses have been benchmarked to experimental data. The design is discussed in Section 5.
4. The use of a simple shell element to represent the 36-inch-thick SC wall module and the use of coarse meshes near the areas of discontinuities may be adequate for performing preliminary evaluations of overall building responses, but are insufficient for performing the subsequent detailed design/analysis (i.e., assessing stress/strain magnitudes) for stress/strain distributions within the elements and at structural discontinuities (e.g., SC-RC and the auxiliary building roof connection areas).	Westinghouse has outlined an analysis approach in the report which utilizes a combination of analysis techniques categorized as Level 2 and Level 3 analyses. Each analysis chapter of this report has both a Level 2 and 3 sections. Both Level 2 and Level 3 analyses use solid elements to represent the 36-inch-thick SC wall module. The Level 3 section provides the very detailed finite element models which are being used to assess stress-strain magnitudes within critical regions, demonstrating the adequacy of that critical region design.
5. WEC has not considered the self-consolidating concrete (SCC) material properties and their effect (e.g., higher shrinkage and creep strains, less shear resistance and ductility compared to that of normal concrete) on the behavior of the shield building, and did not include those effects in its design/analysis process.	An examination of self-consolidating concrete (SCC) behavior has been documented in industry performance tests. In addition, Westinghouse has provided construction field tests performed as part of the AP1000 plant construction in China that demonstrate acceptable strength and shrinkage properties of SCC. SCC has been minimized in the revised design of the AP1000 Shield Building by the constructability reviews performed on the design. SCC will be used in the air inlets and knuckle regions of the roof, and RC/SC connection. The remainder of the Shield Building will be constructed using standard concrete. The use of SCC for the tension ring and knuckle region of the roof is judged acceptable for these sections based on the design analysis performed.

Table ES-1 Compliance Matrix (cont.)

NRC Identified Key Issue	Westinghouse Actions
6. WEC has not considered the daily and seasonal thermal cycling effect on the fatigue of welded joints between the SC module steel faceplate and studs, the stress and strain reversal in concrete and studs, and the degradation of bond strength between the concrete and studs.	The issue of thermal cycling has been addressed in Section 3.3 of the report. In effect, finite element heat transfer and nonlinear analyses were performed to address these issues. In addition, the design modifications to the SC wall, which incorporated shear ties that tie the plates together, make the SC wall design less susceptible to fatigue due to thermal cycling.
7. The thickness of steel faceplates in the SC module (1/2 inch) appears to be less than required, because the actual maximum principal stress appears to be higher than the allowable principal stress.	Westinghouse modified the cylindrical wall by increasing the plate thickness from 0.5-inch ASTM A572 Grade 65 steel plate to 0.75-inch ASTM A572 Grade 50 steel plate connected together with 0.75-inch reinforcing tie bars. These changes provide additional design (stress) margin as well as contributing to overall strength margin of the Shield Building.
8. WEC has not provided sufficient information to demonstrate that the effect of local buckling of the SC module faceplates are precluded.	Section 3.3.2 of the report addresses creep effects on the design. The analysis has demonstrated that creep is not an issue. Even with conservative assumptions on shrinkage and creep, the surface stresses in the steel plate are well below the strength of the steel plate. Additionally the increased plate thickness and decreased stud spacing has reduced the potential for local plate buckling. This is described in Section 3.3.1.
Construction and Inspection	
WEC has not provided construction and inspection methods required to ensure the safety of the shield building design. Inspection of voids, cracking, delamination, and substandard construction of concrete are needed to ensure integrity of the structure.	Section 9 of the revised Shield Building Report is fully dedicated to construction and inspection practices, including critical construction mockups. In addition, Section 9.8 of this report describes the NDE technologies available for post-placement concrete inspection and the results of NDE testing demonstrations performed by Westinghouse.

Table ES-1 Compliance Matrix (cont.)	
NRC Identified Key Issue	**Westinghouse Actions**
Testing	
1. The proposed test specimens are not fully representative of the SC module (e.g., substituting studs for L-shaped angle stiffeners and ignoring welded joints of the faceplates).	The cylindrical wall design has changed and the tests performed were fully representative of the SC module configuration. Section 7 of the report describes at length the design of the test specimens and why they are representative of the design and design loading of the Shield Building.
2. The proposed WEC test setup for demonstrating the adequacy of the SC wall module under combined in-plane shear and tension loading [Test #4] has boundary conditions that will constrain the test specimen and thus lead to an over-estimation of actual strength. Further, the proposed test loads are monotonic and thus do not represent the reversed cyclic dynamic loads on the shield building generated by earthquakes.	The in-plane test has been significantly changed to address the comments provided. Specifically, the setup of the test has been changed that the boundary conditions will not cause an overestimation of actual strength. Section 7 of the report is dedicated to the in-plane test. Two specimens are being tested for in-plane cyclic shear capacity.

