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NSD-NRC-97-5105
DCP/NRC0844
Docket No.: STN-52-003

May 2, 1997

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

ATTENTION: T. R. QUAY

SUBJECT: Response to DSER Open Item 3.7.2.12-1

During a review of the structural design of the AP600 conducted by the NRC staff and consultants the week of December 9-13, 1996 a question was raised about the differences between the results of response spectra analyses and time history analyses for the nuclear island. This item is associated with DSER open item 3.7.2.12-1, OITS# 668. The NRC question on this issue was included in your letter dated March 4, 1997, Summary of Meeting to Discuss Westinghouse AP600 Structural Design.

The Westinghouse response for this item is attached. This response completes the Westinghouse action on this item except for formal revision of the SSAR. The Westinghouse status of this item in the Open Item Tracking System will be Confirm-W pending inclusion of the draft changes in the SSAR.

Please contact Donald A. Lindgren at (412) 374-4856 with any questions.

Brian A. McIntyre

Enclosure

cc: D. Jackson, NRC w/att.
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Open Item # 668 DSER Open Item 3.7.2.12-1

The open issue is summarized in the NRC letter of March 4, 1997, "Summary of Meeting to discuss Westinghouse AP600 structural design", item # 6, as follows:

"Difference between Response Spectra and Time-History Analyses

While making the comparison, the staff observed that: a) the maximum absolute nodal accelerations from response spectrum analysis are consistently higher, sometimes by a very large margin; b) because of item (a) above, the floor response spectra generated from floor time-histories may not be conservative; c) member forces from response spectrum and time history analyses do not always follow the same trend as the nodal accelerations. Sometime the trend is reversed, in which case the design forces and moments from the 3-D finite element response spectrum analysis may not be conservative.

Based on these observations, the staff asked Westinghouse to justify the adequacy of both the final design floor response spectra and the final design forces and moments for structural members."

Westinghouse response

1.0 Introduction

SSAR Tables 3.7.2-17, 3.7.2-18, and 3.7.2-19 show comparisons of maximum response accelerations, member forces and member moments between results from modal time history (TH) and response spectrum analyses (RSA) of the AP600 multiple stick fixed-base model. The differences between the results of the two analytical methods are discussed below. The AP600 final design floor response spectra and the final design forces and moments are adequate. Responses of the steel containment vessel are discussed in section 2, of the coupled auxiliary and shield building in section 3, and of the containment internal structures in section 4.

The time history and the response spectrum analyses use the same fixed-base, multiple-stick model consisting of the nuclear island (NI) stick, the containment internal structures (CIS) stick, the steel containment vessel (SCV) stick and the reactor coolant loop (RCL). The NI stick, representing the coupled auxiliary and shield buildings including the embedded exterior walls and basemat, is fixed at the basemat elevation and is supported horizontally at floor elevations of 82.5' and 100' to represent embedment in Hard Rock. The reactor coolant loop model, RCL, is entirely supported by the CIS model. The CIS model is attached to the NI model at elevation 82.5'. The CIS model is also supported horizontally by the NI model at elevation 100'. The SCV model is attached to the NI model at elevation 100'.

In the modal time history analysis, a uniform time step of 0.005 seconds and a cut-off frequency of 33 hertz are used with the three AP600 input acceleration time histories applied

in the three global coordinates. The responses due to the three directions of input are therefore combined by algebraic summation.

In the response spectrum analysis, the "smooth" ground response spectra for AP600 are applied in the three global directions. The cut-off frequency and ZPA are 33 hertz and 0.3 g. The "double sum" modal combination method, as described in the Standard Review Plan, is used including "missing mass" from high frequency modes. Responses due to the three directional inputs are combined by the SRSS method.

2.0 Steel Containment Vessel (SCV)

2.1 Accelerations

For the SCV, accelerations calculated by time history analysis are used in design while those calculated by the response spectrum analysis are used for comparison purpose only. The maximum accelerations from these analyses are compared in SSAR Table 3.7.2-17 (sheet 2 of 3) where it is shown that response accelerations calculated by the response spectrum analysis are generally higher than those calculated by the time history analysis with the maximum difference occurring in the vertical direction at the top elevation of the SCV model.

70 modes are considered in the response spectrum analyses with a cut-off frequency at 33 hertz as shown in SSAR Table 3.7.2-4. The "double sum" modal combination method is used where:

$$R = \left\{ \sum_{k=1}^{N} \sum_{s=1}^{N} \left| R_k \cdot R_s \right| \cdot \varepsilon_{ks} \right\}^{1/2} ,$$

Where

$\varepsilon_{ks} = \{ 1 + [(\omega_k' - \omega_s') / (\beta_k' \omega_k + \beta_s' \omega_s)]^2 \}^{-1} > 1.0$,

$\beta_k' = \beta_k + (2 / t_d \omega_k)$

$\omega_k' = \omega_k (1 - \beta_k^2)^{1/2}$

ω_k = frequency of the *k*th mode

β_k = damping of the *k*th mode

t_d = earthquake duration.

