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Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: T. R. QUAY

SUBJECT: AP600 STRUCTURAL MODULE OPEN ITEMS

Dear Mr. Quay:

Enclosed are responses for a number of open items related to structural module design and analysis. These responses are provided to support the review meeting with the NRC staff and consultants scheduled for April 14-18, 1997. Proposed SSAR revisions are included where appropriate. These revisions will be included in Revision 12 of the SSAR.

The open items addressed are as follows:

OITS Number	DSER or Other Item Number
725	3.8.3.4-6
732	3.8.3.4-13
754	3.8.4.4-6
5150	NRC Letter March 18, 1997 New item
5151	A 14.2
5152	B 22

If you have any questions please contact D. A. Lindgren at (412) 374-4856.

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

jml

Enclosure

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cc: Diane T. Jackson, NRC (w/Enclosure)
Nicholas J. Liparulo, Westinghouse (w/o Enclosure)

Open Item # 725 DSER Open Item 3.8.3.4-6

The remaining open issue is summarized in the NRC letter of March 18, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural modules" as follows:

Effect of Concrete Cracks to the Seismic Model of the Containment Internal Structures

In addressing the effect of concrete cracks to the seismic model of the containment internal structures, Westinghouse states in Revision 7 of the SSAR (Section 3.8.3.4.1.2 and Table 3.8.3-1) that for considering cracks in the concrete fill, the in-plane shear stiffness is calculated based on a 45-degree diagonal concrete compression strut with tensile loads carried by the steel plates. These calculated stiffnesses are considerably lower than the test data described in SSAR References 27 and 28 where the overall stiffness is reduced to 60 to 70 percent of the monolithic stiffness. If the calculated stiffnesses are used for the boundaries of the in-containment refueling water storage tank, the equivalent shear area of the containment internal structures is reduced by about 30 percent with a corresponding reduction in frequency of about 16 percent. The staff review of this SSAR revision found that the floor response spectra in the containment internal structures are not acceptable for the following two reasons:

(a) As shown in Revision 7 of SSAR Figures 3.7.1-7 and Table 3.7.2-3, the first dominant frequency of the internal structures in the north-south direction is 13.6 hertz and the corresponding ground spectral acceleration is ±0.63 g. If the first dominant frequency reduced from ±13.6 hertz to 11.42 hertz (reduced by 16 percent), the corresponding ground spectral acceleration is increased to ±0.72 g. Westinghouse did not consider this ground spectral acceleration increase due to concrete cracks when they calculated the floor response spectra in the containment internal structures.

(b) In following the guideline of Regulatory Guide 1.122, Westinghouse developed the final floor response spectra by applying the ±15 percent peak broadening rule to the enveloped floor response spectra to cover the uncertainties due to material properties of structures and soil, soil-structure interaction techniques, and approximations in the modeling techniques. However, the ±15 percent peak broadening cannot cover the uncertainties due to the cracked concrete in the structural modules.

In conclusion, Westinghouse should either regenerate the floor response spectra for the containment internal structures or justify the adequacy of the floor response spectra documented in the SSAR.

Westinghouse response

The SSAR used the calculated stiffness of Case 3 as a conservative estimate of the lower bound in-plane shear stiffness of the structural modules. This case assumes that the concrete in tension has no stiffness. For the flexural stiffness this is the conventional stiffness value used in working stress design of reinforced concrete sections. For in-plane shear stiffness, a 45-degree diagonal concrete compression strut is assumed with tensile loads carried only by the steel plate. This assumes that the crack pattern is oriented along the diagonals. The in-plane stiffness calculated by these assumptions are significantly lower than the stiffness measured in the tests of similar construction with in-plane

loads. The case 3 stiffness is not considered to be a realistic best estimates of the stiffness after the postulated PRHR thermal event. It was used only to show that even with the conservative lower bound stiffness the change in frequency in the north-south direction is only about 16 percent.

