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Your ref: Docket No. 52-006
Our ref: DCP/NRC2380

February 16, 2009

Subject: AP1000 Response to Request for Additional Information (SRP 3)

Westinghouse is submitting a response to the NRC request for additional information (RAI) on SRP Section 3.8.4. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in this response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the response for the following RAI:

RAI-SRP3.8.4-SEB-02

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

D. A. Lindgren /FOR

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/Enclosure

1. Response to Request for Additional Information on SRP Section 3.8.4

D063
NRO

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ENCLOSURE 1

Response to Request for Additional Information on SRP Section 3.8.4

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP3.8.4-SEB1-02
Revision: 0

Question:

Complete the actions noted below. These were agreed to during the October 6 and 7, 2008 AP1000 Critical Sections meeting.

1. Provide a revision of RAI responses on TR57 regarding the design of the critical sections (3 typical configurations in steel plate) based on discussions in the meeting. Update RAI with better detail for dowels and methodology. Provide details on typical shear connectors including size and spacing.

2. Prepare a description of the methodology and basis for the design of the shield building (SB) (modular) wall and roof, including a justification for the application of AISC N-690 and ACI-349 for inclusion in the DCD.

3. Provide a description of the basis for the design of the connections between the original SB reinforced concrete wall and the wall modules, the wall and the basemat, and the modules and the roof.

4. Provide a description of the SB construction sequence at the SB roof and other areas.

5. Address absence of thru wall trusses in modules and use of wire rope.

6. Address how curvature of cylinder wall is addressed in methodology and by testing if done.

7. Provide summary of test data directly related to behavior of shield building under loads.

Additional clarification was provided on January 22, 2009 as follows:

A. With Regard to the Subject of:
Steel Plate-Concrete-Topping Composite (SC Module) Roof

The roof of the shield building, in DCD Revision 16, is designed to be built with steel-plate-concrete-topping composite modules (SC module). The SC module is built with steel plates welded to the supporting steel beams with concrete pouring on top of the steel plates that have metal studs welded to them to create a bonding (composite) effect between the steel plate and concrete. The applicant used the steel plate as a form for pouring concrete on top of it, and designed the SC module in accordance with the ACI 349 Code design method with the assumption that the steel plate acts as steel reinforcing bars.

When the steel plate is used as a form and not credited as steel reinforcing bars in reinforced concrete design, it is called non-composite design in the ACI 349 Code. When the steel plate is used as a form and credited as steel reinforcing bars in reinforced concrete design, it is called composite design in the ACI 349 Code. ACI 349 Code, Section 1.1.7.1states "Design and construction of structural concrete slabs cast on stay-in-place, no composite steel form deck are governed by this Code.", and Section 1.1.7.2 states "This Code does not govern the design of structural concrete slabs cast on stay-in-place, composite steel form deck." Therefore, ACI 349 Code design method is not applicable to the DCD Revision 16 shield building roof.

The applicant is requested to substantiate the adequacy of its design method by test data if it intends to use the composite design method. The applicant can use the noncomposite design method in the ACI 349 Code for the DCD Revision 16 shield building roof.

B. With Regard to the Subject of:
Steel-Plates-Concrete Composite (SC Module) Cylindrical Wall

The majority shield building cylindrical walls, in DCD Revision 16, are designed to be built by steel-plates-concrete composite cylindrical wall modules (SC module). The SC module uses two steel faceplates separated by web stiffeners and are shop fabricated and then shipped to the jobsite, where they are welded together to form large assemblies which are then fastened into place to form the SC portion of the shield building cylindrical wall. Steel studs are welded to the interior face of the steel plate that is to receive concrete, and concrete is then poured into the space between the faceplates. The applicant designed the SC Module cylindrical wall of the shield building in accordance with the ACI Code design method with the assumption that faceplates act as steel reinforcing bars. This assumption for the SC module, made by the applicant, is not used by the ACI Code, or not verified by the test data that the ACI Code design method was derived from, as stated above. As a result, the applicant's design method for the SC module by using the ACI Code design method is inappropriate until it is justified. Therefore, the applicant is requested to substantiate the adequacy of its design method by test data.

If the applicant chooses to prove the adequacy of its SC module design method, it should, as a minimum, address the following major design items:

- The applicant's demonstration that its design method for the SC module was derived from, or substantiated by, test data.
- The behavior of the SC modules under loads.
- Design of connections at joints between adjoining SC modules with curvatures.
- Description of how continuity of the concrete and steel faceplates is preserved at these joints.

- Design for shear force in the meridional direction.
- Design for shear force in the circumferential direction.
- Design for shear force in the radial direction.
- Design of welded studs to the faceplate.
- Design of web stiffeners.
- Design of steel faceplates.

C. With Regard to the Subject of:
Anchorage Design from SC Module Cylindrical Walls to the Basemat, and Connection Design between SC wall Modules and Reinforced Concrete Walls

The majority of SC module cylindrical walls span between the roof and the concrete basemat, and these walls are anchored to the basemat. The AP1000 DCD, Revision 16, has not provided the anchorage detail and its design method. Therefore, the applicant is requested to provide the design detail of, and its design method for, the anchorage, and the test data that can substantiate the adequacy of the design method.

The remaining SC module cylindrical walls are connected to the reinforced concrete cylindrical walls below. Since the heights of the reinforced concrete cylindrical walls are varied along the circumferential (hoop) direction, there are two types of connections, one in the meridional (vertical) direction and the other in the hoop direction, to be made. Neither was designed nor detailed in the DCD Revision 16. Therefore, the applicant is requested to provide the design detail of, and its design method for, the connections, and the test data that can substantiate the adequacy of the design method.

D. With Regard to the Subject of:
ACI Code Compliance

During the October 6 and 7, 2008 meeting, the staff learned that the shield building was designed by an Italian company. The staff noted that steel plate strips were embedded in concrete serving as shear reinforcement in the walls. While the use of steel plate strips may be allowed by the Italian code, the ACI Code requires that steel reinforcing bars be used for taking the shear force in the wall. This deviation from the ACI Code was not described in the DCD Revision 16. Therefore, the applicant is requested to document all designs that are non-compliance with, or deviated from, the ACI 349 Code requirements, which the DCD had committed to, and justify the non-compliance or deviations.

E. With Regard to the Subject of:
Inspection Method

All concrete construction requires inspection. ACI 349 Code, Section 1.3.1 states "The owner is responsible for the inspection of concrete construction throughout all work stages."

Voids/honeycombs in reinforced concrete structures have been observed, after the removal of forms, and then repaired. Some structural members were found so deficient, after the removal of forms, that they were demolished and re-poured. Since the steel forms of the SC module walls are not to be removed, the applicant is requested to provide methods, such as acoustic emission or infrared thermograph, to be used to inspect or detect concrete voids/honeycombs and other types of defects for the concrete poured inside the steel forms, and describe the inspection program.

F. With Regard to the Subject of:
Fire Protection for the SC Module for Walls and Floors

The AP1000 DCD design makes extensive use of SC modular construction. SC wall modules similar to, but not identical with, the SC wall module for the shield building are widely used in the containment internal structures and the auxiliary building. SC floor modules similar to the roof SC module for the shield building are also widely used in the containment internal structures and the auxiliary building.

There is one major difference between the SC modules and conventional reinforced concrete structures. In using this type of construction it is noted that the two steel faceplates, which act as the reinforcing for the concrete wall, are exposed to the surrounding atmosphere. For the conventional construction which uses steel reinforcing bars, national building codes, such as ACI 318 and ACI 349, require minimum values of concrete cover over these steel bars, ranging from ¾ inch (for No.11 bars) to 1-1/2 inch (for No. 14 and 18 bars). In some cases, such as more severe fire resisting requirements or possible corrosive atmosphere, these values of minimum concrete cover may be increased. This requirement has been in the ACI building Codes (e.g., ACI 318) for a long time, essentially since their inception. This concrete cover is intended to provide adequate resistance of the reinforced concrete to elevated temperatures such as caused by fire and possible corrosive atmosphere. In the case of the SC modules, there is no concrete cover to protect the steel faceplates. All of the concrete is between the two steel faceplates. Therefore, the ACI 318 and ACI 349 requirements for minimum concrete cover over the primary steel reinforcing bar is not followed in the design of the SC modules.

The applicant is requested to provide the rationale for not complying with the ACI 318 and ACI 349 Code requirements for minimum concrete cover over the primary steel reinforcement. This rationale should include a discussion of the consequences of elevated temperatures in the various compartments created by these SC modules, due to fire and/or design basis accidents such as LOCA and main steam piping breaks. The applicant is also requested to explain how the fire protection issue is addressed for the SC modules used in areas that require fire protection.

G. With Regard to the Subject of: Construction Sequence

No building in the operating nuclear power plants in the United States was designed and built similar to the shield building in the AP1000 DCD, Revision 16. Since this is a new type of construction, construction sequence is important to the success of the shield building construction.