From the above equation for the "double sum" modal combination method, in each of the three global input directions, the response is equal to the summation of a total of 70^2 (or 4,900) terms where each of these terms is defined to be positive. This "absolute summation" of a large number of terms can add large conservatism in analyses using this method of combination. The method may be particularly conservative for a model such as the AP600 multiple sticks where there are large differences in the magnitude of the masses. The masses on the NI stick are two orders of magnitude larger than the mass at the top of the SCV stick. The light mass may occur in a number of closely spaced modes with opposite phasing of the

light mass. In time history analyses the responses in these modes tend to cancel out whereas the response spectrum analysis combines the maximum responses absolutely.

Both the combined CIS-RCL stick model and the SCV stick model are supported at floor elevation 100'. The support points at elevation 100' are themselves well supported, vertically by walls down to the fixed basemat and horizontally by floor slabs outward to the horizontally supported exterior wall. Stick to stick interactions are therefore expected to be small. For comparison purposes to evaluate the effect of the large nuclear island masses, the SCV was re-analyzed without the NI, CIS and RCL stick models that are above elevation 100'. This was accomplished by re-running the response spectrum analysis using the same multiple stick model with masses above elevation 100' on the other sticks removed while retaining other parameters. This modified model has 10 modes within the 33 hertz cut-off frequency. The number of terms in the "double sum" summation reduces from 4,900 to 100. Results from this modified model show reduced acceleration responses which generally are lower in magnitude than those of the original time history analysis. The vertical acceleration responses at the top of the SCV stick, where maximum differences occur between the two analysis methods, are summarized below.

		Vertical Acceleration Responses (g)		
Node #	elevation	T/H (SSAR)	RSA (SSAR)	RSA (Single stick)
3115	256'	1.49	2.91	1.62
3114	248'	1.20	2.03	1.07

This comparison demonstrates that the smaller number of modes in the modified single stick model reduces significantly the number of terms in the "double sum" summation and thus reduces the conservatism of this combination.

Table 1 compares the maximum responses from the modal time history analysis (from SSAR) with those from the "single modified SCV stick". These comparisons support the use of the accelerations and the floor response spectra obtained from the time history analysis for design of the AP600.

2.2 Member Forces

Maximum member forces are compared in SSAR Table 3.7.2-18 (sheets 2 and 3). In the vertical direction, forces calculated by the response spectrum analysis are consistently higher than those calculated by time history. This is also caused by the conservatism of the "double sum" method as discussed for the accelerations. In the two horizontal directions, the shear forces from the response spectrum analysis are generally in agreement with those by time history analysis at elevations below 200'.

The SCV is designed using the accelerations from the time history analysis discussed in section 2.1 above. The calculated member forces in the SCV stick are not used in design.

3.0 Coupled Auxiliary and Shield Buildings

3.1 Accelerations

The maximum accelerations of the Coupled Auxiliary and Shield Buildings (NI) are compared in SSAR Table 3.7.2-17 (sheet 1 of 3). Accelerations calculated by the modal time history analysis are used in developing the design floor response spectra while those calculated by the response spectrum analysis are used for comparison purpose only. Table 2 shows that response accelerations from the response spectrum analysis are generally in agreement with those from time history analysis except at elevations 200', 220', and 241' for vertical responses and elevations 200', 220', 241', 272', and 284' for east-west responses where accelerations from the response spectrum analysis are higher than those from the time history analysis.

In Table 3, response accelerations at the elevations where the responses differ most are separated by the direction of input. For single direction seismic input, acceleration responses in the input direction compare well between response spectrum and time history analyses. However, large responses occur in directions orthogonal to the input direction in the response spectrum analysis but not in the time history analysis.

Modal properties are shown in Table 4 for modes 49 and 50 for responses in the east-west and vertical directions. For these two closely spaced modes (19.34 hertz and 19.70 hertz), the modal participation factors (Γ) and the modeshapes (Φ) in the global Y (east-west) and Z (vertical) directions are shown with their sign. When calculating the cross terms in these modes, east-west responses due to vertical input and vertical responses due to east-west input, the product of ($\Gamma\Phi$) for modes 49 and 50 have opposite signs and will "cancel" each other if the two modes are combined by algebraic sum. However, the cross terms conservatively add together if the modal combination is based on some form of "absolute" summation such as the "double sum" method.

Both time history and response spectrum analyses were re-run excluding modes 49 and 50 and the response accelerations are compared in Table 5. The comparison of time history responses shows that east-west responses are largely unaffected by inclusion or exclusion of these two modes. The comparison of response spectrum analysis responses shows that east-west responses have meaningful reduction when these two modes are excluded. The east-west responses from the response spectrum analysis excluding modes 49 and 50 are similar to those from the time history analysis except at elevation 200' where the time history acceleration is larger. It is concluded that the differences in the east-west accelerations are caused by the conservatism of the "double sum" combination in the response spectrum analysis. The design accelerations and design floor response spectra in the east-west direction calculated by time history analysis are adequate for AP600 design.

The differences in the vertical response accelerations are also caused by the conservatism of the "double sum" combination of the response spectrum analysis. The vertical responses due to vertical input for modes 49 and 50 have the same sign and do not 'cancel" each other even when combined by algebraic summation. As a result the time history results and the response spectrum results show a reduction in response when modes 49 and 50 are excluded. The vertical response due to east-west input for modes 49 and 50 "cancel" out in the time history analysis but not in the response spectrum analysis.