1 INTRODUCTION

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2 SHIELD BUILDING DESIGN

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3 SHIELD BUILDING CYLINDRICAL WALL DESIGN

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4 SHIELD BUILDING STEEL CONCRETE COMPOSITE TO REINFORCED CONCRETE CONNECTIONS

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5 DESIGN OF THE TENSION RING AND AIR INLET STRUCTURE

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6 REINFORCED CONCRETE REGIONS OF THE SHIELD BUILDING

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7 SHIELD BUILDING TEST PROGRAM

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8 BENCHMARKING

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9 CONSTRUCTION AND CONSTRUCTION INSPECTION

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10 SHIELD BUILDING DESIGN PROCESS

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11 SHIELD BUILDING DESIGN MARGIN AND CONSERVATISMS

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12 CONCLUSION

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APPENDIX A
REVIEW OF INTERNATIONAL TEST DATA RELATED TO AP1000 SHIELD BUILDING SC CONSTRUCTION

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APPENDIX B
LEVEL 2 ANALYSES

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APPENDIX C
LEVEL 3 ANALYSES

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APPENDIX D
DESIGN SKETCHES

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APPENDIX E
ACI 349 REINFORCEMENT DESIGN

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APPENDIX F
FORCE CONTOURS OF LINEAR ELASTIC ANALYSIS

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APPENDIX G
EXCEL MACRO TO SIZE REINFORCEMENT

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APPENDIX H
ATTACHMENT TO DCP_NRC_002995

This attachment represents the Westinghouse responses to NRC staff comments from the June 9-11, 2010, meetings in Rockville, Maryland. The staff comments were generated in response to review of the Westinghouse Design Report for the AP1000 Enhanced Shield Building, (APP-1200-S3R-003, Revision 2) from May 2010.

H.1 Item 1

H.1.1 1-A Demand

Westinghouse Position

Westinghouse states that capacity is greater than demand. In Appendix F, WEC shows contour plots of member forces for load combination 6 (for the SC wall).

NRC Understanding

Although Appendix F contains force contours, the plots are insufficient for full understanding of the design demands and related design capacities.

Staff believes that it is necessary to know the magnitude of demands (required bending moment, shear, and torsion), and of the capacity of the member with respect to bending moment, shear, and torsion. This is usually presented by plotting the magnitude of demands and capacities along the entire length of the member. However, these plots are absent in the report.

NRC Question

Provide the calculated demands and capacities in a form that permits the full and ready understanding of the design demands and related design capacities?

For example, provide information, i.e., plots for OOPS (wall, roof, and PCS tank), in-plane shear (wall), torsion (wall), bending moment (wall, roof, and PCS tank). Also, include plots of capacity with only the steel contribution to the OOPS (SC wall) capacity and identify locations where the steel contribution alone would be insufficient to meet demands.

H.1.1.1 Action 1

Westinghouse Understanding

Westinghouse will provide contour plots, demand Vd/Phi*Vs and Vd/Phi* (Vc+Vs) on unfolded SC Wall.

Response

Questions 1 and 2 are a combined response listed in Section H.1.1.2.

H.1.1.2 Action 2

Westinghouse will review current analysis to determine if Phi*Vs is exceeded and provide a justification.

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H.1.1.3 Action 3

Westinghouse will provide an assessment on minimum notch toughness and detailing to mitigate premature fracture under SSE earthquake for significant welds.

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H.1.1.4 Action 4

Westinghouse will assess the effects of cracking, show that the in-plane shear distribution near the base of the West Wall and right above the roof at the Auxiliary Building at [ ]a,c and show that the maximum in-plane shear remains within the code allowable. Westinghouse will utilize [ ]a,c for NI05 and [ ]a,c

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H.1.2 1B- Out-of-plane (OOP) Shear Capacity

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NRC Question

Based on the indicated brittle failure in the OOPS test of the specimen, as provided under Figure 7.7-7 pg. 7-18, and given that Westinghouse indicated that they will demonstrate ductile failure, justify how the resultant brittle failure demonstrates safety in the Shield Building structure.

H.1.2.1 Action 5

Westinghouse will provide stress/strain test data for the tie bars with [ ]a,c and the ASTM specifications used for the construction material.

Designation: A 496/A 496M – 07

Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement[1]

This standard is issued under the fixed designation A 496/A 496M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers deformed steel wire which has been cold-worked by drawing, rolling, or both drawing and rolling, to be used as produced, or in fabricated form, for the reinforcement of concrete in sizes having nominal cross-sectional areas not less than 6.45 mm^2[0.01 in.^{2}].

1.2 Supplement S1 describes high-strength wire, which shall be furnished when specifically ordered. It shall be permissible to furnish high-strength wire in place of regular wire if mutually agreed to by the purchaser and manufacturer.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. (The inch-pound units are shown in brackets except in Table 1).

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 497/A 497M Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment

E 83 Practice for Verification and Classification of Extensometer Systems

2.2 *Military Standards:*[3]

MIL-STD-129 Marking for Shipment and Storage

2.3 *Federal Standard:*[3]

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)

2.4 *ACI Standard:*[4]

ACI 318 Building Code Requirements for Structural Concrete

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *deformed steel wire for reinforcement—as used within the scope and intent of this specification*, shall mean any cold-worked, deformed steel wire intended for use as reinforcement in concrete construction, the wire surface having deformations that: (1) inhibit longitudinal movement of the wire in such construction; and (2) conform to the provisions of Section 5. It shall be permissible for the deformations to be raised or indented.

3.1.2 *size number—as used in this specification*, refers to the numerical designation of the wire as tabulated in Table 1 and Table 2 under the column headed Deformed Wire Size Number, or a number indicating the nominal cross-sectional area of the deformed wire in square millimeters [hundredths of a square inch].

4. Ordering Information

4.1 When deformed wire is ordered by size number, the dimensional requirements shall be as given in Table 1. When deformed wire is ordered to dimensions other than the sizes shown, the nominal dimensions shall be developed from the applicable unit mass per meter [weight per foot] of the section.