The applicant is requested to describe the construction sequence of the shield building. The description should include (1) any special requirements placed on the fabrication, shipping, handling, and installation of the SC modules, which are necessary to avoid overstressing, excessive distortion, and/or any other degradation mechanism of the steel faceplates during these operations, (2) the anchorage from the SD module cylindrical walls to the concrete basemat, (3) the connection between the SD module cylindrical walls and the reinforced concrete walls in both meridional (vertical) and circumferential (hoop) directions, (4) the roof supporting steel beams on the SD module cylindrical walls, (5) the welding between the steel roof steel plats and the steel supporting beams, and (6) the pouring of concrete over the top of the roof steel plate

Westinghouse Response:

This RAI requests additional information (items 1 thru 7) requested during the meeting in October 2008 to supplement that provided in the response to RAI-3.8.4 - Shield Building – SEB1 – 01. These action items were clarified in a separate transmittal and are listed as items A through G above. This clarification was based on review of DCD Revision 16. Minor changes have been included in Revision 17 in some related sections. Additional information proposed for inclusion in the DCD based on both RAIs is shown in the DCD Revision section of this RAI response with changes indicated from Revision 17. In addition detailed responses are provided in this RAI to each item.

<u>Question 1</u>

The response on TR57 (RAI-3.8.4 - Shield Building – SEB1 – 01) regarding the design of the critical sections (3 typical configurations in steel plate) is not being revised. However, the material included in DCD subsection 3.8.4 and Appendix 3H is revised as shown in the proposed DCD revision to address the discussions in the meeting.

A summary of the typical design of the shear connectors is provided below:

- On the enhanced shield building cylindrical wall: 2 rows of ¾ " x 6" studs at 10" centers vertically spaced equally between each of the 6" x 4" vertical angles which are at 2.25 degree centers circumferentially.
- On the shield building roof: on top flanges of W36x393 sloped beams: 7/8" x 6- 3/16" studs; 6" spacing, two rows. (Region: 69'–1" > radius > 46')
- On the shield building roof: on top flanges of W36x393 sloped beams: 7/8" x 6- 3/16" studs; 6" spacing, three rows. (Region: 46' > radius > internal end of sloped beam)
- On the shield building roof: on top flange of W30x90 circular beam: ¾" x 6" studs; 6"spacing, two rows
- On the conical roof, ½" thick liner steel plate: ¾ " x 6" studs (on entire surface area; spacing varies)

Question 2 and Clarification (A)

The description of the methodology for the design of the shield building (SB) (modular) wall and roof has been expanded in the proposed DCD revisions. These clarify the application of AISC N-690 and ACI-349. AISC is applicable to the composite design of the radial steel beams of the shield building roof. ACI plus supplemental requirements is applicable to other composite concrete filled steel plate structures. The methodology is based on provisions for composite construction in both codes plus extensive review of test data described in DCD subsection 3.8.3 and expanded for the cylindrical wall in the response to questions 5, 6 and 7 below. The design methodology is similar to that described in subsection 3.8.3 for the structural modules inside containment which was included in the AP600 Certified Design and in the AP1000 Certified Design for hard rock sites. This approach is permitted by ACI 349 paragraph 1.4 which states:

> **1.4—Approval of special systems of design or construction**
> Sponsors of any system of design or construction within the scope of this Code, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Code, shall have the right to present the data on which their design is based to the AHJ (authority having jurisdiction) for review and approval....

The use of steel plate with studs as reinforcement for a composite floor was described in the DCD for the control room floor and is already included in the AP1000 Certified Design for hard rock sites. The behavior of single plate slabs has been demonstrated by tests similar to the double plate tests described in the response to Question 7.

Question 3 and Clarification (C)

The lower portion of the Shield Building (SB) Cylindrical Wall, shown in the lower part of the F/E model in Fig. RAI-SRP3.8.4-SEB1-02-1, is a hybrid Steel-Concrete (SC, shown in blue) and Reinforced Concrete (RC, shown in green) structure surrounding the containment vessel. The top of the hybrid portion of the cylindrical wall is at the bottom of the air inlets and the bottom at EL-100'-0".

The SC modules are connected to RC along the interface, shown in Figure RAI-SRP3.8.4-SEB1-02-4, by a connection zone such as illustrated in Fig. RAI-SRP3.8.4-SEB1-02-2 for a typical section of the SC shield building wall above the RC basemat at El. 100'. The wall may be subjected to any combination of axial and shear forces and bending and torsional moments. These forces are resisted by the steel surface plate of the SC construction and by #11 rebar dowels rising from the basemat at El. 100', with the SC connection zone above serving a splicing function.

The dowels shown in Fig. RAI-SRP3.8.4-SEB1-02-2 are located in two vertical planes which are offset from the plane of the applied liner tensile force. The connection shown in Fig. RAI-SRP3.8.4-SEB1-02-2 is based on the shear-friction mechanism, as illustrated in Fig. RAI-SRP3.8.4-SEB1-02-3, and designed according to ACI provisions. It uses ties normal to the surface plate consisting of #6 rebars, welded to the steel face. The length of the bars is sufficient to develop the strength of the bar in accordance with the development length requirement of ACI 349.

In addition to El. 100', four other connection locations are identified, as shown in RAI-SRP3.8.4-SEB1-02-4 in different hatch patterns:

- Corners at El. 100' between SC and adjacent RC walls
- Vertical planes at interface with adjacent RC walls
- Horizontal planes just above roof of auxiliary building at El. 155' and 163'
- Vertical plane between El. 155' and 163' above roof of auxiliary building

Connections at vertical interfaces connect circumferential reinforcement and are subjected to circumferential tensile forces and are similar to that described above for the horizontal interface. A typical corner connection is shown in Fig. RAI-SRP3.8.4-SEB1-02-5 and connects both vertical and horizontal reinforcement with the tie bars sized for a combination of both vertical and circumferential forces.

Question 4 and Clarification (G)

The Shield Building cylindrical wall consists of concrete filled steel plate (SC) construction and standard reinforced concrete (RC) construction. The portion protected by the auxiliary building is constructed using standard RC; the wall portion that is not covered by the auxiliary building is constructed using steel plate (SC) construction. In the construction sequence the SC wall will follow the construction of the RC wall of the auxiliary building at each elevation and both the RC and SC will never exceed the height of the Containment Vessel. The SC wall will be lifted in place in panels approximately 20 feet high. These will be filled with concrete to a few feet below the top of the panel before installation of the next elevation of panels. The steel walls will be filled with high strength self consolidating concrete. The SC construction interfaces with the RC construction in the auxiliary building in a connection zone just above the roof at elevation 155' between Wall Q and Wall 7.3, and at elevation 163' between wall 7.3 and wall N. The auxiliary building floors and the steel deck and RC roof in auxiliary building areas 1 to 4 are placed after the shield building steel plated construction is completed above the floor or roof. At the fuel handling roof (auxiliary building area 6 at elevation 180') the steel plated wall will be installed first and then the RC walls on column lines 4 and N and roof will be installed. The steel plate wall is then continued up to the air inlet interface at elevation of about 248'. The air inlets are then installed and concrete placed up to the underside of the shield building roof. The steel portion of the conical roof will be installed on the air inlet structure. This will have the compression ring; the radial beams and the plate in between. These will be assembled on site. The valve room module is directly connected to the steel beams of the conical roof with the dedicated structural columns. The shield plate support structure also will be suspended off the compression ring. The completed roof with the infill plates will be lifted onto the air intake structure. Concrete will be placed on the roof up to the exterior wall of the passive containment cooling system (PCCS) tank. The PCCS stainless steel liner (CB20) will be installed next. The PCCS tank liner provides a leak-tight barrier on the inside wet surfaces of the tank and includes the wall, conical floor and roof, and will have stiffeners and leak chases on the concrete side. This whole assembly CB 20 will be lifted in one piece and set on the roof. This is set on the roof when the roof is partially concreted to this level to provide seating to the CB 20 Module. The stiffened areas of the bottom liner will be supported off stools welded to the roof radial beams. Concrete will be placed below the floor and around the CB20 module.

Question 5 and Clarification (B)

Typical CA Modules, illustrated in Fig. RAI-SRP3.8.4-SEB1-02-6, include C6 channels, welded to the vertical L4x3 angles. Their function is primarily to resist the wet concrete pressures during construction. As a result of the concern that the C6 channels may become secondary missiles during a postulated aircraft impact, they were removed from the SB cylinder SC modules and replaced by wire ropes. As shown in Fig. RAI-SRP3.8.4-SEB1-02-7, Shield Building (SB) cylinder modules are different than other CA modules due to the absence of through wall steel, except in local areas close to base, at air inlets, and at auxiliary building wall discontinuities.

Subsection 3.8.3.5 of the DCD states that the design of the concrete-filled wall modules treats the steel faceplates as reinforcement in conventionally reinforced concrete structures. The NRC staff reviewed this design method during review meetings held on May 22 and 23, 1996, and January 14 to 16, 1997. As a result of that review, the staff concluded that the approach described in the DCD, together with Westinghouse design documents (drawings and sample design calculations), demonstrate that this design method is applicable for the design of the concrete-filled steel wall modules.

NRC approval of AP600 design was based on material submitted in the DCD, RAI responses and audits of Westinghouse Documents. Westinghouse studies GW-SUP-003, Rev 2, Structural Analysis Methodology for Steel-Concrete Composite Panels with Welded Shear Studs and GW-SUP-005, Rev 1, Behavior Studies of Concrete Filled Steel Module, review and evaluate literature, develop analytical solutions for SC in-plane and out-of-plane response, and document calculations of behavior of walls with configurations similar to the AP600 and AP1000 walls. The module behavior studies and literature reviews are summarized in both the AP600 and AP1000 Containment Internal Structures Summary Report. Brookhaven personnel assisted NRC in the review and subsequently published NUREG/CR-6486 Assessment Of Modular Construction For Safety-related Structures At Advanced Nuclear Power Plants.