The above comparison has demonstrated that the "absolute" modal combination used in the "double sum" method introduces additional conservatism in the response spectrum analysis responses. The design accelerations and the design floor response spectra, which are calculated by modal time history analysis, are appropriate for the design of the AP600.

3.2 Member Forces

Maximum member forces are compared in SSAR Table 3.7.2-18 (sheet 1). For the Coupled Auxiliary and Shield Buildings (NI) stick model, maximum member forces from the time history analysis were used to develop the SSI factor for member forces from other soil cases. This SSI factor was then used to amplify the results of the finite element fixed base response spectrum analysis to give the final design forces for the AP600. Member forces calculated by response spectrum analysis of the stick model were used for comparison only. Comparison of these maximum member forces in Table 6 shows that axial (vertical) forces from the time history analysis are higher than those from the response spectrum analysis at elevations below elevation 241'. In both horizontal directions, time history and response spectrum analysis forces are close except at sections close to grade where time history forces are higher.

Maximum vertical forces are re-calculated by (1) time history analysis with only vertical input time history applied in the vertical direction, and (2) response spectrum analysis with only the acceleration response spectra of the vertical input time history applied in the vertical direction. Axial forces from the two modal time history analyses, the original which has three directional input and the new time history analysis which has only vertical input, are summarized in Table 7 and compare well. Maximum axial forces from the two re-analyzed cases, both with only vertical input, are also compared in Table 7. They compare well except at sections close to grade at elevation 100' where time history forces are higher.

Tables 6 and 7 show that the maximum member forces calculated by time history compare well with those calculated by response spectrum analysis except at sections close to grade where the time history forces are higher than the response spectrum analysis forces. The member forces are used in the AP600 design to develop the SSI factor using comparable results of the soil structure interaction analyses using SASSI. Since SASSI also calculates the time history of member forces with algebraic summation of the three directions of input, the member forces from the time history analysis are appropriate for use in the AP600 design.

4.0 Containment Internal Structures

4.1 Accelerations

The maximum accelerations of the Containment Internal Structures (CIS) are compared in SSAR Table 3.7.2-17 (sheet 3 of 3). The Containment Internal Structures are nearly rigid in the vertical direction and below elevation 107' in the horizontal directions where the maximum accelerations are close to the ZPA of the input motion. Between elevations 107' and 158', the maximum NS and EW accelerations calculated by response spectrum analysis are higher than those calculated by time history (Table 8).

Table 9 shows response accelerations when the NS and EW input motions are applied separately. The response accelerations in the primary directions (NS response due to NS input, or EW response due to EW input) calculated by the time history analysis are generally higher than those by the response spectrum analysis. In the cross coupled directions (NS response due to EW input, or EW response due to NS input), responses calculated by the response spectrum analysis are approximately twice as high as those calculated by time history. When responses in the primary directions are combined with those from the other direction, the combined responses from the response spectrum analysis exceed those from time history.

Modal properties for selected dominant horizontal modes are presented in Table 10. The term $\Gamma\phi$, the product of the modal participation factor and the modeshape, as shown in the table indicates that (1) this product is generally positive in the dominant modes in the primary directions; and (2) this product is much more evenly distributed into positive and negative in the cross coupled directions. Relative to the time history modal superposition, the use of "absolute" summation in the double sum modal combination of the response spectrum analysis leads to:

- similar magnitudes of the responses in the primary directions since most of the individual terms are already positive;
- additional conservatism in responses in the cross coupled direction since many terms have opposite participation and are changed into positive values before being combined.

This is shown at the bottom of Table 10 where the summation of the $\Gamma\phi$ terms for east-west and north -south response are given from left to right for: (1) algebraic summation of all modes, (2) algebraic sum of modes 34, 41,and 45 only, (3) SRSS of modes 34, 41,and 45 only, and (4) absolute sum of modes 34, 41, and 45 only.

Response acceleration in the primary directions are shown to be similar between the time history and response spectrum analyses (Table 9). The "double sum" modal combination introduces additional conservatism in the response spectrum analysis accelerations in the cross coupled directions. Therefore, the design accelerations and design floor response spectra

calculated by the time history analysis are appropriate for use in the AP600 design.

4.2 Member Forces

Maximum member forces are compared in SSAR Table 3.7.2-18 (sheet 4). For the Containment Internal Structures (CIS) stick model, maximum member forces from the response spectrum analysis were used to develop the SSI factor for member forces from other soil cases. This SSI factor was then used to amplify the results of the finite element fixed base response spectrum analysis to give the final design forces for the AP600.

Member forces calculated by time history and response spectrum analyses are compared in Table 11. The CIS is "rigid" in the vertical direction and most of its vertical mass does not participate in the time history analysis with a cut off frequency of 33 hertz. Therefore, axial forces from the time history analysis are much smaller than the axial forces from the response spectrum analysis which include the high frequency "missing mass".

In the response spectrum analysis, the "missing mass" is multiplied by the ZPA of 0.3 g and combined with member forces for modes below 33 hertz by the SRSS method. For comparison with the time history results, the "missing mass" of the CIS is summarized and equivalent forces for 0.3 g static acceleration are calculated in Table 12. These additional forces due to the high frequency "missing mass" are combined with the time history analysis forces by SRSS method. The combined response forces are shown in Table 13 and are similar to those from the response spectrum analysis.