4.2 It shall be the responsibility of the purchaser to specify all requirements that are necessary for the manufacture and delivery of the wire under this specification. Such requirements to be considered include, but are not limited to, the following:

4.2.1 Quantity (mass [weight]),

4.2.2 Name of material (deformed steel wire for concrete reinforcement),

4.2.3 Wire diameter (see Table 1 and Table 2),

4.2.4 Yield strength measurement (see 8 and 13.3),

4.2.5 Packaging (see Section 17), and

4.2.6 ASTM designation and year of issue,

4.2.7 Special requirements, if any. (See Supplement S1.)

NOTE 1—A typical ordering description is as follows: 50 000 lb

[1] This specification is under the jurisdiction of ASTM A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of A01.05 on Steel Reinforcement.

Current edition approved Sept. 1, 2007. Published October 2007. Originally approved in 1964. Last previous edition approved in 2005 as A 496/A 496M–05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

[4] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.aci-int.org.

***A Summary of Changes section appears at the end of this standard.**

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TABLE 1 Dimensional Requirements for Deformed Wire for Concrete Reinforcement in SI Units

Nominal Dimensions								Deformation Requirements							
Deformed Wire Size[A,B,C]	[D in.²] [× 100]	Unit Wt.		Diameter[D]		Cross-Sectional Area[D,E]		Perimeter		Spacing, Maximum		Spacing, Minimum		Min. Avg. Height of Deformations	
		kg/m	[lbs/ft.]	mm	[in.]	mm²	[in.²]	mm	[in.]	mm	[in.]	mm	[in.]	mm[F]	[in.]
MD 25	[D 3.9]	0.196	[0.132]	5.64	[0.222]	25	[0.039]	17.7	[0.698]	7.24	[0.285]	4.62	[0.182]	0.252	[0.010]
MD 30	[D 4.7]	0.235	[0.158]	6.18	[0.243]	30	[0.047]	19.4	[0.764]	7.24	[0.285]	4.62	[0.182]	0.279	[0.011]
MD 35	[D 5.4]	0.275	[0.185]	6.68	[0.263]	35	[0.054]	21.0	[0.826]	7.24	[0.285]	4.62	[0.182]	0.302	[0.012]
MD 40	[D 6.2]	0.314	[0.211]	7.14	[0.281]	40	[0.062]	22.4	[0.883]	7.24	[0.285]	4.62	[0.182]	0.320	[0.013]
MD 45	[D 7.0]	0.353	[0.237]	7.57	[0.298]	45	[0.070]	23.8	[0.936]	7.24	[0.285]	4.62	[0.182]	0.342	[0.014]
MD 50	[D 7.8]	0.392	[0.264]	7.98	[0.314]	50	[0.078]	25.1	[0.987]	7.24	[0.285]	4.62	[0.182]	0.360	[0.014]
MD 55	[D 8.5]	0.432	[0.290]	8.37	[0.329]	55	[0.085]	26.3	[1.04]	7.24	[0.285]	4.62	[0.182]	0.378	[0.015]
MD 60	[D 9.3]	0.471	[0.316]	8.74	[0.344]	60	[0.093]	27.5	[1.08]	7.24	[0.285]	4.62	[0.182]	0.392	[0.015]
MD 65	[D 10.1]	0.510	[0.343]	9.10	[0.358]	65	[0.101]	28.6	[1.13]	7.24	[0.285]	4.62	[0.182]	0.455	[0.018]
MD 70	[D 10.9]	0.549	[0.369]	9.44	[0.372]	70	[0.109]	29.7	[1.17]	7.24	[0.285]	4.62	[0.182]	0.470	[0.018]
MD 80	[D 12.4]	0.628	[0.422]	10.1	[0.397]	80	[0.124]	31.7	[1.25]	7.24	[0.285]	4.62	[0.182]	0.505	[0.020]
MD 90	[D 14.0]	0.706	[0.475]	10.7	[0.421]	90	[0.140]	33.6	[1.32]	7.24	[0.285]	4.62	[0.182]	0.535	[0.021]
MD 100	[D 15.5]	0.785	[0.527]	11.3	[0.444]	100	[0.155]	35.4	[1.40]	7.24	[0.285]	4.62	[0.182]	0.565	[0.022]
MD 120	[D 18.6]	0.942	[0.633]	12.4	[0.487]	120	[0.186]	38.8	[1.53]	7.24	[0.285]	4.62	[0.182]	0.620	[0.024]
MD 130	[D 20.2]	1.02	[0.686]	12.9	[0.507]	130	[0.202]	40.4	[1.59]	7.24	[0.285]	4.62	[0.182]	0.645	[0.025]
MD 200	[D 31.0]	1.57	[1.05]	16.0	[0.628]	200	[0.310]	50.1	[1.97]	7.24	[0.285]	4.62	[0.182]	0.800	[0.031]
MD 290	[D 45.0]	2.28	[1.53]	19.2	[0.757]	290	[0.450]	60.4	[2.38]	7.24	[0.285]	4.62	[0.182]	0.961	[0.0379]

[A] The number following the prefix indicates the nominal cross-sectional area of the deformed wire in square millimeters.

[B] For sizes other than those shown above, the Size Number shall be the number of one hundredths of a square inch in the nominal area of the deformed wire cross section, prefixed by the letters MD.

[C] These sizes represent the most readily available sizes in the welded wire reinforcement industry. Other wire sizes are available and many manufacturers can produce them in 1-mm² [0.0015-in.²] increments.

[D] The nominal diameter of a deformed wire is equivalent to the diameter of a plain wire having the same mass per metre as the deformed wire.

[E] The cross-sectional area is based on the nominal diameter. The area in square millimetres [inches] is calculated by dividing the unit mass [weight] in kg/mm [lbs./in.] by 7×10^{-6} (mass of 1 mm³ of steel [0.2833 weight of 1 in.³ of steel]) or by dividing the unit mass [weight] in kg/m [lbs./ft.] by 0.007849 (mass of steel 1 mm square and 1 m long) [3.4 (weight of steel 1in. square and 1 ft. long)].