None of the supporting material submitted by Westinghouse indicates that through wall trusses are a pre-requisite for SC modules response as reinforced concrete structures. Recently published tests results, discussed in the response to question 7, further confirm this conclusion.

<u>Question 6 and Clarification (B)</u>

The AP1000 shield building was designed based on numerical results of a combination of Finite Element (F/E) analyses, hand calculations, and, where required, published test data. As common practice in the industry, curved structures such as the cylindrical Shield Building wall shown in Fig. RAI-SRP3.8.4-SEB1-02-1, are modeled by flat shell elements, whose constitutive models are developed based on membrane and out-of-plane response of flat panels. The corresponding SC response, as shown in the AP1000 DCD material, is evaluated based on RC equivalence. RC response and required reinforcement was evaluated according to ACI349 guidelines.

Testing of SC construction has been performed on flat panels. The loading in these tests is representative of the state of stress in portions of a cylinder under dead and seismic loads.

<u>Question 7 and Clarification (B)</u>

Test data directly related to behavior of the shield building cylinder under membrane loads is the same as was provided in support of the CA module design included in the AP1000 hard rock Design Certification. Additional literature specific to the absence of through wall ties is summarized below. The original paper is in Japanese and a translation has been prepared for Westinghouse. Copies of both the original paper and the translation are available for NRC review.

Out-of-Plane Response of SC panels without Cross-Ties

Paper 21619 "Experimental Study on Steel Plate Reinforced Concrete Structure Part 28 Response of SC Members Subjected to Out-of-plane Load (1)", TAKEUCHI, Masayuki et al, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, 1999.

The above paper describes the out-of-plane load test results of 24 specimens with shear studs connectors and with and without cross-ties, consisting of 16 SC, 7 Half-SC (reinforced with a steel plate on one side and with rebar on the other side) and one RC (reinforced concrete). As shown in Table RAI-SRP3.8.4-SEB1-02-2, Specimens 3 to 7, shown in Fig. RAI-SRP3.8.4-SEB1-02-8 have shear studs, steel plates and concrete parameters similar to AP1000 Shield Building, and no cross-ties.

Loading Pattern A, shown in Fig. RAI-SRP3.8.4-SEB1-02-9a, simulates distribution of member forces in specimens fixed at both ends. Fig. RAI-SRP3.8.4-SEB1-02-9b shows typical force versus mid-span displacements where Q=2P (Kgf), b=specimen width (cm), T=specimen thickness (cm) and σB is the concrete compressive strength (Kgf/cm2

Tests results, together with hand calculation results of the corresponding ACI349 out-of-plane shear and bending response, are plotted in Fig. RAI-SRP3.8.4-SEB1-02-10. The comparison clearly shows that flexural design of SC members without cross-ties as equivalent RC members according to ACI349 guidelines is not only adequate but also conservative. In particular, (a) calculated ACI349 bending capacity and deformations, the latter based on the average of cracked and un-cracked cross-section properties, is found to be a good representation of the SC response, and, (b) calculated ACI349 out-of-plane shear capacity (see Fig. RAI-SRP3.8.4-SEB1-02-11) significantly underestimates the actual SC capacity.

Clarification (D)

D. ACI Code Compliance

The design organization for the AP1000 is international under the direction of Westinghouse. It is designed to US codes and methodology established by Westinghouse. The through wall flat bars are similar to the channels being used in the approved design for the CA modules inside containment. The typical configuration shown in DCD Figure 3.8.3-2 has 6" deep channels at 4' centers vertically and 30" spacing horizontally. These provide additional shear capacity as described in subsection 3.8.3.5.3.5. In the air inlet region the through wall ties are flat bars rather than channels due to the limited space between adjacent inlets. The through wall channels and flat bars are welded to vertical stiffeners attached to the surface plates providing mechanical anchorage so that the through wall steel acts as a shear stirrup. This approach was included in the AP1000 Design Certification for hard rock sites as part of the structural module design methodology and satisfies ACI 349 as a special system under paragraph 1.4 shown in the response to question 2.

It may be noted that headed studs (not deformed reinforcement) have been used as shear reinforcement for many years. They are now included in ACI318-08. Similar paragraphs are being balloted for inclusion in the next revision of ACI 349.

Clarification (E)

E. Inspection Method

Concrete module construction technology has been in use for a long time. 'Self Consolidating Concrete', that precludes the possibility of voids or honeycombs, will be used for the modules.

Mock up tests are planned to confirm that the construction technology assures no voids and honeycomb free modules.

Clarification (F)

F. Fire Protection for the SC Module for Walls and Floors

This response is limited to the shield building since there are no changes to the modules inside containment and in the auxiliary building which have been approved in the AP1000 Certified Design for hard rock sites.

Fire protection is addressed in DCD Section 9.5 and Appendix 9A. The figures in Appendix 9A show the shield building cylinder and roof as a "3 hour fire barrier (non-rated, but capable of qualifying as a rated 3 hour fire barrier)". This classification is primarily to address external events since there is no source for a fire of extended duration in the annulus area.

The structural configuration of the shield building roof and wall is controlled by radiation shielding, external event and seismic considerations. Forces in these structures under normal operating loads are small. In the event that a fire weakens one surface plate there is adequate strength in the fire damaged section to resist the normal loads.

The surface plates are coated to protect the steel against corrosion.

Reference(s):

Table RAI-SRP3.8.4-SEB1-02 -1

Comparison of Test and AP1000 Shield Building Parameters

Quantity		**Test**	**AP1000 Shield Building**
Concrete Fill	Depth (T)	17.7" (450 mm) and 26.6" (675 mm)	36"
	Compressive Strength (f'_c)	5005 psi to 5574 psi (352 Kgf/cm^2 to 392 Kgf/cm^2)	6 ksi
Steel	Thickness (t_s)	0.177" (4.5 mm)	0.5 "
	Reinforcement Ratio (ρ_s)	0.67 % to 1 %	1.388 %
	Yield Stress (f_y)	49.8 ksi to 55.8 ksi (3500 Kgf/cm^2 to 3920 Kgf/cm^2)	65 ksi
Shear Studs	Diameter (Φ)	0.3543" (9 mm)	0.75" (#6)
	Length (h)	2.835" (72 mm)	6"
	Length Ratio 2h/T	0.213 to 0.32	0.33
	Cross-Sectional Area	0.0986 in^2 (63 mm^2)	0.442 in^2
	Layout	5.31" x5.31" (135 mm x 135 mm)	11"x10"
	Reinforcement Ratio (ρ_w)	0.35 %	0.401%

Table RAI-SRP3.8.4-SEB1-02-2

Specimens Parameters

試験体 NO.	Test Specimen	Width (mm)	Depth (mm)	Plate Thickness (mm)	Dowel	Number of Dowel (本)	Splice Length (d)	Tie Bar 量(%)	Location of Dowel α*1
a	L38X40	800	900	6	D38	3	40	0.50	4.05
b	L51X40	750	1200	9	D51	2	40	0.61	3.45
c	L38M40N	800	900	6	D38	3	40	0.17	1.00
d	L38M40F	800	900	6	D38	3	40	0.17	5.50
e	L38M50	800	900	6	D38	3	50	0.17	4.05
f	L51H40	750	1200	9	D51	2	40	0.30	3.45
g	L38L40	800	900	6	D38	3	40	0.11	4.05
h	L38N40N	800	900	6	D38	3	40	0.00	1.00

スタッド

a:4-13 ϕ @200+4-16 ϕ @200, c,d,e,g,h:4-13 ϕ @100

b:3-16 ϕ @250+3-22 ϕ @250, f :3X3-16 ϕ @500+3-22 ϕ @500

*1 : The Value divided the distance between plate and dowel by the diameter of the dowel