The design member forces for the CIS are developed from the finite element model amplified by the SSI factor. This factor is obtained using the member forces from the stick model results of the response spectrum analysis. These member forces from the stick model are appropriate for the design of the AP600.

5.0 SSAR Revision - Add summary of comparison in subsection 3.7.2.12 as shown below:

The three-dimensional lumped mass fixed base stick model of the nuclear island was analyzed by mode superposition time history analysis and by the response spectrum analysis method for the hard rock site condition. Tables 3.7.2-17, 3.7.2-18, and 3.7.2-19 compare the maximum absolute nodal accelerations, member forces, and moments, respectively. Both analyses considered vibration modes up to 33 hertz. In the response spectrum analyses, the combination of modal responses used the double sum method and included high frequency effects as discussed in subsection 3.7.2.7 and summarized in Table 3.7.2-16. The two methods of analysis give similar results with the response spectrum analysis being generally more conservative. Investigations of the two analyses showed that the conservatism in the response spectrum analyses is due to cross coupling of the directions in the multistick model. The double sum modal combination method used in the response spectrum analyis is very conservative when there are closely spaced modes some of which are out-of-phase.

Table 1: SCV - Maximum response acceleration

Node #	Elev. (feet)	(1) TH, SSAR			(2) RSA			(3) Ratio (T/H) / (RSA)		
		NS	EW	V	NS	EW	V	NS	EW	V
		-------- (g) --------			-------- (g) --------					
3115	256	0.94	1.21	1.49	1.03	1.21	1.62	0.92	1.00	0.92
3114	248	0.90	1.17	1.20	0.98	1.15	1.07	0.92	1.02	1.12
3113	240	0.87	1.13	1.04	0.93	1.10	0.86	0.94	1.03	1.22
3112	229	0.83	1.07	0.84	0.86	1.02	0.64	0.97	1.05	1.32
3111	218	0.78	1.01	0.77	0.79	0.95	0.56	0.98	1.07	1.38
3110	205	0.72	0.93	0.75	0.72	0.86	0.53	1.00	1.08	1.41
3109	190	0.65	0.82	0.70	0.63	0.75	0.48	1.03	1.09	1.45
3108	170	0.56	0.68	0.64	0.53	0.61	0.41	1.06	1.12	1.56
3107	162	0.51	0.62	0.60	0.48	0.55	0.38	1.06	1.13	1.58
3106	144									
3105	132									
3104	116									
3103	112									

Notes: (1) Maximum acceleration calculated by modal time history analyses as reported in SSAR.
(2) Maximum acceleration with single SCV stick.
(3) Ratio of maximum accelerations, time history over response spectrum analyses, (1)/(2) = (3)

Conclusion: From the ratios shown above, most of the maximum accelerations calculated by modal time history analyses are conservative (ratio > 1.0) except at a few places where it is no more than 8% below those calculated by RSA of the modified model (SCV alone).

Table 2: Maximum response accelerations at NI (from SSAR)

Node #	Elev. (feet)	(1) T/H, SSAR NS (g)	(1) T/H, SSAR EW (g)	(1) T/H, SSAR V (g)	(2) RSA, SSAR NS (g)	(2) RSA, SSAR EW (g)	(2) RSA, SSAR V (g)	(3) Ratio (T/H) / (RSA) NS	(3) Ratio (T/H) / (RSA) EW	(3) Ratio (T/H) / (RSA) V
3016	306	1.44	1.47	0.90	1.43	1.49	0.88	1.01	0.99	1.02
3015	297	1.32	1.27	0.90	1.31	1.39	0.88	1.01	0.91	1.02
3014	284	1.20	0.98	0.89	1.16	1.25	0.87	1.03	**0.78**	1.02
3013	272	1.09	0.94	0.88	1.09	1.16	0.86	1.00	**0.81**	1.02
3011	241	0.82	0.78	0.55	0.85	0.97	0.75	0.96	**0.80**	**0.73**
3010	220	0.73	0.69	0.53	0.75	0.89	0.70	0.97	**0.78**	**0.76**
3009	200	0.63	0.67	0.49	0.69	0.77	0.62	0.91	**0.87**	**0.79**
3008	180	0.51	0.60	0.45	0.59	0.61	0.47	**0.86**	0.98	0.96
3007	161	0.44	0.54	0.42	0.48	0.56	0.37	0.92	0.96	1.14
3006	153	0.42	0.51	0.40	0.44	0.54	0.33	0.95	0.94	1.21
3005	135	0.38	0.41	0.37	0.33	0.45	0.30	1.15	0.91	1.23
3004	117	0.34	0.34	0.35	0.30	0.30	0.30	1.13	1.13	1.17
3003	100	0.30	0.30	0.32	0.30	0.30	0.30	1.00	1.00	1.07

Table 3 : Maximum Nodal Accelerations due to seismic input in individual direction (T/H vs. RSA)

Modal Time History

		Nouth-South Input			East-West Input			Vertical Input		
Node #	Elev. (feet)	NS	EW (ft/sec^2)	V	NS	EW (ft/sec^2)	V	NS (ft/sec^2)	EW	V
3014	284	----	0.59	----	----	32.75	----	----	4.52	----
3013	272	----	0.74	----	----	30.30	----	----	3.08	----
3011	241	----	0.77	1.27	----	25.52	1.70	----	2.65	17.26
3010	220	----	0.84	1.24	----	22.90	1.63	----	1.75	16.49
3009	200	----	0.94	1.19	----	21.88	1.58	----	1.45	15.44
3008	180	16.04	----	----	0.43	----	----	0.55	----	----