[F] The minimum average height of the deformations shall be determined from measurements made on not less than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentation as described in 7.7.

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TABLE 2 Dimensional Requirements for Deformed Steel Wire for Concrete Reinforcement—US Customary Units Wire Sizes[A]

	Nominal Dimensions			Deformation Requirements			
Deformed Wire Size Number[B,C]	Unit Weight, lb/ft [kg/m]	Diameter, in. [mm][D]	Cross-sectional Area, in.^{2}[mm^2][E]	Perimeter, in. [mm]	Maximum Spacing, in. [mm]	Minimum Spacing, in. [mm]	Minimum Average Height of Deformations, in. [mm][F,G]
D-1	0.034 [0.051]	0.113 [2.87]	0.010 [6.45]	0.354 [9.00]	0.285 [7.24]	0.182 [4.62]	0.0045 [0.114]
D-2	0.068 [0.101]	0.160 [4.05]	0.020 [12.9]	0.501 [12.7]	0.285 [7.24]	0.182 [4.62]	0.0063 [0.160]
D-3	0.102 [0.152]	0.195 [4.96]	0.030 [19.4]	0.614 [15.6]	0.285 [7.24]	0.182 [4.62]	0.0078 [0.198]
D-4	0.136 [0.202]	0.226 [5.73]	0.040 [25.8]	0.709 [18.0]	0.285 [7.24]	0.182 [4.62]	0.0101 [0.257]
D-5	0.170 [0.253]	0.252 [6.41]	0.050 [32.3]	0.793 [20.1]	0.285 [7.24]	0.182 [4.62]	0.0113 [0.287]
D-6	0.204 [0.304]	0.276 [7.02]	0.060 [38.7]	0.868 [22.1]	0.285 [7.24]	0.182 [4.62]	0.0124 [0.315]
D-7	0.238 [0.354]	0.299 [7.58]	0.070 [45.2]	0.938 [23.8]	0.285 [7.24]	0.182 [4.62]	0.0134 [0.304]
D-8	0.272 [0.405]	0.319 [8.11]	0.080 [51.6]	1.00 [25.5]	0.285 [7.24]	0.182 [4.62]	0.0143 [0.363]
D-9	0.306 [0.455]	0.339 [8.60]	0.090 [58.1]	1.06 [27.0]	0.285 [7.24]	0.182 [4.62]	0.0152 [0.386]
D-10	0.340 [0.506]	0.357 [9.06]	0.100 [64.5]	1.12 [28.5]	0.285 [7.24]	0.182 [4.62]	0.0160 [0.406]
D-11	0.374 [0.557]	0.374 [9.51]	0.110 [71.0]	1.18 [29.9]	0.285 [7.24]	0.182 [4.62]	0.0187 [0.475]
D-12	0.408 [0.607]	0.391 [9.93]	0.120 [77.4]	1.23 [31.2]	0.285 [7.24]	0.182 [4.62]	0.0195 [0.495]
D-13	0.442 [0.658]	0.407 [10.3]	0.130 [83.9]	1.28 [32.5]	0.285 [7.24]	0.182 [4.62]	0.0203 [0.516]
D-14	0.476 [0.708]	0.422 [10.7]	0.140 [90.3]	1.33 [33.7]	0.285 [7.24]	0.182 [4.62]	0.0211 [0.536]
D-15	0.510 [0.759]	0.437 [11.1]	0.150 [96.8]	1.37 [34.9]	0.285 [7.24]	0.182 [4.62]	0.0218 [0.554]
D-16	0.544 [0.810]	0.451 [11.5]	0.160 [103]	1.42 [36.0]	0.285 [7.24]	0.182 [4.62]	0.0225 [0.572]
D-17	0.578 [0.860]	0.465 [11.8]	0.170 [110]	1.46 [37.1]	0.285 [7.24]	0.182 [4.62]	0.0232 [0.589]
D-18	0.612 [0.911]	0.479 [12.2]	0.180 [116]	1.50 [38.2]	0.285 [7.24]	0.182 [4.62]	0.0239 [0.607]
D-19	0.646 [0.961]	0.492 [12.5]	0.190 [122]	1.55 [39.2]	0.285 [7.24]	0.182 [4.62]	0.0245 [0.622]
D-20	0.680 [1.01]	0.505 [12.8]	0.200 [129]	1.59 [40.3]	0.285 [7.24]	0.182 [4.62]	0.0252 [0.604]
D-21	0.714 [1.06]	0.517 [13.1]	0.210 [135]	1.62 [41.3]	0.285 [7.24]	0.182 [4.62]	0.0259 [0.658]
D-22	0.748 [1.11]	0.529 [13.4]	0.220 [141]	1.66 [42.2]	0.285 [7.24]	0.182 [4.62]	0.0265 [0.673]
D-23	0.782 [1.16]	0.541 [13.7]	0.230 [148]	1.70 [43.2]	0.285 [7.24]	0.182 [4.62]	0.0271 [0.688]
D-24	0.816 [1.21]	0.553 [14.0]	0.240 [154]	1.74 [44.1]	0.285 [7.24]	0.182 [4.62]	0.0277 [0.704]
D-25	0.850 [1.26]	0.564 [14.3]	0.250 [161]	1.77 [45.0]	0.285 [7.24]	0.182 [4.62]	0.0282 [0.716]
D-26	0.884 [1.32]	0.575 [14.6]	0.260 [167]	1.81 [45.9]	0.285 [7.24]	0.182 [4.62]	0.0288 [0.732]
D-27	0.918 [1.37]	0.586 [14.9]	0.270 [174]	1.84 [46.8]	0.285 [7.24]	0.182 [4.62]	0.0293 [0.744]
D-28	0.952 [1.42]	0.597 [15.2]	0.280 [180]	1.88 [47.6]	0.285 [7.24]	0.182 [4.62]	0.0299 [0.759]
D-29	0.986 [1.47]	0.608 [15.4]	0.290 [187]	1.91 [48.5]	0.285 [7.24]	0.182 [4.62]	0.0304 [0.772]
D-30	1.02 [1.52]	0.618 [15.7]	0.300 [193]	1.94 [49.3]	0.285 [7.24]	0.182 [4.62]	0.0309 [0.785]
D-31	1.05 [1.57]	0.628 [16.0]	0.310 [200]	1.97 [50.1]	0.285 [7.24]	0.182 [4.62]	0.0314 [0.798]
D-45	1.53 [2.28]	0.757 [19.2]	0.450 [290]	2.38 [60.4]	0.285 [7.24]	0.182 [4.62]	0.0379 [0.961]

