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September 23, 2010

Subject: AP1000 Response to Request for Additional Information (TR85)

Westinghouse is submitting a response to the NRC request for additional information (RAI) on SRP Section TR85. 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(s):

RAI-TR85-SEB1-27 R4

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,

TJRay / for

R. F. Ziesing
Director, U.S. Licensing

/Enclosure

1. Response to Request for Additional Information on SRP Section TR85

D063
NRO

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ENCLOSURE 1

Response to Request for Additional Information on SRP Section TR85

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR85-SEB1-27
Revision: 4

Question:

Section 2.6.1.4 discusses liftoff analyses performed for 16 load cases of dead, live, and seismic loads. The results of the analyses are used for the basemat design. Explain what the 16 load cases correspond to and why weren't all possible load combinations utilized in accordance with the 100/40/40 rule.

Additional Request (Revision 1):

The response explains that the non-linear analyses were not performed for the cases with 1.0 applied in the vertical direction since the maximum bearing demand is due to overturning rather than vertical seismic. It is not evident that this would always be the case. Please explain.

The purpose of the calculation described in Section 2.6 is not to find the maximum bearing pressure under the basemat, but rather to design the entire basemat. Explain your confidence that at other locations away from the maximum bearing pressure location, the combination with 1.0 applied to the vertical direction may not govern (e.g., near the line of rotation where overturning contribution would be very small). The applicant is requested to consider the 100/40/40 combination method for considering the three earthquake directions as it was intended, and not to drop certain combinations based on a judgment that has not been justified.

Additional Request (Revision 2):

- SCV
  - Identify where 100/40/40 was applied
  - Describe methodology for analysis
  - Develop justification for the use of the 100/40/40 method for the SCV
- Roof (Tension ring and air inlet)
  - Identify where 100/40/40 was applied to confirm the tension ring and air inlet were the only two locations.
  - Describe methodology for analyses – Explain in sufficient detail (before proceeding with the evaluation) how the two analyses below are performed (e.g., what models, what seismic inputs, type of analysis, etc.)
    - 100/40/40
    - Linear elastic analysis (ANSYS)
  - Compare member forces at key locations in the tension ring and air inlet for both methods used. The key locations consist of representative locations throughout the two structural regions identified above where the 100/40/40 gave results within 20% of the code limits. Provide discussion of the results and justification of 100/40/40.

Additional Request (Revision 3):

The response to RAI-TR85-SEB1-27, R2, which was submitted in WEC letter dated July 30, 2010, addresses the questions raised regarding the WEC 100/40/40 combination method for seismic loads. WEC indicated that the 100/40/40 combination method was used in three locations: containment vessel (CV), NI basemat, and roof of the shield building (SB). The response for the CV is considered to be acceptable. The assessment for the 100/40/40 method for the basemat is addressed separately in the WEC response to RAI-TR85-SEB1-32, R4C. The assessment for the use of the WEC 100/40/40 method for the SB roof is discussed below. The questions listed below were raised primarily because WEC did not fully address all of the items identified in the Path Forward document (with NRC comments) transmitted to WEC, which is also presented on page 1 of 14 of the RAI response.

1. As indicated in the Path Forward document (also on page 1 of 14 of the response), the locations where the 100/40/40 method was applied in the SB roof should have been identified in order to confirm that the tension ring and air inlet were the only two locations that utilize the 100/40/40 method. In the RAI response, WEC only provided a comparison for the air inlet region of the roof. WEC should clarify in their response whether the 100/40/40 method was only used for the air inlet region; otherwise, comparisons for the other regions in the SB roof should have been performed.

2. As indicated in the Path Forward document (also on page 1 of 14 of the response), a description of the methodology for analyses (i.e., "Explain in sufficient detail (<u>before proceeding with the evaluation</u>) how the two analyses below are performed (e.g., what models, what seismic inputs, type of analysis, etc.)" should have been provided. Although some very limited information was presented, WEC is requested to provide sufficient information as requested in the Path Forward document so it is clearly understood by others what was done.

3. The 2nd bullet on page 3 of 14 indicates that the response spectrum analysis and equivalent static method use the SRSS method. The 3rd bullet indicates that the equivalent static method utilizes the 100/40/40 method. Confirm that for the response spectrum method, the SRSS method is <u>always</u> used and confirm whether the two bullets mean that for the equivalent static method, the both the SRSS and the 100/40/40 method are used.