RSA

Node #	Elev. (feet)	NS	EW (ft/sec^2)	V	NS	EW (ft/sec^2)	V	NS (ft/sec^2)	EW	V
3014	284	----	2.55	----	----	37.90	----	----	13.01	----
3013	272	----	3.77	----	----	35.99	----	----	8.91	----
3011	241	----	4.41	1.93	----	26.76	8.93	----	15.40	22.32
3010	220	----	4.33	1.81	----	23.35	8.42	----	16.01	20.85
3009	200	----	4.47	1.62	----	21.48	7.49	----	11.60	18.33
3008	180	18.22	----	----	4.41	----	----	2.32	----	----

Table 4 : Modal Participation Factors and Modeshapes in the Y & Z (EW & Vertical) directions for Modes 49 & 50.

Mode # Freq.	49 19.34 hz.		50 19.70 hz	
Direct.	Y	Z	Y	Z
P.F.	10.25	20.73	8.84	-17.41
Node				
3014	1.80E-02	-4.80E-03	1.40E-02	3.70E-03
3013	1.30E-02	-4.20E-03	1.20E-02	3.30E-03
3011	-1.90E-02	2.90E-02	-2.70E-02	-2.30E-02
3010	-2.10E-02	2.70E-02	-2.90E-02	-2.20E-02
3009	-1.40E-02	2.40E-02	-1.90E-02	-1.90E-02

Table 5a

Node #	Elev. (feet)	(a) T/H -49,50 NS	(a) T/H -49,50 EW	(a) T/H -49,50 V	(b) T/H, SSAR NS	(b) T/H, SSAR EW	(b) T/H, SSAR V	(c) = (a)/(b) NS	(c) = (a)/(b) EW	(c) = (a)/(b) V
		-------- (g) --------			-------- (g) --------					
3014	284		0.99			0.98			1.01	
3013	272		0.96			0.94			1.02	
3011	241		0.77	0.44		0.78	0.55		0.99	0.80
3010	220		0.68	0.42		0.69	0.53		0.99	0.80
3009	200		0.65	0.40		0.67	0.49		0.97	0.82
3008	180	0.51			0.51			1.00		

Table 5b

Node #	Elev. (feet)	(d) RSA -49,50 NS	(d) RSA -49,50 EW	(d) RSA -49,50 V	(e) RSA, SSAR NS	(e) RSA, SSAR EW	(e) RSA, SSAR V	(f) = (d)/(e) NS	(f) = (d)/(e) EW	(f) = (d)/(e) V	(g) = TH(a) / RSA(d) NS	(g) = TH(a) / RSA(d) EW	(g) = TH(a) / RSA(d) V
		-------- (g) --------			-------- (g) --------								
3014	284		1.10			1.25			0.88			0.90	
3013	272		0.98			1.16			0.85			0.97	
3011	241		0.77	0.27		0.97	0.75		0.80	0.36		1.00	1.63
3010	220		0.60	0.25		0.89	0.70		0.68	0.35		1.13	1.72
3009	200		0.48	0.21		0.77	0.62		0.62	0.34		1.35	1.92
3008	180	0.58			0.59			0.98			0.88		

Table 5a, comparison of max EW accelerations from Modal Time History analyses with & without modes 49 and 50. The comparison shows "no change" in EW acceleration.

Table 5b, (1)comparison of max EW accelerations from RSA with & without modes 49 and 50, and (2)comparison of EW acceleraions from T/H and RSA, both without modes 49 and 50.
The comparisons show reduced EW acceleration in RSA when modes 49 & 50 are excluded. These nodal accelerations become comparable to those calculated by Modal Time History analyses, with and without modes 49 and 50. This shows the conservatism built into the "double sum" modal combination method as stated in SRP where all of the terms combined used absolute summation.

Table 6: NI - Maximum member forces

Element No. gp #2	Element No. gp #1	Elev. (feet)	(1) TH, SSAR Axial	(1) TH, SSAR NS	(1) TH, SSAR EW	(2) RSA, SSAR Axial	(2) RSA, SSAR NS	(2) RSA, SSAR EW	(3) Ratio (TH1 / RSA2) Axial	(3) Ratio (TH1 / RSA2) NS	(3) Ratio (TH1 / RSA2) EW
			---- (1,000 kips) ----			---- (1,000 kips) ----					
		306									
---	14		1.45	2.46	2.43	1.48	2.40	2.51	0.98	1.03	0.97
		297									
---	13		3.40	4.47	4.36	3.46	4.40	4.63	0.98	1.02	0.94
		284									
---	12		7.65	8.30	7.67	7.76	8.26	8.80	0.99	1.00	0.87
		272									
---	11		11.54	12.52	10.57	11.66	12.39	13.22	0.99	1.01	0.80
		241									
---	10		15.44	16.43	15.68	12.78	16.41	17.03	1.21	1.00	0.92
		220									
---	9		18.05	18.72	18.32	14.24	18.64	19.44	1.27	1.00	0.94
		200									
8	8		20.43	20.68	20.32	15.77	20.21	21.32	1.30	1.02	0.95
		180									
7	7		23.40	23.28	23.03	17.62	22.11	23.18	1.33	1.05	0.99
		161									
6	6		25.45	25.51	25.17	18.90	23.32	24.48	1.35	1.09	1.03
		153									
5	5		28.14	28.82	28.40	20.80	25.11	26.57	1.35	1.15	1.07
		135									
4	4		31.92	34.03	33.57	23.54	27.82	29.96	1.36	1.22	1.12
		117									
3	3		34.96	37.54	37.59	26.04	29.79	32.85	1.34	1.26	1.14
		100									