[A] In this table only, inch-pound units are regarded as standard and SI units are shown in brackets.

[B] The number following the prefix indicates the nominal cross-sectional area of the deformed wire in square inches [square millimeters].

[C] For sizes other than those shown above, the Size Number shall be the number of one hundredths of a square inch in the nominal area of the deformed wire cross section, prefixed by the letter D.

[D] The nominal diameter of a deformed wire is equivalent to the diameter of a plain wire having the same weight per foot as the deformed wire.

[E] The cross-sectional area is based on the nominal diameter. The area in square inches [millimeters] is calculated by dividing the unit weight [mass] in lbs./in. [kg/mm] by 0.2833 (weight of 1 in.^{3} of steel) [7×10^{-6}(mass of 1 mm^3 of steel)], or by dividing the unit weight [mass] in lbs./ft. [kg/m] by 3.4 (weight of steel 1 in. square and 1 foot long) [0.007849 (mass of 1 mm square and 1 m long)].

[F] The minimum average height of the deformations shall be determined from measurements made on not less than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentation as described in 6.2.

[G] These sizes represent the most readily available sizes in the welded wire reinforcement industry. Other wire sizes are available and many manufacturers can produce them in 0.0015-in^2 [1-mm^2] increments.

deformed steel wire for concrete reinforcement, size No. MD80 [D12.4], in 800 kg [2000 lb] secured coils, to ASTM A 496/A 496M –____ .

5. Materials and Manufacture

5.1 The steel shall be made by one of the following processes: open-hearth, electric furnace, or basic oxygen.

5.2 The deformed steel wire shall be produced from rods or bars that have been hot rolled from billets.

6. Requirements

6.1 Deformations shall be spaced along the wire at a substantially uniform distance and shall be symmetrically dispersed around the perimeter of the section. The deformations on all longitudinal lines of the wire shall be similar in size and shape. A minimum of 25 % of the total surface area shall be deformed by measurable deformations.

6.2 Deformed wire shall have two or more lines of deformations.

6.3 The average longitudinal spacing of deformations shall be not less than 3.5 nor more than 5.5 deformations per 25.4 mm [1 in.] in each line of deformations on the wire.

6.4 The minimum average height of the center of typical deformations based on the nominal wire diameters shown in Table 1 and Table 2 shall be as follows:

Wire Sizes	Minimum Average Height of Deformations, Percent of Nominal Wire Diameter
MD20 [D3] and smaller	4
Larger than MD20 [D3] through MD65 [D10]	4 ½
Larger than MD65 [D10]	5

6.5 The deformations shall be placed with respect to the axis of the wire so that the included angle is not less than 45°; or if deformations are curvilinear, the angle formed by the transverse axis of the deformation and the wire axis shall be not less than 45°. Where the line of deformations forms an included

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TABLE 3 Tension Test Requirements

	MPa [psi] min
Tensile strength	585 [85 000]
Yield strength	515 [75 000]

angle with the axis of the wire from 45 to 70° inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the included angle is greater than 70°, a reversal in direction is not required.

7. Dimensions

7.1 The average spacing of deformations shall be determined by dividing a measured length of the wire specimen by the number of individual deformations in any one row of deformations on any side of the wire specimen. A measured length of the wire specimen shall be considered the distance from a point on a deformation to a corresponding point on any other deformation in the same line of deformations on the wire.

7.2 The minimum average height of deformations shall be determined from measurements made on not less than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentations.

8. Mechanical Property Requirements

8.1 *Tension Tests*:

8.1.1 When tested as described in Test Methods and Definitions A 370, the material, except as specified in 8.1.2 shall conform to the tensile property requirements in Table 3, based on the nominal area of wire.

8.1.2 When required by the purchaser, yield strength shall be determined using a Class B-1 extensometer as described in Practice E 83. The yield strength shall be determined as described in Test Methods and Definitions A 370 and an extension of 0.5 % of gage length. It shall be permissible to remove the extensometer after the yield strength has been determined. The wire shall meet the requirements of Table 3 or 4, whichever is applicable.

8.1.3 For material to be used in the fabrication of welded wire reinforcement, the tensile and yield strength properties shall conform to the requirements given in Table 4, based on the nominal area of the wire.

8.1.4 The material shall not exhibit a definite yield point as evidenced by a distinct drop of the beam or halt in the gage of the testing machine prior to reaching ultimate tensile load.

8.2 *Bend Test*—The bend test specimen shall withstand being bent at room temperature through 90° without cracking on the outside of the bent portion, as prescribed in Table 5.

