AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

Telephone Conference Call Summary

On January 21, 2003, Westinghouse and NRC held a telephone conference call to discuss issues associated with the structural design portion of the AP1000. The following discussion summarizes our responses to the issues raised regarding in the telephone conference call that was summarized in the NRC Memorandum from Lawrence J. Burkhart to Marsha Gamberoni dated February 6, 2003. Specifically, this memorandum requested that Westinghouse inform the NRC staff of its intentions regarding how Westinghouse plans to address the issues of (1) peer review of its AP1000 design models and (2) stiffness reduction of shear wall models.

Question: (NRC Letter of January 21, 2003, Telephone Conference Call Summary)

Peer Review

Given that the AP1000 NI model is very complex and was developed through the collaborative efforts of consultants from Switzerland, Spain, Italy, Japan and two entities in the United States, The NRC staff is concerned about the process used by Westinghouse to ensure the adequacy of the structural model for use in the design of structures, systems and components (SSCs). The requirement regarding reasonable assurance of the quality of the design of SSCs stems from general design criterion (GDC) No. 1, "Quality Standards and Records," of Title 10 of the *Code of Federal Regulations* (10CFR) Part 50. The importance of ensuring the appropriateness of analytical assumptions made (including the size and type of finite elements used to develop the dynamic model) is emphasized in the design control criteria of Appendix A to Part 50 which states that "[m]easures shall be established for the identification and control of design interfaces and for coordination among participating design organizations. These measures shall include the establishment of procedures among participating design organizations for the review, approval, release, distribution, and revision of documents involving design interfaces. The design control measures shall provide for verifying or checking the adequacy of design, such as by the performance of a suitable testing program. The verifying or checking process should be performed by individuals or groups other than those who performed the original design, but who may be from the same design organization." To address this issue, the NRC staff highlighted the need for a peer review of the NI design model during the November 2002 meeting and reiterated the same position at the January 21, 2003, telephone conference call. The NRC staff believes that a peer review of the complex NI model of the AP1000 is especially important in the light of the fact that Westinghouse did not consider the stiffness reduction of the shear walls. Westinghouse agreed to inform the NRC staff of its intentions to address the issues of (1) peer review of its AP1000 design models and (2) stiffness reduction of shear wall models.

NRC Tests on Concrete Shear Walls:

Seismic tests on scaled shear wall structures were conducted by the Los Alamos National Laboratory under the sponsorship of NRC's Office of Nuclear Regulatory Research and the shear walls exhibited natural frequencies that were lower than those calculated by the gross section properties of uncracked concrete sections even at relatively low levels of shaking, far

less than the SSE level of vibration. This was a surprise to many, including the Review Panel members. After a lot of peer review and detailed investigation by academicians, a paper written by Prof. Sozen (a member of the Review Panel) explained the reasons and made some recommendations for capturing the stiffness of shear walls in modeling their behavior in a seismic motion. The reference to this paper is: J.P. Moehle, P. Monteiro, H.T. Tang, and M.A. Sozen, "Effects of Cracking and Age on Stiffness of Reinforced Concrete Walls Resisting In-Plane Shear," Proceedings of the Fourth Symposium on Nuclear Power Plant Structures, Equipment, and Piping, North Carolina State University, Raleigh, N.C., December 1992, pp. 3.1-3.13. This paper recommends that the shear deformation part should be evaluated using gross uncracked area values, but the flexural properties should be based on cracked section properties.

The most recent guidance on the effective stiffness of reinforced concrete members is given in the proposed (Draft) ASCE Standard, "Seismic Design Criteria For Structures, Systems And Components In Nuclear Facilities" in Section 3.4. Provisions of this Section are excerpted below:

3.4 Modeling and Input Parameters

3.4.1 Effective Stiffness of Reinforced Concrete Members

In lieu of a detailed stiffness calculation, the effective stiffness of reinforced concrete members provided in Table 3.4-1 shall be used in linear elastic static or dynamic analysis. When finite element methods are used, the element stiffness shall be modified using the effective stiffness factor for the dominant response parameter.