Note: Maximum forces from SSAR (1) by TH analyses, and (2) by RSA, and
(3) Ratio of (TH forces) / (RSA forces)

Table 7: NI - Maximum axial forces

Element No. gp #2	Element No. gp #1	Elev. (feet)	(a) TH Axial (1,000 kips)	(b) TH Axial (1,000 kips)	(c) ratio (a) / (b)	(d) RSA Axial (1000k)	(e) ratio (b) / (d)
		306					
---	14		1.45	1.50	0.97	1.60	0.94
		297					
---	13		3.40	3.50	0.97	3.73	0.94
		284					
---	12		7.65	7.84	0.98	8.36	0.94
		272					
---	11		11.54	11.80	0.98	12.57	0.94
		241					
---	10		15.44	13.72	1.13	13.67	1.00
		220					
---	9		18.05	15.58	1.16	14.99	1.04
		200					
8	8		20.43	17.51	1.17	16.35	1.07
		180					
7	7		23.40	20.58	1.14	18.02	1.14
		161					
6	6		25.45	23.13	1.10	19.17	1.21
		153					
5	5		28.14	26.94	1.04	20.86	1.29
		135					
4	4		31.92	33.10	0.96	23.01	1.44
		117					
3	3		34.96	38.62	0.91	25.64	1.51
		100					

Note: Maximum member forces

(a) Axial forces calculated by modal time history analysis, taken from SSAR.
(b) modal time history analysis with only vertical input time history
(c) Ratio of max time history forces, 3 directional input vs. vertical input. (c) =(a) / (b)
(d) response spectrum analysis, input only ARS of vertical input time history
(e) ratio of max acceleration with only vertical input, (e) = TH(b) / RSA(d)

Table 8: Maximum Response Accelerations at CIS

Node No	Elev. (feet)	(1) TH, SSAR NS	EW	V	(2) RSA, SSAR NS	EW	V	(3) Ratio, TH(1) / RSA(2) NS	EW	V
		---- g ----			---- g ----					
		West SG Compartment								
3207	158	0.79	0.65	0.30	0.84	0.82	0.30	0.94	0.79	1.00
3206	148	0.73	0.58	0.31	0.76	0.70	0.30	0.96	0.83	1.03
----	135									
		East SG Compartment								
3205	148	0.69	0.54	0.32	0.77	0.67	0.30	0.90	0.81	1.07
----	135									
		Below Elevation 135								
3204	135	0.61	0.52	0.30	0.53	0.57	0.30	1.15	0.91	1.00
3203	107	0.32	0.30	0.30	0.30	0.30	0.30	1.07	1.00	1.00
3202	103	0.31	0.30	0.30	0.30	0.30	0.30	1.03	1.00	1.00
	100	0.30	0.30	0.30						

Note: Maximum response accelerations in (1) and (2) are taken from SSAR.
Response acceleration in the vertical and response acceleration below elevation 135' are closed to the zpa of 0.30 g which reflects "rigid" condition.

Table 9: Maximum Accelerations at CIS (single direction input motion)

Node No.	Elev. (feet)	(4) NS input, TH NS (g)	(4) NS input, TH EW (g)	(5) EW input, TH NS (g)	(5) EW input, TH EW (g)	(6) NS input, RSA NS (g)	(6) NS input, RSA EW (g)	(7) EW input, RSA NS (g)	(7) EW input, RSA EW (g)
3207	158	0.76	0.20	0.26	0.68	0.65	0.40	0.56	0.71
3206	148	0.70	0.19	0.25	0.61	0.57	0.40	0.51	0.58
3205	148	0.67	0.18	0.27	0.56	0.68	0.43	0.37	0.51
3204	135	0.60	0.15	0.14	0.54	0.44	0.34	0.32	0.46

Node No.	Elev. (feet)	(8) Ratio, TH/RSA NS/NS (4)/(6) (direct. of input)	(8) Ratio, TH/RSA EW/EW (5)/(7) (direct. of input)	(9) Ratio, TH/RSA EW/NS (4)/(6) (90 from input)	(9) Ratio, TH/RSA NS/EW (5)/(7) (90 from input)	SRSS(NS,EW) input (10) TH NS	SRSS(NS,EW) input (10) TH EW	SRSS(NS,EW) input (11) RSA NS	SRSS(NS,EW) input (11) RSA EW	Ratio of SRSS (12) = (10) / (11) NS	Ratio of SRSS (12) = (10) / (11) EW
3207	158	1.17	0.96	0.51	0.47	0.80	0.71	0.86	0.82	0.94	0.87
3206	148	1.22	1.05	0.46	0.48	0.74	0.63	0.77	0.71	0.97	0.90
3205	148	0.99	1.09	0.43	0.71	0.72	0.59	0.77	0.67	0.93	0.88
3204	135	1.36	1.17	0.45	0.43	0.61	0.56	0.54	0.57	1.13	0.98

Notes: Maximum accelerations due to NS Time History input and EW Time History input are shown in (4) and (5), while those due to NS ARS input and EW ARS input and calculated by RSA are shown in (6) and (7).