Additional investigation has been performed to obtain a better estimate of the post PRHR thermal event stiffness. A new stiffness value has been calculated in which the effects of aggregate interlock are considered across the preexisting cracks (due to the PRHR thermal event). In the previous calculation the stiffening due to aggregate interlock was conservatively neglected. The stiffening due to aggregate interlock is significant when the preexisting crack pattern is in the horizontal and vertical directions as would occur with the PRHR thermal event due to the horizontal and vertical boundary restraint for each panel.

Analysis

The previous analyses were extended to include consideration of aggregate interlock using the approach of reference 1. It was assumed that the crack pattern due to thermal would be horizontal and vertical. These cracks would be on one face, the cold face, and would close after the thermal event. It was found that for small residual cracks due to the thermal event the calculated stiffness was 70 percent of the monolithic stiffness.

Test results

Vecchio and Collins (reference 2) tests of reinforced concrete panels under in-plane shear includes a case where the panel was precracked under biaxial tension and was then cycled with pure shear loading.

The double reinforced panel (PV30) was 890 mm square and 70 mm thick with a concrete cylinder strength of 19.1 MPa. The reinforcing mesh, with a yield strength of 437 MPa, was constructed of smooth wires welded into an orthogonal grid at 50 mm centers. The wire diameters were 6.35 mm ($\rho = 1.78\%$) in one direction and 4.78 mm ($\rho = 1.0\%$) in the other. The panel cracked under the biaxial tension loads at a tensile loading of 1.55 MPa. The tensile loading was then increased to 60 percent of the yield strength of the steel. Following biaxial cracking and unloading, the panel was loaded in pure shear. The panel was cycled 10 times at each load increment. New cracking developed along the diagonals and the initial precracking of the panel had little effect on the in-plane stiffness. At the diagonal cracking limit the in-plane stiffness of the panel was about 88% of the calculated monolithic stiffness.

In-plane shear stresses due to the SSE in the structural modules are below the concrete cracking stress as described in SSAR sub-section 3.8.3.4.1.2. In-plane stiffness may be reduced from the monolithic value (to 70% by analysis and 88% by test) due to horizontal and vertical cracking from a prior PRHR thermal event. This stiffness reduction applies only to the boundary of the IRWST. The $\pm$ 15% broadening of the floor response spectra is sufficient to accommodate the frequency shift due to this small reduction in stiffness.

References:

1. M. P. Divakar, A. Fafitis, and S. P. Shah,"Constitutive model for shear transfer in cracked concrete", ASCE Journal of Structural Engineering, Vol 113, No.5, May, 1987

2. F. Vecchio and M. P. Collins,"The response of reinforced concrete to in-plane shear and normal stresses", Publication No. 82-03, University of Toronto, 1982 - Pages related to test PV30 are attached (pages 35, 36, 205, 206, 311 - 314, 328 - 332)

SSAR revision

3.8.3.4.1.2 Stiffness Assumptions for Global Seismic Analyses

The monolithic initial stiffness (Case 1 of Table 3.8.3-1) is used in the seismic analyses of the containment internal structures and the auxiliary building modules. This stiffness is used since the stresses due to mechanical loads including the safe shutdown earthquake are less than the cracking stress. The maximum in-plane concrete shear stresses in the containment internal structures modules are 97 psi for the 48-inch wall and 137 psi for the 30-inch wall due to the safe shutdown earthquake based on the monolithic section properties.

The broadening of the floor response spectra is sufficient to account for lower structural frequencies due to cracking of those portions of the structural modules that are boundaries of the in-containment refueling water storage tank exposed to abnormal thermal transients. Cracking due to the abnormal thermal event is primarily in the horizontal and vertical directions. Both tests and analyses show that this cracking has only small effect on the in-plane shear stiffness of a panel. ~~Case 3 of Table 3.8.3-1 shows a calculated in-plane shear stiffness based on a 45-degree diagonal concrete compression strut with tensile loads carried only by the steel plate. These calculated stiffnesses are considerably lower than the test data described in References 27 and 28 where the overall stiffness reduced to 60 to 70 percent of the monolithic stiffness. If the calculated stiffnesses are conservatively used for the boundaries of the in-containment refueling water storage tank, the equivalent shear area of the containment internal structures stick model is reduced by about 30 percent with a corresponding reduction in frequency of about 16 percent.~~

OITS 732 DSER Open Item 3.8.3.4-13

During the January 14-16, 1997 review meeting, the staff found Westinghouse's design calculations to be lacking in clarity and completeness. Westinghouse should conduct its own design review of these calculations to improve their quality and completeness and finalize them before the staff's review.