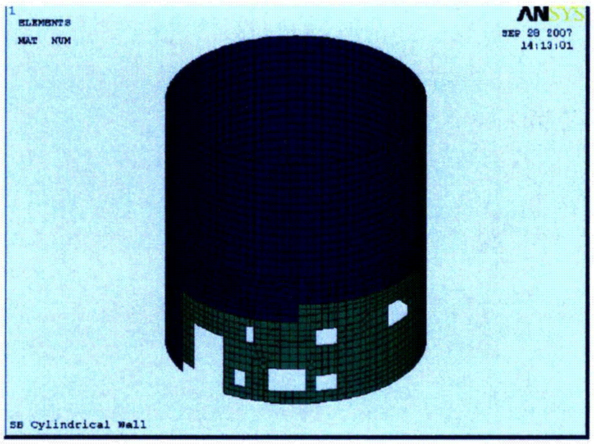


Fig. RAI-SRP3.8.4-SEB1-02-1 F/E Model of SB Cylindrical Wall

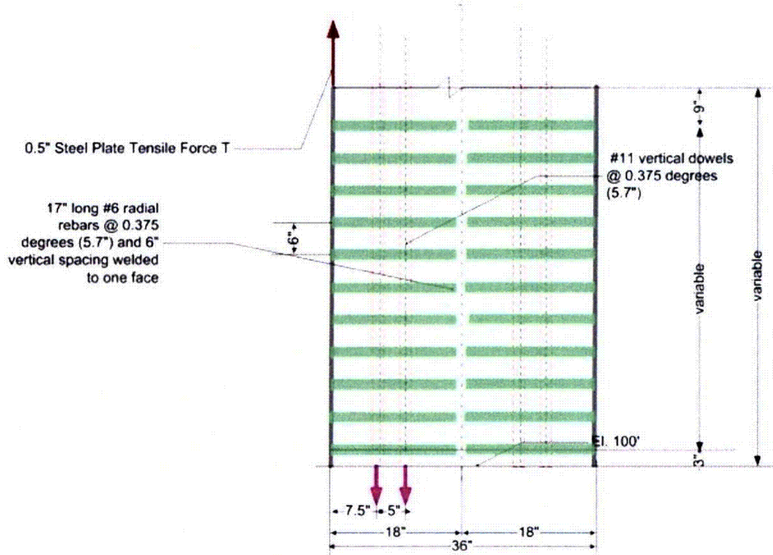


Fig. RAI-SRP3.8.4-SEB1-02-2 Typical Mid-Section Connection at El. 100'

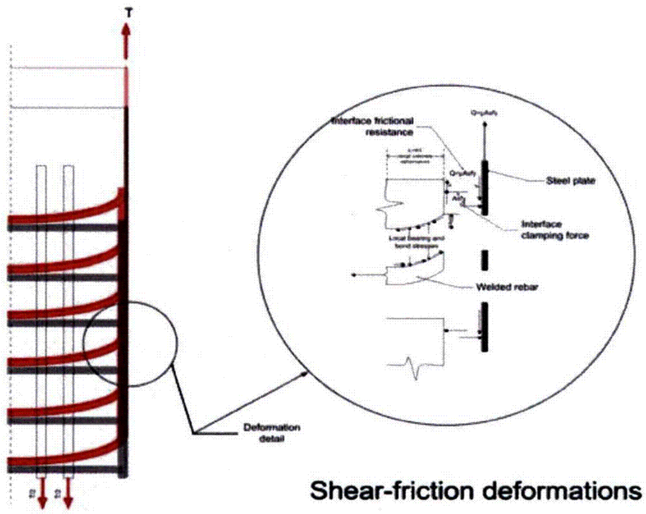


Fig. RAI-SRP3.8.4-SEB1-02-3 Shear-Friction Mechanism

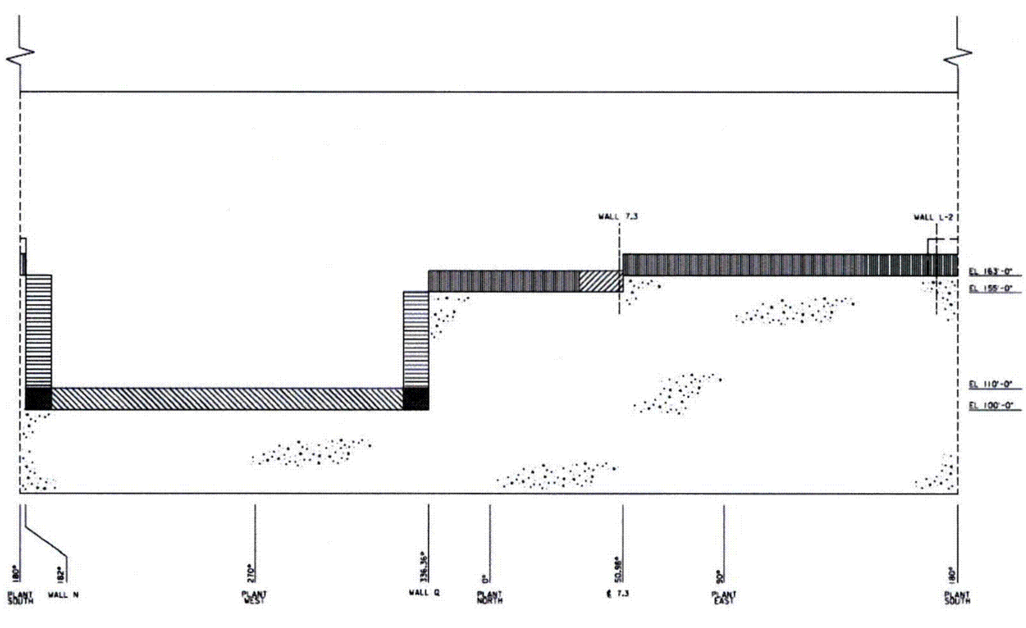
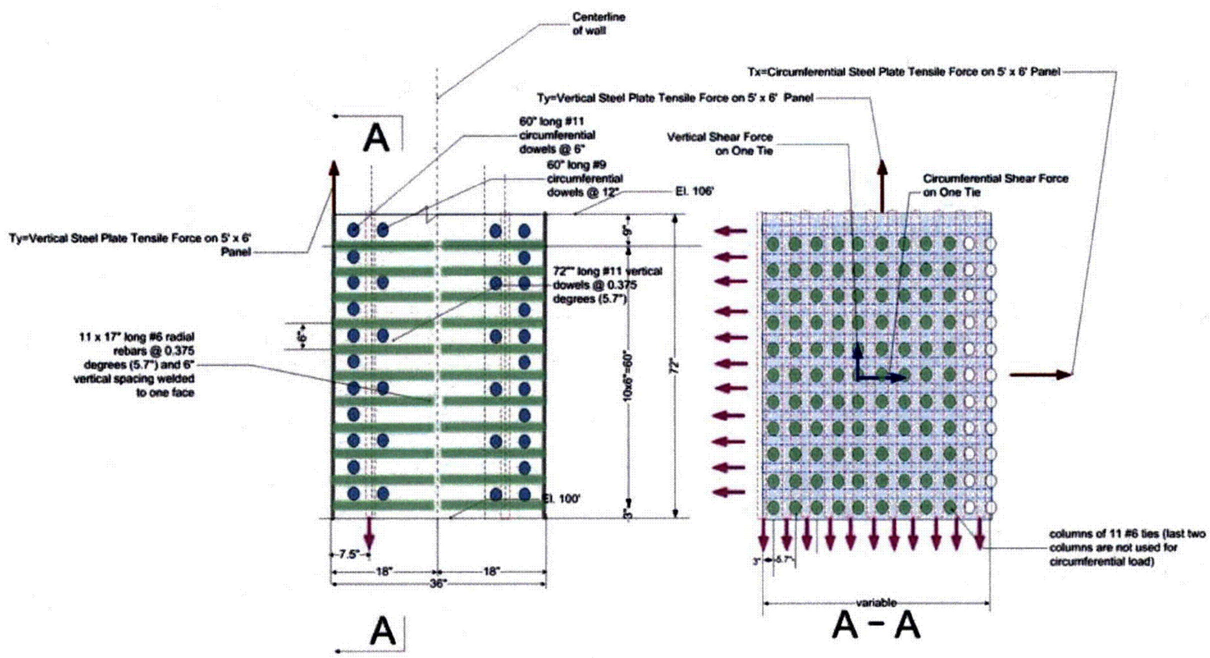