9. Permissible Variation in Mass [Weight]

9.1 The permissible variation in mass [weight] of any deformed wire shall be ±6 % of its nominal weight. The theoretical masses [weights] shown in Table 1, or similar calculations on unlisted sizes, shall be used to establish the variation.

10. Workmanship, Finish, and Appearance

10.1 The wire shall be free of detrimental imperfections and shall have a workmanlike finish.

TABLE 4 Tension Test Requirements (Material for Welded Wire Reinforcement)

	MPa [psi] min
Tensile strength	550 [80 000]
Yield strength	485 [70 000]

TABLE 5 Bend Test Requirements

Size Number of Wire	Bend Test
MD39 [D6] and smaller	Bend around a pin the diameter that is equal to twice the diameter of the specimen
Larger than MD39 [D6]	Bend around a pin the diameter that is equal to four times the diameter of the specimen

10.2 Rust, surface seams, or surface irregularities shall not be a cause for rejection provided the requirements of 10.3 are met, and the minimum dimensions and mechanical properties of a hand wire-brushed test specimen meet the requirements of this specification.

10.3 Wire intended for welded wire reinforcement shall be sufficiently free of rust and drawing lubricant, so as not to interfere with electric resistance welding.

11. Sampling

11.1 Test specimens for testing mechanical properties shall be full wire sections and shall be obtained from the ends of the wire product as drawn or rolled, or both drawn and rolled. The specimens shall be of sufficient length to perform testing described in 8.1 and 8.2.

11.2 Any test specimen exhibiting obvious isolated imperfections that are not representative of the product shall be discarded and another specimen substituted.

12. Number of Tests

12.1 One tension and one bend test shall be made from each 9000 kg [10 tons] or less of each size of wire or fraction thereof in a lot, or a total of seven samples, whichever is less. A lot shall consist of all the coils of a single size offered for delivery at the same time.

13. Inspection

13.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's facilities that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification.

13.2 Except for yield strength, all tests and inspections shall be made at the manufacturer's facilities prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the manufacturer's facilities.

13.3 The purchaser shall have the option to require a yield strength measurement to determine compliance with yield strength requirements in 8.1, and shall specify that the measurements be performed by the manufacturer at the manufacturer's facilities, a recognized laboratory, or the purchaser's

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representative at the manufacturer's facilities. Such measurements shall be conducted without unnecessarily interfering with manufacturing operations.

13.4 *For U.S. Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor shall have the option to use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

14. Rejection

14.1 Material that shows detrimental imperfections subsequent to its acceptance at the manufacturer's facilities shall be rejected, and the manufacturer shall be notified.

14.2 Failure of any of the test specimens to comply with the requirements of this specification shall constitute grounds for rejection of the lot represented by the specimen.

14.3 Any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within two weeks of the date of inspection or test. The material shall be adequately protected and correctly identified such that the manufacturer is able to make a proper investigation.

15. Rehearing

15.1 Rejected material shall be preserved for a period of not less than two weeks from the date of inspection, during which time the manufacturer shall have the option to make claim for a rehearing and retesting.

15.2 The manufacturer shall have the option to resubmit the rejected lot for re-inspection or retesting by inspecting or testing every coil for the property in which the specimen failed and sorting out non-conforming coils.

16. Certification

16.1 When specified in the purchase order or contract, the purchaser shall be furnished with the manufacturer's written certification that the material was manufactured, sampled, tested, and inspected in accordance with, and meets the requirements of, this specification. When specified in the purchase order or contract, a report of the test results shall be furnished. The certification shall include the specification number, year-date of issue and revision letter, if any.

16.2 A Material Test Report, Certificate of Inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked ASTM standard(s) and conform to any existing EDI agreement between the purchaser and the manufacturer. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

NOTE 2—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

17. Packaging and Marking

17.1 The size of the wire, ASTM designation, and name or mark of the manufacturer shall be marked on a tag securely attached to each coil of wire.

17.2 Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with Practices A 700.

17.3 When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 or U.S. government civil agencies.

18. Keywords

18.1 concrete reinforcement; deformations (indentations); steel wire

SUPPLEMENTARY REQUIREMENTS

S1. High-Strength Wire

S1.1 *Scope*—This supplement delineates only those details that are relative to high-strength wire and to the mechanical requirements for wire having properties generally as described in this specification.

NOTE S1.1—Building codes, for example, ACI 318 permit the use of reinforcement with a yield strength up to 550 MPa [80 000 psi]. For compatibility with the codes' design provisions for high-strength reinforcement, this supplement prescribes requirements for the mechanical properties of wire that exceed the minimum values for yield strength and tensile strength in Table 3 and Table 4 of this specification

S1.2 *Mechanical Property Requirements:*

S1.2.1 Minimum yield strength shall be specified in the purchase order in increments of 17.5 MPa [2500 psi]. When tested the yield strength shall be determined at an extension under load of 0.35 %.

NOTE S1.2—To conform to the limit on yield strength in building codes, the minimum yield strength specified in the purchase order should not be greater than 550 MPa [80 000 psi].

S1.2.2 Minimum tensile strength shall be 70 MPa [10 000 psi] greater than the minimum specified yield strength.

NOTE S1.3—A typical order entry line for minimum yield strength is, "72 500 psi minimum yield strength" or "500 MPa minimum yield strength."

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S1.3 *Certification*—Certification for material produced to this supplement shall include a report of the test results for yield strength, tensile strength, and bend tests. Frequency of testing shall conform to Section 12 of this specification and Section 12 of Specification A 497/A 497M as applicable.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 496/A 496M–05) that may impact the use of this standard.

(*1*) Removed reference to MIL-STD-163.