Table 3.4-1 Effective Stiffness of Reinforced Concrete Members

Member	Flexural Rigidity	Shear Rigidity	Axial Rigidity
Beams – nonprestressed	$0.5E_cI_g$	G_cA_w	
Beams – prestressed	E_cI_g	G_cA_w	
Columns in compression	$0.7E_cI_g$	G_cA_w	E_cA_g
Columns in tension	$0.5E_cI_g$	G_cA_w	E_sA_s
Walls and Diaphrams – uncracked, $f_b<f_{cr}$, $V<V_c$	$0.8E_cI_g$	$0.8G_cA_w$	E_cA_g
Walls and Diaphrams – cracked, $f_b>f_{cr}$, $V>V_c$	$0.5E_cI_g$	$0.5G_cA_w$	E_cA_g

E_c = concrete compressive modulus	A_w = web area	f_{cr} = cracking stress
G_c = concrete shear modulus = $0.4E_c$	A_g = gross area of the concrete section	V = wall shear
E_s = steel modulus	A_s = gross area of the reinforcing steel	V_c = nominal concrete shear capacity
I_g = gross moment of inertia	f_b = bending stress	

Effective Stiffness of Reinforced Concrete Members

Table 3.4-1 is derived from FEMA 356, Table 6-5. For additional information on effective stiffness, consult FEMA 274, Section C6.4.1.2.

Consideration of Realistic Stiffness Properties of Shear walls:

Using the recommendation in the reference in Sozen's paper, the cracked moment of inertia of a shear wall section is 63% of the gross value.

Recommendation:

Westinghouse should use the criteria in the FEMA documents. These criteria are based on substantial new research.

Westinghouse Response:

Peer review of AP1000 design models

Westinghouse has performed the structural design of the AP1000 in accordance with the applicable portions of the Code of Federal Regulations including 10 CFR Part 50 Appendix B "Quality Assurance Requirements for Nuclear Power Plants and Fuel Reprocessing Plants." As discussed with the NRC, there is not a regulatory requirement for Westinghouse to conduct a peer review of the AP000 structural design. The Westinghouse design procedures have been followed, and the fidelity of the AP1000 structural design is acceptable. The following discussion provides our response on how this issue should be resolved.

The analytical models of the nuclear island were prepared by a number of different organizations under Westinghouse direction. Westinghouse defined the interfaces between these models and combined the models together in various analyses.

- Axisymmetric, finite element shell and stick models were created by Westinghouse for the shield building roof following the approach used by Ansaldo in preparing the AP600 models previously reviewed by NRC. These AP1000 models were verified by Ansaldo.
- Finite element shell and stick models of the auxiliary building were created by NOK and verified by Westinghouse. These models include the shield building roof models described in the previous paragraph. Westinghouse defined the interface with the containment internal structures at the 69' 6" radius of the inside face of the shield building cylinder from the bottom of the basemat at elevation 60' 6" up to grade at elevation 100'. Westinghouse worked closely with NOK in defining the analytical assumptions (including the size and type of finite elements used to develop the dynamic model). The model was established as a solid model in ANSYS to permit subsequent finite element generation with refinement appropriate to the scope of the analyses. In this approach, the solid model includes areas representing each different design configuration of the structure (walls, floors, thickness, floor loads, openings, etc.). This solid model is then used to generate finite element models. NOK generated and Westinghouse verified the finite element model used for the modal analyses. Westinghouse generated and verified the more refined finite element model used in the equivalent static analyses to provide member forces in each of the walls and floor slabs.
- Finite element shell and stick models of the containment internal structures and the basemat below the containment vessel inside the shield building were created and verified by Ansaldo and reviewed by Westinghouse. Walls and floors were modeled by shell elements following the approach used by Ansaldo for the AP600 analyses previously reviewed by NRC. The basemat was modeled using solid elements.
- Finite element axisymmetric and stick models of the containment vessel were created and verified by CBI and reviewed by Westinghouse. These followed the approach used by CBI for the AP600 analyses previously reviewed by NRC.

The modeling approach is similar to that used for the AP600 and was performed in most cases by personnel who had been involved in AP600 analyses. The primary change is the replacement of the BSAP computer program by ANSYS and the use of the ANSYS solid model capability in developing the finite element models.

Finite element models and analyses are documented as engineering calculations in accordance with Westinghouse quality assurance procedures. This includes verification by an independent person. Typical results are compared during this documentation process against those previously reviewed for the AP600. In addition to the formal quality assurance procedures followed by Westinghouse's partners, Westinghouse interacts with the partner during the work and reviews the final documentation. This review is extensive in the early stages of work with a partner and is reduced as Westinghouse establishes confidence in their capability.