Fig. RAI-SRP3.8.4-SEB1-02-4 Five Connection Locations



0.375 degrees (5.7") corner cross-section

Fig. RAI-SRP3.8.4-SEB1-02-5

Location 2 - El. 100' – Corner Detail and Force Equilibrium

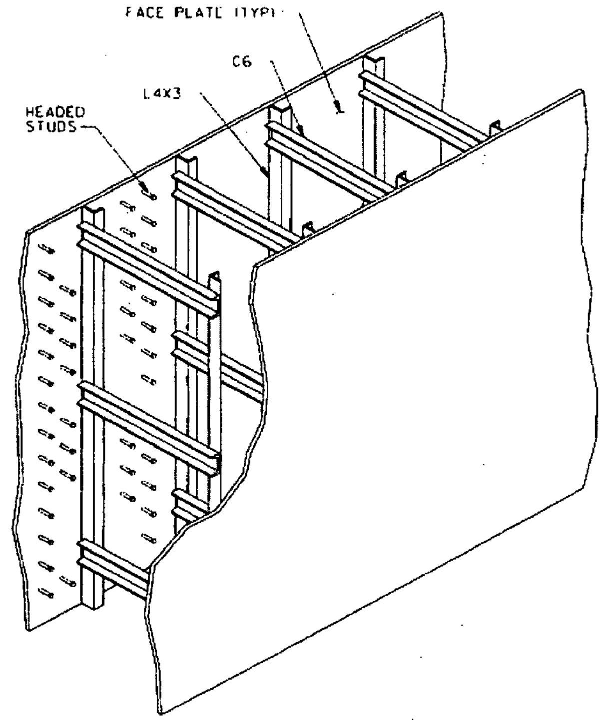


Fig. RAI-SRP3.8.4-SEB1-02-6 Typical CA Module

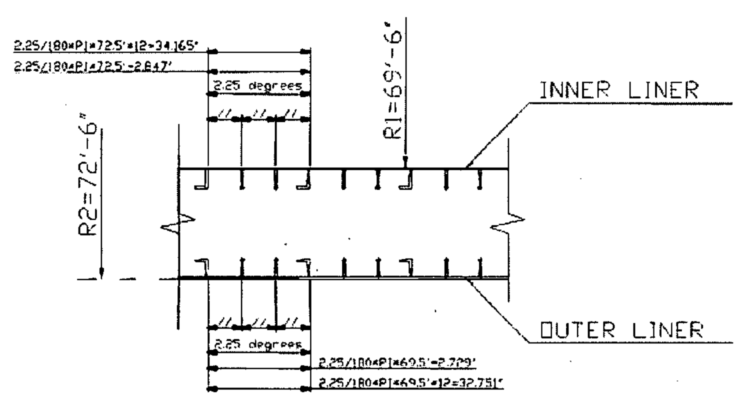


Fig. RAI-SRP3.8.4-SEB1-02-7 Typical SB Cylinder SC Module - Cross-Section

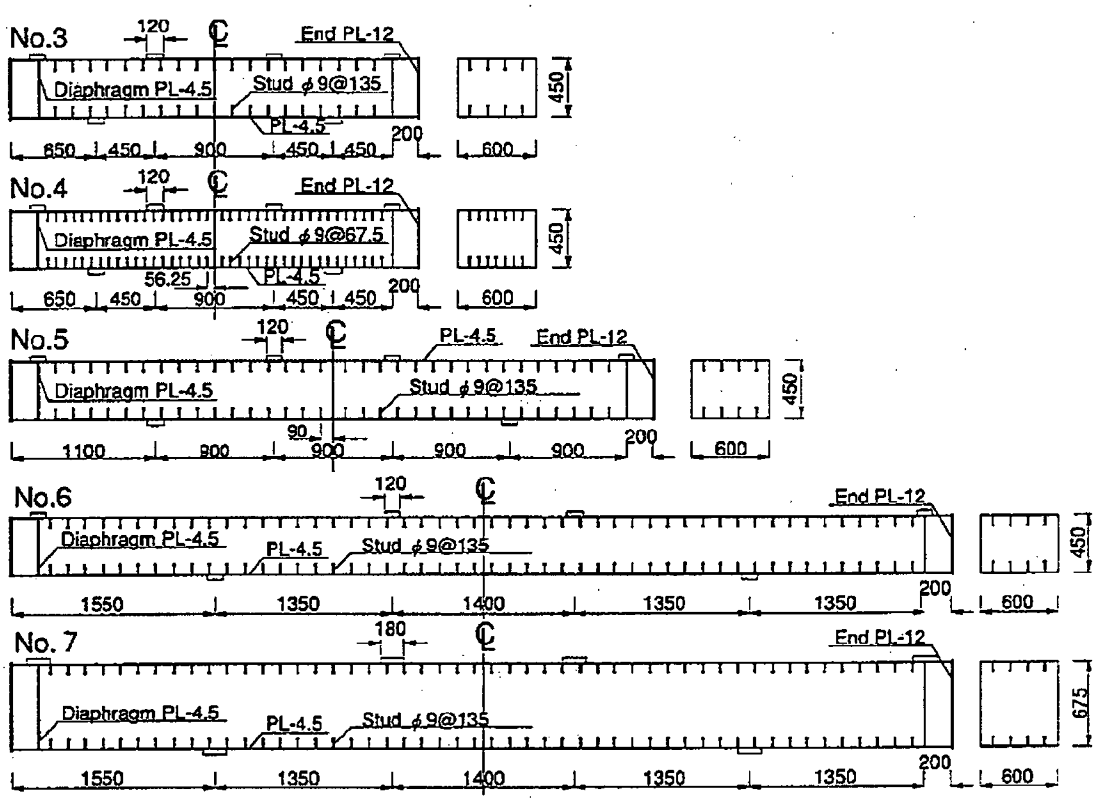
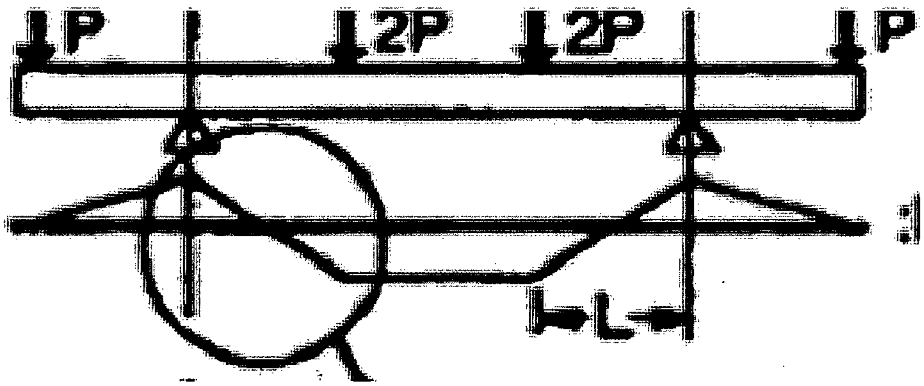
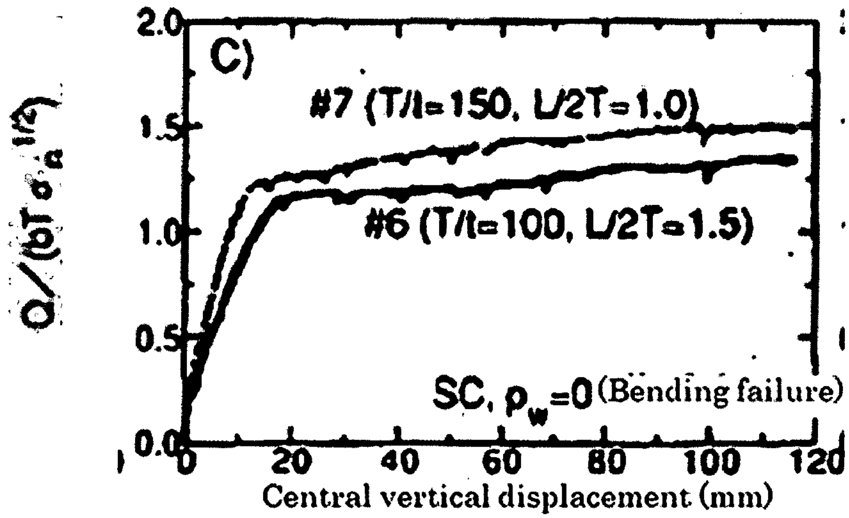