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H.1.3 1C- Global Stability

Westinghouse Position

In report Section 3.3.1, Westinghouse addresses local buckling of the Shield Building, but does not address global buckling.

NRC Understanding

ACI 334.1R-92 (reapproved 2002), "Concrete Shell Structures Practice and Commentary," Chapter 5-stability, states "In common with other structures, shell should be investigated for buckling...Poor correlation between the results of theory and experiment exists when both principal membrane forces are compressive, as in the case of: 1. Cylindrical shells under axial compressive load; 2. Cylindrical shells under distributed load normal to the surface, which causes bending; and 3. Domes under inward radial pressure. In extreme cases, the buckling load obtained experimentally has been found to be as little as 10% of that predicated by the small deflection theory."

NRC Question

Given the uniqueness of the Shield Building design, with a significant concentrated load at the top of the structure (i.e., PCS tank), how does Westinghouse address concerns with global stability, such as that provided for under the ACI 334.1R-92, or justify why it is not required?

H.1.3.1 Action 6

Westinghouse will provide buckling justification and the tolerances. a,c

[ ]

H.2 ITEM 2 (RC/SC CONNECTION)

H.2.1 2A- RC/SC Connection, Load Path

Westinghouse Position

Westinghouse's proposed connection between the SC and RC as shown in Figure D.1-5, pg. D6 and Figure 4.1-2, pg. 4-6.

NRC Understanding

The proposed connection between the SC and RC transfers loads from the steel faceplates to a horizontal steel plate, which is welded to the faceplates and supported by a gusset plate. The horizontal steel plate supports the vertical rod by a nut on top of the plate. The rod passes through the interface between the SC module and the RC module and is threaded to a mechanical connector in the RC. Such a connection is unconventional.

The staff has identified the following concerns: (1) possibility for an alternative load path for shear friction at the interface above the mechanical couplers when the steel faceplates bear on the concrete; (2) possible ineffective bond between the tie rods and the concrete that may reduce the shear friction of the same joint; (3) lack of qualification and production criteria and programs for the mechanical splice; and (4) that the concrete below the anchor plates may not be in close contact with these plates.

NRC Questions

1. How does Westinghouse address the effects of a possible alternative load path for shear friction at the joint above the mechanical couplers when the steel faceplates bear on the concrete?

2. How does Westinghouse address the effects of ineffective bond between the tie rods and the concrete on the shear friction behavior of the interface above the mechanical couplers?

3. What are the qualification and production criteria and programs for the mechanical splices?

4. How does Westinghouse address the concern that the concrete below the anchor plates may not be in close contact with these plates (lack of contact would affect the transmission of compressive forces)?

H.2.1.1 Action 7

Westinghouse will clarify the design approach and the load path for the RC/SC connection. Westinghouse will walk through individual components and the load path and confirm its strengths. Westinghouse will also describe any design changes to the RC/SC connection (i.e., possible replacement of [.][a,c]

H.2.1.2 Action 8

Westinghouse will provide justification that voids in the RC/SC region will not affect load path in compression.

a,c

H.2.2 2B- RC/SC Connection, Bonding of Rods and Concrete

H.2.2.1 Action 9

Westinghouse will verify the [ ][a,c] shear friction was used and the basis for acceptability when using [ ][a,c]. Additionally, Westinghouse will address the limiting failure mode and check to ensure this is in the [ ][a,c]. If changes are made from [ ][a,c], Westinghouse will provide details of those changes. In addition, Westinghouse will provide the technical justification [ ][a,c] for a higher shear friction capacity factor to be used for purposes of beyond design basis.

a,c

H.2.2.2 Action 10

Westinghouse will clarify use of SCC and the specific locations where it will be used for the Shield Building.

a,c

H.2.3 2C- Qualification of Mechanical Splices

H.2.3.1 Action 11

Westinghouse will consider use of ACI 318-08 CH 21. Indicate specific type used for Shield Building and if it is type 1, Westinghouse will provide a justification. Provide qualification and production criteria.

a,c

[ ]

H.3 ITEM 3 (RING GIRDER)

H.3.1 Ring Girder

Westinghouse Position

Table 5.2.6 of the Shield Building report indicates that the stress for the tie bar from the confirmatory [ ]a,c is about one-third of that from the [ ]a,c analysis, and the stress for vertical and circumferential stresses from [ ]a,c analysis is about one-fifth of that from the [ ]a,c.

NRC Understanding

Westinghouse used [ ]a,c to confirm a level of conservatism in the design of the ring girder. However, differences as large as those shown in the table indicate that such reductions in stresses may not be achievable.

NRC Question

Explain the reasons for the differences between the results in the [ ]a,c and [ ]a,c analyses and describe the implications on the design of the structure.

H.3.1.1 Action 12

Westinghouse will provide a typical load case at SSE to show the cross sectional forces for both the Standard (ANSYS) and Confirmatory (LS_DYNA) analyses.

a,c

H.3.1.2 Action 13

Westinghouse will perform a calculation to address shear friction loads at the air inlets connection and construction joint in the tension ring.

a,c

H.3.1.3 Action 14

Westinghouse will show a calculation of the capacity of the shear ties to show that they are adequate to address the transition from a [ ]a,c wall.

a,c

[ ]

H.4 ITEM 4 (OTHER)

H.4.1 Issue 1- Benchmarking and System Ductility

Westinghouse Position

1. In Figure 8.7-7 (Page 8-28 of the Shield Building), the experimental load displacement curve indicates that specimen [ ]^{a,c} shows a brittle failure mode. The specimen failed at a 1.5-inch deflection. This specimen was also benchmarked by four different concrete models in the [ ]^{a,c}. The predicted results from these four different concrete models in the [ ]^{a,c} indicate that the specimen behaves in a ductile manner with no sign of failure at 3-inch deflection and keep going strong. Also, as stated on page 10-49, "A hand-off procedure is used to compare the analysis results from the [ ]^{a,c} models to the detailed [ ]^{a,c} for the critical regions of the Shield Building. These regions are Wall Q, the west wall, air inlets, and Wall 5."