A second level of model review occurs as the member forces from the detailed analyses are used in the design of the critical structural elements. In most cases the design of reinforcement in the structural element is performed by individuals who were not responsible for either the global analyses or for their verification. Critical sections are being designed through the collaborative efforts of Westinghouse and its partners including personnel from Ansaldo in Italy, Initec in Spain and Obayashi in Japan following Westinghouse quality assurance procedures. The designer of the critical section is responsible for reviewing the results of the global analysis in his assigned area and for determining that the results are appropriate for his use. Where the review shows areas in which the model could be improved, the results are evaluated by the designer and Westinghouse together to confirm that the models are appropriate for use and the results are adjusted if necessary in the design calculation for the individual wall or floor. Such cases are documented and will be considered for incorporation in a revised model if it is necessary to rerun any of the analyses. Westinghouse considers this process to provide an appropriate level of design assurance.

Recognizing the concern of the NRC staff, Dr William LaPay will perform an independent peer review of the finite element structural models of the auxiliary building. He will concentrate on the areas where the methodology has changed from the AP600, namely the creation of the ANSYS solid model and its use in generation of the finite element models. He has provided technical support to the AP600 project, including similar roles working closely with Quality Assurance and technical reviews acting as the technical review chairman of established peer review panels. Although he is already providing support to the AP1000, he has not been involved in the development of the structural models that he will be requested to assess, and is therefore, considered independent. He is a recognized technical expert in the area of commercial nuclear power plants. This review will be initiated by May 1, 2003.

Stiffness reduction of shear wall models

Westinghouse accepts the NRC staff recommendation to adopt the criteria in the FEMA documents for the stiffness of reinforced concrete shear wall structures. The reduction in stiffness will be included in existing analyses by changing the broadening of the floor response spectra. It will be considered directly in any new structural analyses.

FEMA 356, Table 6-5 recommends a flexural rigidity of $0.8E_c I_g$, a shear rigidity of $0.4E_c A_w$, and an axial rigidity of $E_c A_g$ for walls that are generally uncracked. The draft ASCE standard replaces the shear rigidity of $0.4E_c A_w$ by $0.8\ G_c A_w$ and defines G_c as $0.4\ E_c$. The existing AP1000 analyses use gross uncracked properties, i.e. a flexural rigidity of $E_c I_g$, a shear rigidity of $G_c A_w$ ($= 0.43E_c A_w$), and an axial rigidity of $E_c A_g$.

Westinghouse agrees that gross concrete properties may be overly stiff for the dynamic analyses. Westinghouse presented results of non-linear analyses to assess the effect of cracking during the meeting with NRC staff in November, 2002. These analyses showed a reduction in frequency of about 7% due to cracking with a reduction in the peak acceleration. The non-linear analyses were performed on a simplified stick model using methods described in NUREG/CR-6241, "Technical Guidelines for A Seismic Design of Nuclear Power Plants (Translation of JEAG 4601-1987)". These methods are supported by seismic testing in Japan.

Structural analyses of the AP1000 have been completed for the hard rock site. These analyses will not be revised since the dominant building structural frequencies are already at or near the peak of the ground response spectrum, and the study of the effect of cracking has shown a reduction of frequency of about 7% with a lower peak acceleration in structural response. However, the floor response spectra specified for equipment design will be revised by broadening the raw spectra by +10% and –20% instead of the ±15% currently described in DCD subsection 3.7.2.5. DCD subsection 3.7.2.5 and Figure 3.7.2-15 will be revised accordingly.

If the dynamic analyses are rerun, reductions in stiffness will be considered for reinforced concrete elements of the auxiliary building. The stiffness reductions will be considered in the auxiliary and shield building analyses using an elastic modulus of $0.8\ E_c$ and broadening the resulting spectra by ±15%. No reduction will be considered where the principal structures are structural modules such as inside containment and in the fuel pit area. As described in DCD subsection 3.8.3.4, shear stresses in the structural modules due to seismic loads are low. Also the behavior studies show less degradation of stiffness for the concrete filled steel plate modules than for reinforced concrete.

DCD Revision:

Revise DCD subsection 3.7.2.5 as follows:

The spectral peaks associated with the structural frequencies are broadened by **+10% and –20% for the auxiliary and shield buildings and by** ±15 percent **for the containment vessel and containment internal structures** to account for the variation in the structural frequencies, due to the uncertainties in parameters such as material and mass properties of the structure and soil, damping values, seismic analysis technique, and the seismic modeling technique. Figure 3.7.2-14 shows the broadening procedure used to generate the design floor response spectra.

Revise broadened spectra in Figure 3.7.2-15 to show +10% and –20% broadening.

PRA Revision:

None