Fig. RAI-SRP3.8.4-SEB1-02-8 Specimens # 3 to #7 Dimensions



a) Loading Pattern A



(b) Displacement plot

Fig. RAI-SRP3.8.4-SEB1-02-9 Typical Test Results -Tests #6 and #7

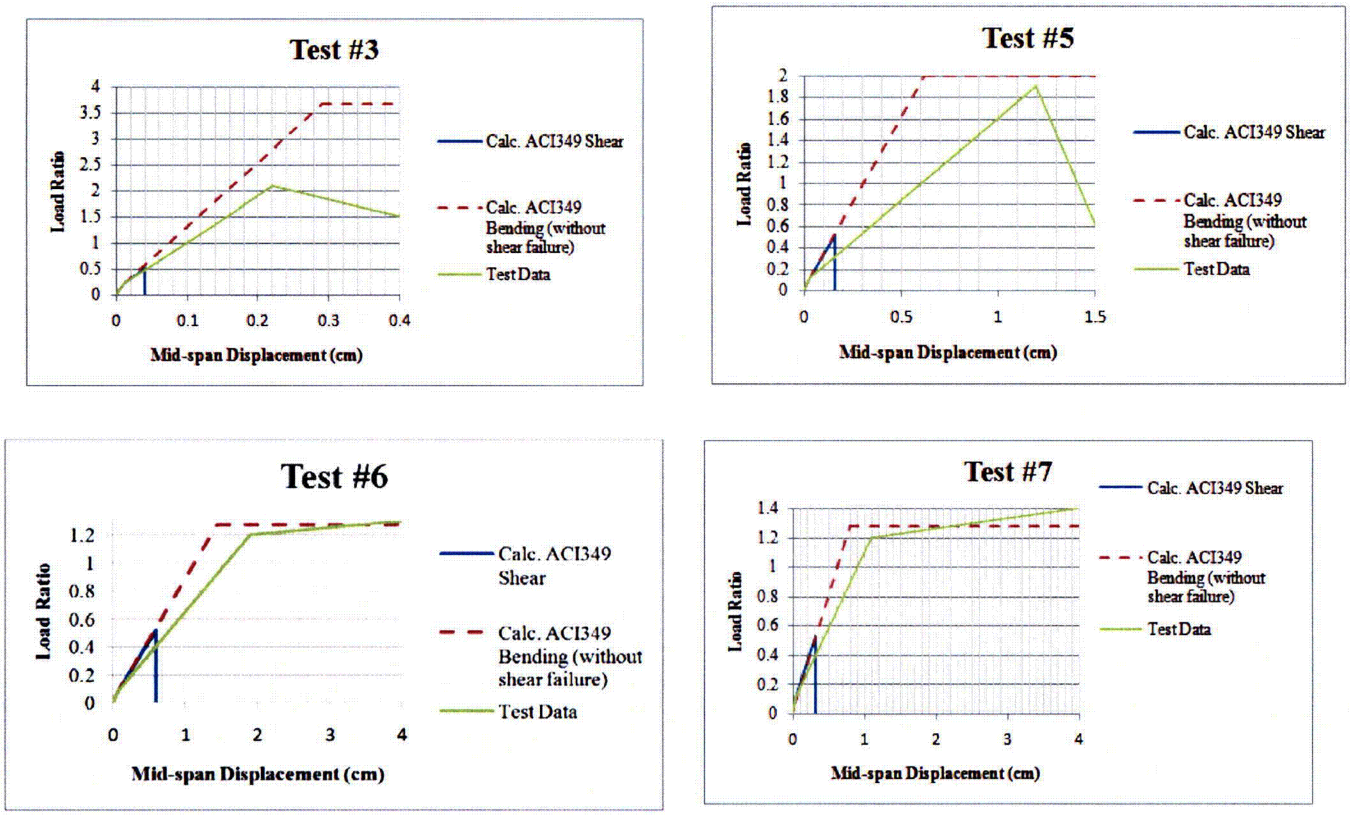


Fig. RAI-SRP3.8.4-SEB1-02 -10 Comparison of ACI349 and test results

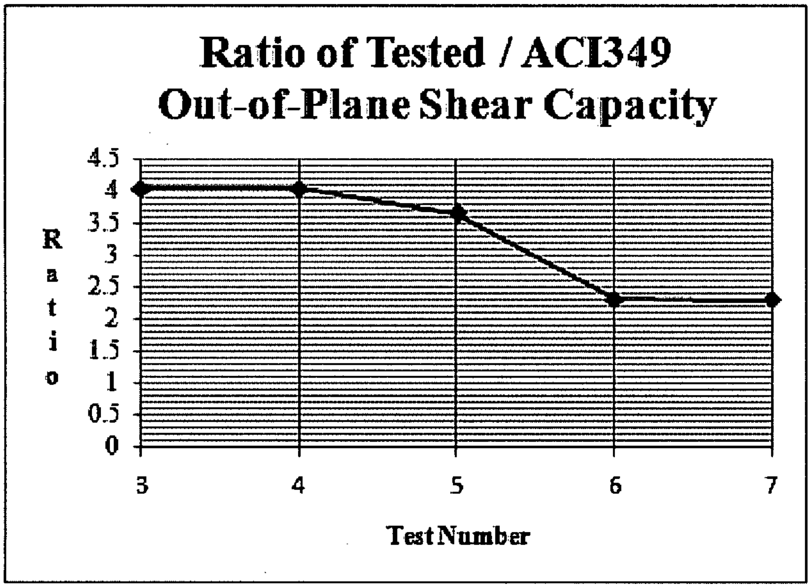


Fig. RAI-SRP3.8.4-SEB1-02 - 11 Ratio of Tested / ACI349 Out-of-Plane Shear Capacity

Design Control Document (DCD) Revision:

3.8.4.1 Description of the Structures

3.8.4.1.1 Shield Building

The shield building is the shield building structure and annulus area that surrounds the containment building. It shares a common basemat with the containment building and the auxiliary building. The shield building cylinder is a concrete filled steel plate (SC) structure except for the portion surrounded by the auxiliary building which is a reinforced concrete (RC) structure. The figures in Section 1.2 show the layout of the shield building and its interface with the other buildings of the nuclear island.

The following are the significant features and the principal systems and components of the shield building:

- Shield building cylindrical structure
- Shield building roof structure
- Lower annulus area
- Middle annulus area
- Upper annulus area
- Passive containment cooling system air inlet
- Passive containment cooling system water storage tank
- Passive containment cooling system air diffuser
- Passive containment cooling system air baffle
- Passive containment cooling system air inlet plenum

The cylindrical section of the shield building provides a radiation shielding function, a missile barrier function, and a passive containment cooling function. Additionally, the cylindrical section structurally supports the roof with the passive containment cooling system water storage tank and serves as a major structural member for the nuclear island. The floor slabs and structural walls of the auxiliary building are structurally connected to the cylindrical section of the shield building. The cylindrical section of the shield building protected by the auxiliary building is reinforced concrete. The section above the auxiliary building is constructed with steel surface plates which act as reinforcement. The nominal thickness of the steel faceplates is 0.5 inch. Shear studs are welded to the inside faces of the steel faceplates. Figure 3.8.4-3 shows a developed view of the cylindrical wall showing the boundary of the SC and RC construction and a typical connection at the bottom of the wall on the west side. The SC portion is designed as a reinforced concrete structure in accordance with the intent of ACI-349 and supplemental requirements using the same methodology as described for the modules inside containment in subsection 3.8.3. This methodology is supported by the behavior studies described in subsection 3.8.3.4.1. The steel plate modules are anchored to the reinforced concrete basemat and walls by connection zones in which reinforcement dowels extend into the bottom of the SC wall with tie bars normal to the surface plates designed according to the shear friction provisions of ACI 349 (see Figure 3.8.4-3).

The air inlet region of the shield building is 4'-6" thick, with high strength concrete contained within steel liner plates on both faces (as shown in Appendix 3H, Figure 3H.5-11). The liner plates acts as reinforcement. The air inlets consist of 5/16" thick square steel tubes (16"x16"), inclined upward from outside face to inside face. Vertical and horizontal stiffeners are provided to reinforce around the air inlet openings.

The shield building roof is a composite steel and reinforced concrete shell supporting the passive containment cooling system tank and air diffuser. The conical roof is constructed as a structural steel frame and is lifted into place during construction. Steel beams provide permanent structural support for steel liner and concrete. Shear studs are welded to the top flanges of the steel beams and to the steel liner which acts as reinforcement. Air intakes are located at the top of the cylindrical portion of the shield building. The conical roof supports the passive containment cooling system tank as shown in Figure 3.8.4-2. The air diffuser is located in the center of the roof and discharges containment cooling air upwards.

3.8.4.4 Design and Analysis Procedures

3.8.4.4.1 Seismic Category I Structures

[*The design and analysis procedures for the seismic Category I structures (other than the containment vessel and containment internal structures), including assumptions on boundary conditions and expected behavior under loads, are in accordance with ACI-349 for concrete structures, with AISC-N690 for steel structures, and AISI for cold formed steel structures.]** The concrete filled steel plate cylindrical wall for the shield building, including the air inlet region, and the structural wall modules in the auxiliary building are designed using the same procedures as the structural modules in the containment internal structures described in subsection 3.8.3.5.3.

[*The criteria of ACI-349, Chapter 12, are applied in development and splicing of the reinforcing steel. The ductility criteria of ACI-349, Chapter 21, are applied in detailing and anchoring of the reinforcing steel.*

The application of Chapter 21 detailing is demonstrated in the reinforcement details of critical sections]* in subsection 3.8.5 and Appendix 3H.

[*Sections 21.2 through 21.5 of Chapter 21 of ACI 349 are applicable to frame members resisting earthquake effects. These requirements are considered in detailing structural elements subjected to significant flexure and out-of-plane shear. These elements include the following examples described in Appendix 3H:*]*

- ~~Reinforcement for the shield building roof tension ring: [*The hoop reinforcement is detailed in accordance with 21.3.3.6 of ACI 349-01.*]*~~

- Reinforcement details for the basemat are described in subsection 3.8.5. [*Shear stirrups have T headed anchors at each end.*]*
- Reinforcement details for the exterior walls below grade are described in subsection 3H.5.1.1. [*Shear stirrups have T headed anchors at each end.*]*

[*Sections 21.2 and 21.6 of Chapter 21 of ACI 349 are applicable to walls, diaphragms, and trusses serving as parts of the earthquake force-resisting systems as well as to diaphragms, struts, ties, chords and collector elements. These requirements are considered in the detailing of reinforcement in the walls and floors of the auxiliary building and in the shield building cylindrical wall and roof.*]*

- Reinforcement for the shear walls and floors are shown in subsections 3H.5.1 to 3H.5.4. [*Transverse reinforcement terminating at the edges of structural walls or at openings is detailed in accordance with 21.6.6.5 of ACI 349.*]*
- ~~Air inlet region of shield building cylinder: The cylinder in this region is 4'-6" thick, with high strength concrete contained within steel liner plates on both faces (as shown in Appendix 3H, Figure 3H.5-11). The liner plates, tied to concrete with shear connectors, behave as concrete reinforcement. Vertical stiffeners are provided to support the wet concrete load. The air inlets consist of 5/16" thick square steel tubes (16"x16"), inclined upward from outside face to inside face.~~

The bases of design for the tornado, pipe breaks, and seismic effects are discussed in Sections 3.3, 3.6, and 3.7, respectively. The foundation design is described in subsection 3.8.5.

The seismic Category I structures are reinforced concrete, concrete filled steel plate and structural module shear wall structures consisting of vertical shear/bearing walls and horizontal slabs supported by structural steel framing. Seismic forces are obtained from the ~~equivalent static~~ response spectrum analysis of the three dimensional finite element models described in Table 3.7.2-14. The out-of-plane bending and shear loads for flexible floors and walls are analyzed using the methodology described in subsections 3.7.2.6 and 3.7.3. These results are modified to account for accidental torsion as described in subsection 3.7.2.11. Where the refinement of these finite element models is insufficient for design of the reinforcement, for example in walls with a large number of openings, detailed finite element models are used. Also evaluated and considered in the shear wall and floor slab design are out-of-plane bending and shear loads, such as live load, dead load, seismic, lateral earth pressure, hydrostatic, hydrodynamic, and wind pressure. These out-of-plane bending and shear loads are obtained from the ~~equivalent static~~ response spectrum analyses supplemented by hand calculations.