Westinghouse Response

During the structural audits it has been Westinghouse practice to have engineers available to assist the NRC reviewer in understanding the calculation. This is done to speed up the review particularly in the case of large calculations. The NRC comment resulted when calculations were reviewed by the NRC and their consultants after the scheduled audit was over when an attempt was being made to close out

an open item by review of a small part of the calculation. The comments could probably have been resolved if a Westinghouse engineer had been present.

Westinghouse calculations are prepared to meet our QA requirements, and are periodically audited to assure compliance with these procedures. Each calculation is verified by an engineer other than the author. In many cases, the calculations are further reviewed by independent reviewers to assure clarity, completeness and the validity of assumptions. Similar procedures are followed by the design agents working on AP600 design. Westinghouse engineers continuously monitor the quality of calculations prepared by the design agents. Indeed, in the December 1996 meeting, Westinghouse was complimented in the exit meeting by the ECGB Chief , for the quality of calculation packages.

Calculation 1100-SUC-101 has since been independently reviewed by Westinghouse engineers. A few comments have been provided to the design agent to improve the clarity. These comments have been incorporated in revision 2 of the calculation which will be available for NRC review during the week of April 14, 1997.

Open Item # 754 DSER Open Item 3.8.4.4-6

The open issue is summarized in the NRC letter of March 4, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural design" as follows:

Open Item 3.8.4.4-6 (OITS 754) Analysis Procedures and design Details of Spent Fuel Pool, Fuel Transfer Canal and New Fuel Storage Area

Westinghouse needs to provide (a) cross references of the definition of design loads including seismic loads, and (b) restrictions for the design of spent fuel pool floor and fuel racks in the SSAR. Westinghouse will (1) add a reference in SSAR Subsection 3.8.4 to the fuel rack design criteria and loads in Section 9.1, (2) revise the description of the spent fuel pool in Subsection 9.1.2.2 paragraph 3, from reinforced concrete to structural module, and (3) provide a reference to Subsection 3.7.2 in Section 9.1. This open item remains unresolved.

Westinghouse response

A reference was added to the fuel rack design criteria and loads in Section 9.1 in SSAR Subsection 3.8.4, Rev 11. The description of the spent fuel pool in Subsection 9.1.2.2 paragraph 3, is revised from reinforced concrete to a combination of reinforced concrete and the structural module, and the reference to Subsection 3.7.2 in Section 9.1 is added in the SSAR revision shown below.

SSAR revision

Revise first paragraph of subsection 9.1.2.2 as shown below.

The spent fuel storage facility is designed to the guidelines of ANS 57.2 (Reference 4). The spent fuel storage facility is located within the seismic Category I auxiliary building fuel handling area. The walls of the spent fuel pool are an integral part of the seismic Category I auxiliary building structure.

The facility is protected from the effects of natural phenomena such as earthquakes (subsection 3.7.2), wind, and tornados (Section 3.3), floods (Section 3.4), and external missiles (Section 3.5).

Revise last paragraph of subsection 9.1.2.2 as shown below.

The spent fuel pool provides storage space for spent fuel. The pool is approximately 41 feet deep, and constructed of reinforced concrete, and concrete filled structural modules as described in subsection 3.8.4. The portion of the structural modules in contact with the water in the pool is stainless steel and the reinforced concrete portions are lined with a stainless steel plate. The normal water volume of the pool is about 176,000 gallons of borated water (including racks without fuel at a water level 2 foot 6 inches below the operating deck) with a nominal boron concentration of 2500 ppm. Figures 1.2-7 through 1.2-10 show the spent fuel pool and other features of the fuel handling area.