(8) = ratio of maximum acceleration due to input in the same direction, (TH responses)/(RSA responses)

(9) = ratio of maximum acceleration due to input 90 degrees away.

(10), and (11) = square root of sum of squares of responses due to NS and EW input for TH and RSA, respectively. For RSA, SRSS is the exact method of combination; for TH, SRSS gives an approximation.

Table 10: Modal Properties at CIS

Mode No.		33		34		36		37		39		41		45	
Freq (cps)		12.85		12.99		13.64		14.36		14.846		15.103		17.126	
Modal Part. F.		-1.15	-25.57	-4.94	9.50	7.52	-0.76	-6.66	0.50	-5.40	-3.72	9.52	8.01	11.30	-4.78
Node	Elev.	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW
No.	(feet)	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
3204	135	.0014	-.0050	-.0137	.0413	.0022	-.0002	-.0059	-.0005	-.0106	-.0129	.0336	.0264	.0335	-.0148
3205	148	-.0025	-.0053	.0227	.0424	.0034	-.0004	-.0076	-.0005	-.0001	-.0162	.0097	.0338	.0914	-.0229
3206	148	.0031	-.0065	-.0304	.0530	.0023	-.0002	-.0071	-.0007	-.0178	-.0153	.0533	.0312	.0260	-.0155
3207	158	.0032	-.0033	-.0310	.0693	.0026	-.0001	-.0080	-.0090	-.0195	-.0149	.0590	.0294	.0341	-.0073

Γϕ (NS=NS responses due to NS input, EW=EW response due to EW input)

3204	*(.0016)*	*.1284*	*.0677*	*.3925*	*.0166*	*.0002*	*.0393*	*(.0003)*	*.0574*	*.0479*	*.3203*	*2111*	*.3779*	*.0705*
3205	*.0029*	*.1348*	*(.1123)*	*.4027*	*.0259*	*.0003*	*.0506*	*(.0003)*	*.0007*	*.0602*	*.0919*	*.2711*	*1.0321*	*.1094*
3206	*(.0036)*	*.1649*	*.1504*	*.5038*	*.0172*	*.0002*	*.0470*	*(.0003)*	*.0961*	*.0570*	*.5078*	*.2501*	*.2932*	*.0743*
3207	*(.0036)*	*.2130*	*.1531*	*.6586*	*.0195*	*.0000*	*.0536*	*(.0045)*	*.1052*	*.0556*	*.5614*	*.2353*	*.3856*	*.0348*

Γϕ (NS=NS responses due to EW input, EW=EW response due to NS input)

3204	*(.0350)*	*.0058*	*(.1301)*	*(.2041)*	*(.0017)*	*(.0019)*	*(.0030)*	*.0033*	*.0395*	*.0695*	*.2695*	*.2509*	*(.1598)*	*(.1668)*
3205	*.0649*	*.0061*	*.2158*	*(.2095)*	*(.0026)*	*(.0029)*	*(.0038)*	*.0034*	*.0005*	*.0874*	*.0773*	*.3222*	*(.4363)*	*(.2588)*
3206	*(.0802)*	*.0074*	*(.2892)*	*(.2621)*	*(.0017)*	*(.0017)*	*(.0035)*	*.0045*	*.0662*	*.0827*	*.4272*	*.2972*	*(.1240)*	*(.1756)*
3207	*(.0811)*	*.0096*	*(.2944)*	*(.3425)*	*(.0020)*	*(.0004)*	*(.0040)*	*.0600*	*.0724*	*.0807*	*.4723*	*.2797*	*(.1630)*	*(.0823)*

Σ (Γϕ) :

	NS	EW	Modes 34, 41, 45 only			Modes 34, 41, 45 (SRSS)			Modes 34, 41, 45 (ABS)		
3204	.8776	.8502	3204	.7658	.6741	3204	.5000	.4512	3204	.7658	.6741
3205	1.0919	.9782	3205	1.0117	.7832	3205	1.0423	.4976	3205	1.2362	.7832
3206	1.1081	1.0499	3206	.9515	.8282	3206	.6054	.5674	3206	.9515	.8282
3207	1.2748	1.1928	3207	1.1002	.9287	3207	.6981	.7002	3207	1.1002	.9287
3204	(.0206)	(.0434)	3204	(.0204)	(.1201)	3204	.3392	.3639	3204	.5593	.6218
3205	(.0842)	(.0520)	3205	(.1432)	(.1461)	3205	.4929	.4633	3205	.7295	.7904
3206	(.0052)	(.0475)	3206	.0141	(.1405)	3206	.5306	.4334	3206	.8404	.7349
3207	.0002	.0047	3207	.0149	(.1451)	3207	.5800	.4498	3207	.9298	.7045

(Γ= Modal Participation Factor)