The exterior walls of the seismic Category I structures below the grade are designed to resist the worst case lateral earth pressure loads (static and dynamic), soil surcharge loads, and loads due to external flooding as described in Section 3.4. The lateral earth pressure loads are evaluated for two cases:

- Lateral earth pressure equal to the sum of the static earth pressure plus the dynamic earth pressure calculated in accordance with ASCE 4-98 (Reference 3), Section 3.5.3, Figure 3.5-1, "Variation of Normal Dynamic Soil Pressures for the Elastic Solution"

- Lateral earth pressure equal to the passive earth pressure

The shield building roof and the passive containment cooling water storage tank are analyzed using three-dimensional finite element models with the ANSYS computer codes. Loads and load combinations are given in subsection 3.8.4.3 and include construction, dead, live, thermal, wind and seismic loads. Seismic loads are applied as equivalent static accelerations. The seismic response of the water in the tank is analyzed in a separate finite element response spectrum analysis with seismic input defined by the floor response spectrum.

The liner for the passive containment cooling water storage system tank is analyzed by hand calculation. The design considers construction loads during concrete placement, loads due to handling and shipping, normal loads including thermal, and the safe shutdown earthquake. Buckling of the liner is prevented by anchoring the liner using the embedded stiffeners and welded studs. The liner is designed as a seismic Category I steel structure in accordance with AISC N690 with the supplemental requirements given in subsection 3.8.4.

The structural steel framing is used primarily to support the concrete slabs and roofs. Metal decking, supported by the steel framing, is used as form work for the concrete slabs and roofs. The structural steel framing is designed for vertical loads. Appendix 3H shows typical structural steel framing in the auxiliary building.

Computer codes used are general purpose computer codes. The code development, verification, validation, configuration control, and error reporting and resolution are according to the quality assurance requirements of Chapter 17.

[*The finned floors for the main control room and the instrumentation and control room ceilings are designed as reinforced concrete slabs in accordance with ACI-349. The steel panels are designed and constructed in accordance with AISC-N690. For positive bending, the steel plate is in tension and the steel plate with fin stiffeners serves as the bottom reinforcement. For negative bending, compression is resisted by the stiffened plate and tension by top reinforcement in the concrete.*]*

The concrete floors on steel plates, including the control room ceiling, the floors in the CA20 module, and the shield building conical roof spanning between radial beams, are designed as reinforced concrete slabs in accordance with ACI-349. The steel panels are designed and constructed in accordance with AISC-N690. For positive bending, the steel plate is in tension and the steel plate and stiffeners serve as the bottom reinforcement. For negative bending, compression is resisted by the concrete and stiffened plate and the tension by top reinforcement in the concrete. This methodology is described for the control room ceiling in subsection 3H.5.4.

3.8.4.5.4 Design Summary of Critical Sections

[*The design of representative critical elements of the following structures is described in Appendix 3H.*

- *South wall of auxiliary building (column line 1), elevation 66'-6" to elevation 180'-0"*
- *Interior wall of auxiliary building (column line 7.3), elevation 66'-6" to elevation 160'-6"*
- *West wall of main control room in auxiliary building (column line L), elevation 117'-6" to elevation 153'-0"*
- *North wall of MSIV east compartment (column line 11), elevation 117'-6" to elevation 153'-0"*
- *Shield building cylinder, elevation 160'-6" to elevation 200'-0"*
- *Roof slab at elevation 180'-0" adjacent to shield building cylinder*
- *Floor slab on metal decking at elevation 135'-3"*
- *2'-0" slab in auxiliary building (operations work area (tagging room) ceiling) at elevation 135'-3" (Note: The 'Tagging Room' has been renamed as "Operations Work Area." However, to avoid changing the associated design and analysis documents, this room is referred to as the 'Tagging Room.')*
- *Finned floor in the main control room at elevation 135'-3"*
- *Shield building roof, exterior wall of the PCCS water storage tank*
- *Shield building roof, tension ring and columns between air inlets, elevation 251'-0" to elevation 272'-0"*
- *Divider wall between the spent fuel pool and the fuel transfer canal*]*

3.8.4.6.1 Materials

3.8.4.6.1.1 Concrete

The compressive strength of concrete used in the seismic Category I structures and containment internal structures is $f_c' = 4000$ psi. For the steel plate portion of the shield building structure, the compressive strength of concrete is $f_c' = 6000$ psi. The test age of concrete containing pozzolan is 56 days. The test age of concrete without pozzolan is the normal 28 days. Concrete is batched and placed according to Reference 6, Reference 7, and ACI-349.

3.8.4.8 Construction Inspection

Construction inspection is conducted to verify the concrete wall thickness and quantity of concrete reinforcement. The construction inspection includes concrete wall thickness and reinforcement expressed in units of in^2/ft (linear length) equivalent when compared to standard reinforcement bar sections. Inspections will be measured at applicable sections excluding designed openings or penetrations. Inspections will confirm that each applicable section provides the minimum required reinforcement, steel plate thickness and concrete thickness ~~as shown in Appendix 3H~~. The minimum required reinforcement, steel plate thickness and concrete thickness represents the minimum values to meet the design basis loads. Appendix 3H also indicates the reinforcement provided which may exceed the minimum required reinforcement for the following reasons:

- Structural margin
- Ease of construction
- Use of standardized reinforcement sizes and spacing

Table 3.8.4-6

MATERIALS USED IN STRUCTURAL AND MISCELLANEOUS STEEL

Standard	Construction Material
ASTM A1	Carbon steel rails
ASTM A36/A36M	Rolled shapes, plates, and bars
ASTM A108	Weld studs
ASTM A123	Zinc coatings (hot galvanized)
ASTM A240	Duplex 2101 stainless steel (designation S32101)
ASTM A307	Low carbon steel bolts
ASTM A325	High strength bolts
ASTM A354	Quenched and tempered alloy steel bolts (Grade BC)
ASTM A572	High-strength low alloy structural steel
ASTM A588	High-strength low alloy structural steel
ASTM-F1554	Steel anchor bolts, 36, 55, and 105-ksi Yield Strength

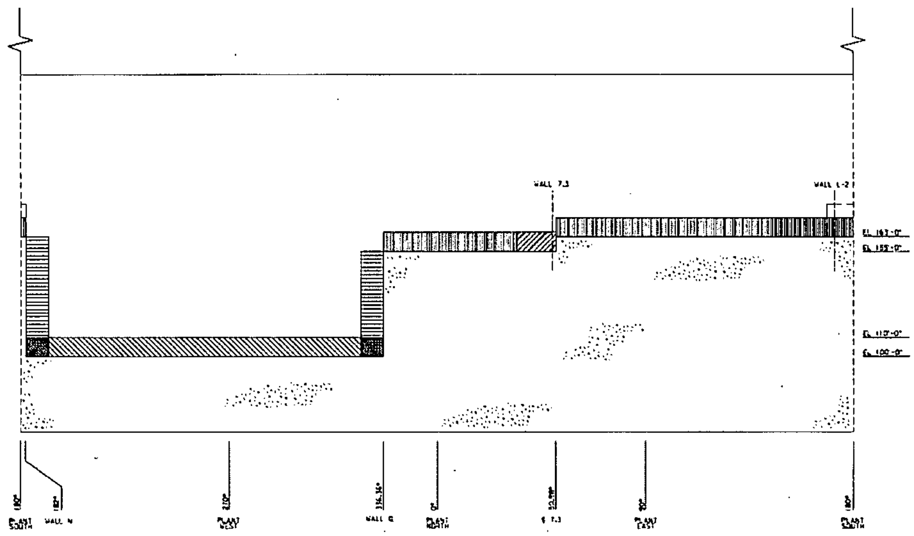


Figure 3.8.4-3

Developed View of Shield Building Wall locations: between SC and RC Construction

3H.5.1.5 Shield Building Cylinder at Elevation 180′-0″

[*The thickness of the cylindrical portion of the shield building wall is 3 feet. Below the air inlets region, the wall consists of high strength concrete contained within ½-inch* ~~*think*~~ *thick steel liner plates on both faces. The liner plates, tied to concrete with shear connectors, behave as reinforcement bars. There are no through wall steel members in the general shell area away from the connection zone to the reinforced concrete or air inlet region, except for wire ropes used to resist wet concrete loads during construction. Vertical angle stiffeners are provided to support the wet concrete load.*

The wall is designed for the applicable loads described in subsection 3H.3-3. A finite element analysis is performed to determine the design forces.