2. Westinghouse stated that [ ]^{a,c} would be benchmarked.

3. Westinghouse uses displacements for the [ ]^{a,c} "handoff."

4. Page 10-48 of the report states "The results, shown in Table 10.2-4, indicate that the building has sufficient system ductility (> 3.5)."

NRC Understanding

1. The staff is concerned that all the four concrete models in the [ ]^{a,c} over predicted the ductility of the AP1000 Shield Building SC wall by a significant amount. Therefore, the adequacy of the results is questionable.

2. The report does not describe how the [ ]^{a,c}, used for [ ]^{a,c}, was benchmarked to experimental results. Further, the report does not provide any assessment of the mesh size sensitivity for the [ ]^{a,c} model.

3. Staff is concerned that the handoff from [ ]^{a,c} would underestimate demands if the [ ]^{a,c} is too stiff.

4. Table 10.2-4 only shows loads and stresses, and no deformations and ductility are reported.

NRC Questions

1. Given that all four concrete models in the [ ]^{a,c} over predicted the ductility of the AP1000 Shield Building SC wall by a significant amount (i.e., does not predict failure), how does Westinghouse ensure the adequacy of the [ ]^{a,c} results?

2. Given that the report does not describe how the [ ]^{a,c}, used for [ ]^{a,c}, was benchmarked to experimental results, and does not provide any assessment of the mesh size sensitivity for the [ ]^{a,c}, how does Westinghouse justify the adequacy of the Level 2 confirmatory analysis results.

3. In addition given that the handoff from [ ]^{a,c} would underestimate demands if the [ ]^{a,c} model is too stiff, how does Westinghouse verify adequacy of the handoff procedure that was used?

4. Given that Table 10.2-4 only shows loads and stresses, and that no deformations and ductility are reported, how did Westinghouse use these results to make an evaluation of system ductility? What is the basis for [ ]^{a,c} being designated as sufficient system ductility?

H.4.1.1 Action 15 [ ]^{a,c}

Westinghouse will present an analysis of test specimens, using material [ ]^{a,c}, and indicate strain limits and the points where a [ ]^{a,c} would occur.

H.4.1.2 Action 16 (LS-DYNA)

Westinghouse will provide the benchmarking of the [ ]a,c model to the staff.

a,c

[ ]

H.4.1.3 Action Item 17 [ ]a,c

Provide the handoff procedure from the [ ]a,c.

a,c

[ ]

H.4.1.4 Action 18 (Out-of-Plane Shear Capacity for Tie Bars)

For tie bars, Westinghouse will determine whether [
]a,c.

a,c

[ ]

H.4.2 Issue 2 [ ][a,c]

Westinghouse Position

Tie bars are spaced at 6 inches, 8 inches, and 17 inches as stated on page 4-1, and 7 inches on page 4-2, but only 6-inch and 17-inch spacings have been tested.

NRC Understanding

The staff does not know the strength (capacity) for tie bars spaced at 7 inches and 8 inches, because there is no test for them.

NRC Question

How does Westinghouse compute the out-of-plane shear strengths for the Shield Building with tie bars spaced at 7 inches and 8 inches?

H.4.2.1 Action 19

Westinghouse will provide the calculation basis for the tie bar spacing other than those that were explicitly tested [.][a,c] Westinghouse will identify the regions where these nonstandard spacings were used, and demonstrate the capacity versus the demand in these regions and whether it is large.

a,c

H.4.3 Issue 3 (Thermal Cracking Problem)

Westinghouse Position

The analysis results indicate that thermal cycling will cause vertical concrete cracking in the SC wall (page 3-50).

NRC Understanding

Westinghouse did not address effects of cracking on Shield Building design capacity.

NRC Staff

Given that Westinghouse has predicted vertical concrete cracks due to thermal cycling, what is the effect on the Shield Building design and capacity?

H.4.3.1 Action 20

Westinghouse will review the crack width assumption calculation used to evaluate the effect on design, including: cement content, coefficient of thermal expansion, and concrete volumetric expansion.

a,c

a,c

H.4.3.2 Action 21

PCS Tank Design

1. What is the maximum height of the sloshing wave? How was it calculated? How much freeboard is provided?

2. How is the hydrodynamic pressure that is used in designing the tank walls calculated?

   a. Describe how impulsive and convective loads are calculated and applied in the Shield Building roof design

   b. Provide floor response spectra at top and bottom of the PCS tank

   c. Provide typical floor response spectra at PCS tank elevation extending down to 0.1 Hz (to show that spectra at roof elevation at this frequency are similar to the ground input motion)

3. What is the maximum deflection of the W36 x 393 beam? Provide mid-span deflection relative to ends of beam.

a,c

a.c

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a,c

APPENDIX I
BENCHMARKING ANALYSIS

a,c

APPENDIX J
SHIELD BUILDING BEHAVIOR AND DESIGN PHILOSOPHY

a,c

a.c

APPENDIX K
SHIELD BUILDING MARKUPS

a,c

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SECURITY-RELATED INFORMATION – WITHHOLD UNDER 10 CFR 2.390(d)

Westinghouse Proprietary Class 2

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Design Report for the AP1000 Enhanced Shield Building

Westinghouse