Table 11: Maximum Member Forces at CIS

ment No.		Elev.	(1) TH, SSAR			(2) RSA, SSAR			(3) Ratio (RSA2 / TH1)		
			Axial	NS	EW	Axial	NS	EW	Axial	NS	EW
gp #4	gp #3	(feet)	---- (1,000 kips) ----			---- (1,000 kips) ----					
			West SG Compartment								
		158									
8	11		0.02	0.16	0.13	0.05	0.16	0.15	2.50	1.00	1.15
		153									
8	10		0.02	0.28	0.22	0.05	0.29	0.28	2.50	1.04	1.27
		148									
7	9		0.08	0.81	0.65	0.24	0.81	0.76	3.00	1.00	1.17
		135									
			East SG Compartment								
		148									
6	8		0.03	0.31	0.24	0.13	0.31	0.27	4.33	1.00	1.13
		135									
			Below Elevation 135								
		135									
5	7		0.32	6.14	6.09	1.99	5.73	5.98	6.22	0.93	0.98
		121									
5	6		0.32	6.24	6.16	1.99	5.83	6.07	6.22	0.93	0.99
		107									
4	5		0.67	7.30	6.34	4.07	7.02	6.90	6.07	0.96	1.09
		103									
3	4		0.86	7.35	6.37	6.55	7.65	7.54	7.62	1.04	1.18
		100									

Note: Maximum acceleration calculated (1) by modal time history analyses and
(2) by Response Spectrum Analysis, both as reported in SSAR.
(3) Ratio of (RSA forces) / (Time History forces), as reported in SSAR.

Table 12: CIS - Equivalent Member Forces for "Missing Mass"

Node No	Element No. gp #4	Element No. gp #3	Elev. (feet)	(1) Model Mass X	(1) Model Mass Y	(1) Model Mass Z	(2) "Missing" Forces @ 0.3 g ZPA X (percent)	Y (percent)	Z (percent)	X (1,000 kips)	Y (1,000 kips)	Z (1,000 kips)	(3) Cumulative, Shear X (1,000 kips)	Y (1,000 kips)	Z (1,000 kips)
				West SG Compartment											
3207			158	5.75	5.75	5.75	----	----	-99.36	0.00	0.00	0.06			
	8	11											0.00	0.00	0.06
----			153	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
	8	10											0.00	0.00	0.06
3206			148	21.48	21.48	21.48	----	----	-99.46	0.00	0.00	0.21			
	7	9											0.00	0.00	0.26
----			135												
				East SG Compartment											
3205			148	12.60	12.60	12.60	----	----	-100.00	0.00	0.00	0.12			
	6	8											0.00	0.00	0.12
----			135												
				Below Elevation 135											
3204			135	258.31	258.31	187.31	-0.14	-0.32	-99.77	0.00	0.01	1.81			
	5	7											0.00	0.01	2.19
----			121	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
	5	6											0.00	0.01	2.19
3203			107	304.57	304.57	238.62	-94.94	-96.03	-99.99	2.79	2.83	2.30			
	4	5											2.80	2.83	4.49
3202			103	136.46	136.46	273.40	-98.37	-98.76	-99.98	1.30	1.30	2.64			
	3	4											4.09	4.14	7.13
			100	----	----	----									
			total =	739.17	739.17	739.16									

Notes: (1) = Mass at CIS stick model.
(2) = Percent of nodal mass not already considered at cut-off frequency of 33 hertz, and force equivalent of "missing mass" at acceleration of 0.30 g.
(3) = Cumulative of "missing" force = equivalent shear forces.

Table 13: CIS - Maximum Member Forces, Adjusted for "Missing Mass".

Node No.	Element No. gp #4	Element No. gp #3	Elev. (feet)	(4) TH, SSAR Axial	(4) TH, SSAR NS	(4) TH, SSAR EW	(5) SRSS {(TH,SSAR (4)), + (Missing Mass (3))} Axial	(5) NS	(5) EW	(6) RSA, SSAR Axial	(6) NS	(6) EW	(7) Ratio (6) / (5) Axial	(7) NS	(7) EW
				---- (1,000 kips) ----			---- (1,000 kips) ----			---- (1,000 kips) ----					
				West SG Compartment											
3207			158												
	8	11		0.02	0.16	0.13	0.06	0.16	0.13	0.05	0.16	0.15	0.85	1.00	1.15
----			153												
	8	10		0.02	0.28	0.22	0.06	0.28	0.22	0.05	0.29	0.28	0.85	1.04	1.27
3206			148												
	7	9		0.08	0.81	0.65	0.27	0.81	0.65	0.24	0.81	0.76	0.88	1.00	1.17
----			135												
				East SG Compartment											
3205			148												
	6	8		0.03	0.31	0.24	0.13	0.31	0.24	0.13	0.31	0.27	1.04	1.00	1.13
----			135												
				Below Elevation 135											
3204			135												
	5	7		0.32	6.14	6.09	2.21	6.14	6.09	1.99	5.73	5.98	0.90	0.93	0.98
----			121												
	5	6		0.32	6.24	6.16	2.21	6.24	6.16	1.99	5.83	6.07	0.90	0.93	0.99
3203			107												
	4	5		0.67	7.30	6.34	4.54	7.82	6.94	4.07	7.02	6.90	0.90	0.90	0.99
3202			103												
	3	4		0.86	7.35	6.37	7.19	8.41	7.59	6.55	7.65	7.54	0.91	0.91	0.99
			100												