Open Item # 5150

This new open issue is identified in the NRC letter of March 18, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural modules" as follows:

"AP600 critical section details

Westinghouse was requested to include section details in a formal revision to the SSAR."

Westinghouse response

The draft design summary reports provided during the structural audits will be issued as WCAPs to document the critical sections reviewed during the structural audits. The draft reports will be modified to include typical details from the drawings that were also available during the audit. The summary design reports will be referenced from the SSAR as shown below.

SSAR Revision

Add the following subsection:

3.8.4.5.3 Design Summary Report

A design summary report is prepared for seismic Category I structures documenting that the structures meet the acceptance criteria specified in subsection 3.8.4.5. References 49, 50 and 51 provide the design summary report. Deviations from the design are acceptable based on an evaluation consistent with the methods and procedures of Section 3.7 and 3.8 provided the following acceptance criteria are met. Depending on the extent of the deviations, the evaluation may range from documentation of an engineering judgement to performance of a revised analysis and design.

- the structural design meets the acceptance criteria specified in Section 3.8

- the amplitude of the seismic floor response spectra do not exceed the design basis floor response spectra by more than 10 percent

Add reference to new subsection 3.8.4.5.3 from subsection 3.8.3 (containment internal structures) and 3.8.5 (basemat).

Add to references:

49. WCAP xxxx, "Design summary report for containment internal structures"

50. WCAP xxxx, "Design summary report for auxiliary building"

51. WCAP xxxx, "Design approach and summary report for nuclear island basemat"

Open Item # 5151

This new open issue is identified in the NRC letter of March 18, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural modules" as follows:

A 14.2 Reference to ASME "$3S_M$" allowable for thermally- induced stresses in steel face plates, in Subsection 3.8.3.5.3.4, was revised to clarify its application. Draft revision needs further clarification, to provide justification for accepting thermally induced stresses greater than the yield strength.

Westinghouse Response

SSAR Subsection 3.8.3.5.3.4 will be revised as follows:

3.8.3.5.3.4 Evaluation for Thermal Loads

The effect of thermal loads on the concrete-filled structural wall modules is evaluated by using the working stress design method for the load combinations of Table 3.8.4-2 with the load factors taken as unity. This evaluation is in addition to the evaluation using the strength design method of ACI-349 for the load combination without the thermal load. Acceptance for the load combination with thermal loads is that the stress in general areas of the steel plate be less than yield. In local areas the stress may exceed yield and the allowable stress intensity is 3 S_{mr}. This is allowable based on the allowable stress intensity for Service Level A loads given in ASME Code, Section III, Subsection NE, Paragraph NE-3221.4. For the purpose of establishing allowable stresses, the ASME Code recognizes two types of thermal stresses; general thermal stress and local thermal stress. General thermal stress is associated with distortion of the structure. If the strain exceeds twice the yield strain of the material, successive thermal cycles may produce incremental distortion. Local yielding and minor distortions may occur and failure is not expected to occur. Local thermal stress is associated with almost complete suppression of the differential expansion. Such stresses are only considered from the fatigue standpoint. Thermal stresses in the

structural modules are closer to the local thermal stresses since the steel in some locations is almost totally restrained by the concrete. However, the acceptance criteria are specified conservatively as though they are general thermal stresses.

Open Item # 5152

This new open issue is identified in the NRC letter of March 18, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural modules" as follows:

"B 22. Based on discussions at the January 14-16, 1997, meeting, Westinghouse will review the need to postulate loads due to pipe break for the structural modules."

Westinghouse response

Global loads due to subcompartment pressurization are specified for design of the structural module walls.

Piping greater than 4 inches in diameter, except the main and startup feedwater piping, is qualified to leak-before break criteria. There are no pipe rupture loads other than the subcompartment pressurization on the three walls identified as critical sections and included in design calculation 1100-SUC-101 (south-west wall of the refueling canal, south wall of the steam generator compartment (Module M1) or on the wall containing the PRHR HX).

Pipe rupture effects at other locations of the structural modules are identified in the pipe rupture hazard evaluation. Generally the loads are due to postulated breaks in small diameter piping and will not be significant to the overall design of the wall.