The design of the shield building roof is described in 3H.5.6.]*

3H.5.6 Shield Building Roof

[*The shield building roof is a reinforced concrete shell (supporting the passive containment cooling system tank and air diffuser), which is supported on a structural steel module. The structural configuration is shown on sheets 7, 8, and 9 of* ~~*DCD (Reference 1)*~~ *Figure 3.7.2-12. Air intakes are located at the top of the cylindrical portion of the shield building. The conical roof supports the passive containment cooling system tank. The conical roof is constructed as a structural steel module and lifted into place during construction. Steel beams provide permanent structural support for steel liner and concrete. The concrete is cast in place. Connection between concrete and steel liner are made using shear studs.*

The design of the shield building is shown in Figure 3H.5-11 (Sheets 1-7). These figures show the typical details of the "Tension Ring," "Columns between Air Inlets," and the "Exterior Wall of the Passive Containment Cooling System Tank." Figure 3H.5-11, Sheets 6 and 7, also shows the typical dimensions of the surface plates on the shield building cylindrical segment.

A detailed ANSYS model was used to represent these components of the enhanced design. Analyses were performed to determine the response of the structures for the dead weight, hydrostatic load due to PCS water, snow load, wind load, tornado load, seismic load (including seismic-induced pressure on PCS wall), and thermal loads. The design was evaluated to comply with the requirements of ANSI/AISC N690-94 and of ACI 349-01. The design summaries of the components are included in this report in Table 3H.5-9.]*

The steel frame for the shield building roof and the concrete placed directly thereon is designed to AISC N690.

- In the radial direction the steel beams, the steel surface plate and the concrete are evaluated as a composite section using the axial and bending member forces in the steel and concrete section from the finite element analyses. Steel stresses and the end connection are calculated assuming the steel alone resists all loads applied before the concrete has reached 75% of its required strength and the effective composite section resists all loads applied after that time.

- The steel surface plate and the concrete are evaluated using all member forces in the concrete and surface steel plate from the finite element analyses (in-plane and out-of-plane forces and moments). The circumferential channels are provided for construction only and are not modeled in the finite element analysis or credited for resisting permanent loads. The concrete section is evaluated by the strength method of ACI349. For positive bending, the steel plate is in tension and serves as the bottom reinforcement. For negative bending, the compression is resisted by the concrete.

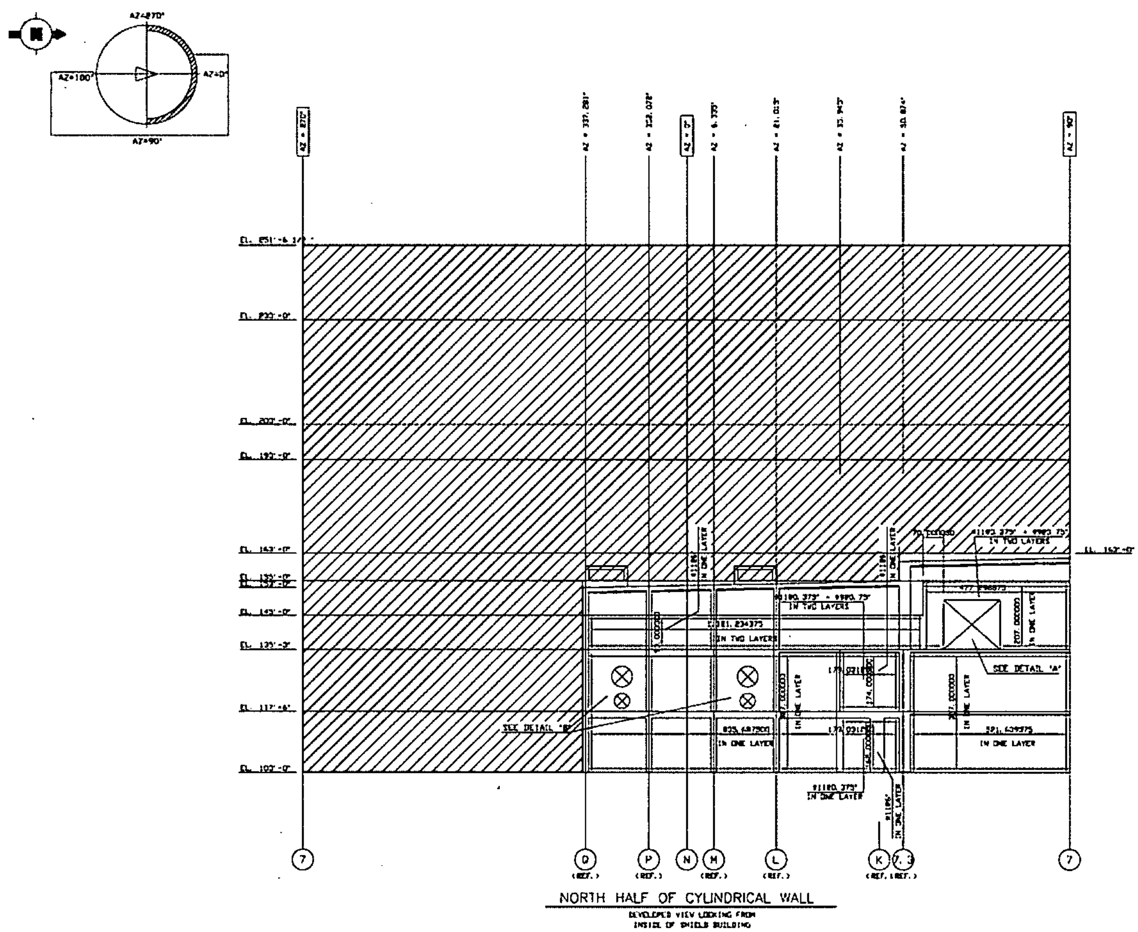


Figure 3H.5-11 (Sheet 6 of 7)

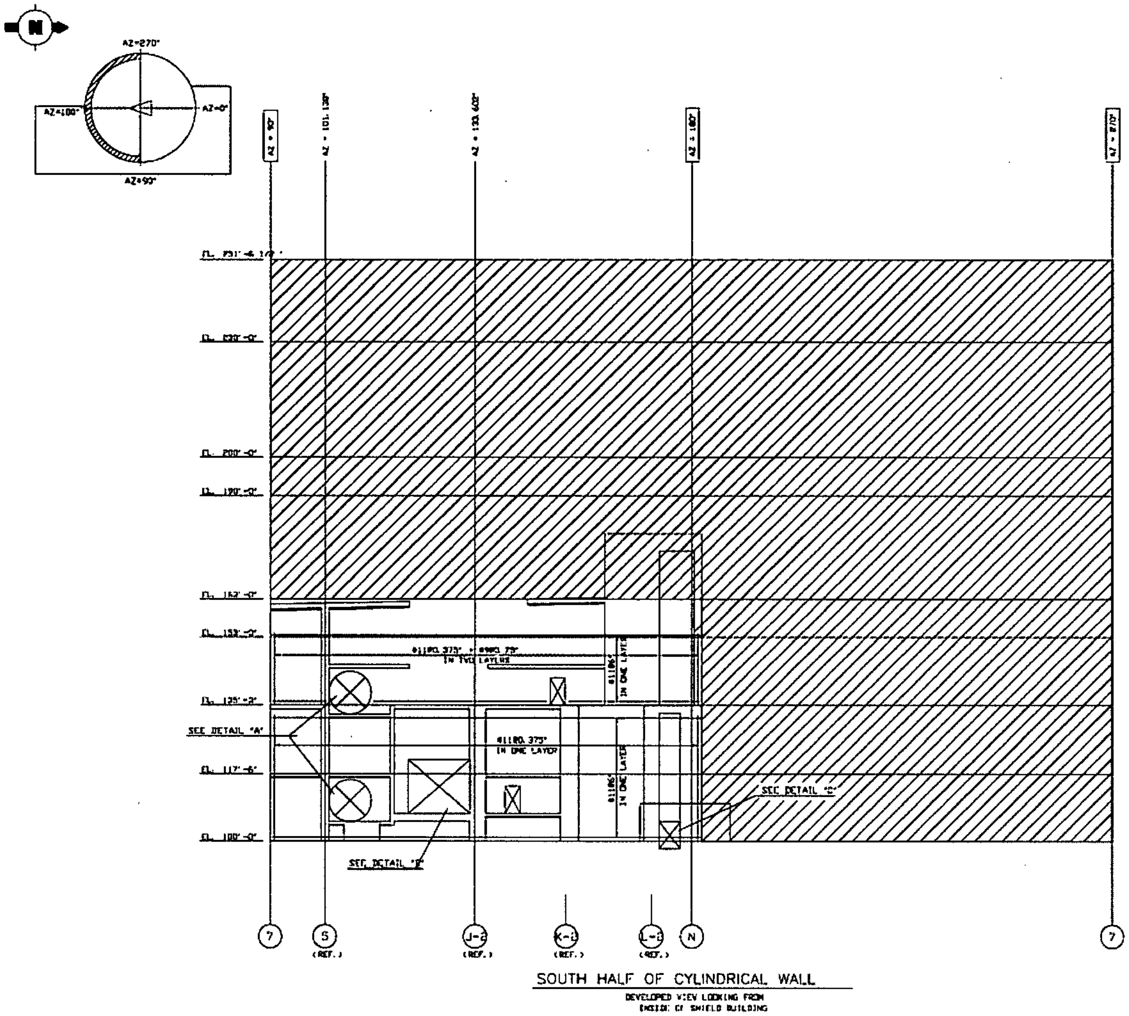


Figure 3H.5-11 (Sheet 7 of 7)

PRA Revision:
None

Technical Report (TR) Revision:
None