4. A comparison was provided for member forces corresponding to the 24 cases of the WEC 100/40/40 method with the member forces from the ASCE 4-98 method. As indicated by the response, "one of the individual cases is always close to including the maximum values of the axial force and moment (TX, MX or TY, MY)... The evaluation does not combine the maximum axial tension (e.g., TX or TY) with the maximum in-plane shear (TXY). These forces are clearly caused by different directions of horizontal input so the assumptions of the 100/40/40 combination are realistic." The concern with these statements is that for this single finite element considered in the RAI response, one of the individual cases for axial and

moment (e.g., TX & MX) are close to the maximum values; however, for other elements this may not always be the case. Furthermore, the response did not adequately justify why the in-plane shear does not have to be included in this evaluation. The in-plane shear contributes to the required reinforcement in addition to the axial force and moment. The two out of 24 cases where the axial forces and moments are close to the maximum values do not contain the maximum in-plane shear force. Therefore, it is not clear that the WEC 100/40/40 method is adequate. The resolution of the WEC 100/40/40 method could be determined if the WEC response went to the next step and determine the required reinforcement using the 24 cases, as is done in their design process, and compare the governing case (envelop) of the required steel to the required steel calculated using the SRSS method or the ASCE 4-98 100/40/40 method. Alternatively, WEC could have compared their results to the more accurate time history method of analysis which does not have the conservatism present in either the SRSS or ASCE 4-98 combination method.

5. WEC should clarify the statements included in the 3rd paragraph on page 5 of 14: "The design of the shield building roof uses results from equivalent static analyses of a detailed finite element (FE) model. The equivalent static accelerations applied to this model were developed from analyses of the NI20 nuclear island model such that the member forces from the equivalent static analysis would envelope those from the response spectrum analysis performed for input motion applied at the foundation level enveloping all the soil cases." This needs to be expanded with figures and a description in sufficient detail to fully understand what was done. Also, why would the equivalent static accelerations be "<u>developed</u> ... <u>such that the member forces</u> from the equivalent static analysis <u>would envelop</u> those from the <u>response spectrum analysis</u>"? This appears as if WEC raised the equivalent static forces much higher so that the results of the study would show that the WEC 100/40/40 method is conservative when compared to the SRSS method.

Additional Request (Revision 4):

WEC shall expand the revision 3 response. The previous revision attempted to justify the 100/40/40 combination method by comparing building member forces only. NRC staff has requested WEC expand the response to include a comparison of the calculated reinforcement demand assuming either the ASCE 4-98 100/40/40 combination technique or SRSS combination technique to the provided reinforcement capacity.

WEC is requested to identify the smallest margin that exists in their current design calculations for the steel radial beams in order to confirm that there also exists substantial margin in their design. Obtaining the margin for the axial stresses and shear stresses should not be difficult since these stresses have already been calculated in the existing design. If sufficient margin does not exist, then WEC can provide similar tables for the steel radial beams to those presented in the current draft response for the tension ring which was treated as a steel beam.

Westinghouse Response (Revisions 0 and 1):

Linear analyses were performed for all 24 cases of the 100/40/40 combination method in the initial hard rock analyses and used to select the 16 cases analyzed in subsequent non-linear analyses. Typical results are shown in Figure RAI-TR85-SEB1-027-01 and 2. The cases with unit load factor in the vertical direction are load cases 17 to 24. The following 16 cases for the 1.0, 0.4, 0.4 method were used. Non-linear analyses were not performed for the cases with 1.0 applied in the vertical direction since the maximum bearing and member force demand is due to overturning rather than vertical seismic.

Load Case 3-# = D+L+Es where Es takes the following forms for each #.

#=1:	Es= 1.0xSns	+0.4xSew	+0.4xSvt
#=2:	Es= 1.0xSns	+0.4xSew	-0.4xSvt
#=3:	Es= 1.0xSns	-0.4xSew	+0.4xSvt
#=4:	Es= 1.0xSns	-0.4xSew	-0.4xSvt
#=5:	Es= -1.0xSns	+0.4xSew	+0.4xSvt
#=6:	Es= -1.0xSns	+0.4xSew	-0.4xSvt
#=7:	Es= -1.0xSns	-0.4xSew	+0.4xSvt
#=8:	Es= -1.0xSns	-0.4xSew	-0.4xSvt
#=9:	Es= 0.4xSns	+1.0xSew	+0.4xSvt
#=10:	Es= 0.4xSns	+1.0xSew	-0.4xSvt
#=11	Es= 0.4xSns	-1.0xSew	+0.4xSvt
#=12	Es= 0.4xSns	-1.0xSew	-0.4xSvt
#=13:	Es= -0.4xSns	+1.0xSew	+0.4xSvt
#=14:	Es= -0.4xSns	+1.0xSew	-0.4xSvt
#=15:	Es= -0.4xSns	-1.0xSew	+0.4xSvt
#=16:	Es= -0.4xSns	-1.0xSew	-0.4xSvt

where,

Sns element forces due to SSE acceleration in X (NS)
Sew element forces due to SSE acceleration in Y (EW)
Svt element forces due to SSE acceleration in Z (VT)

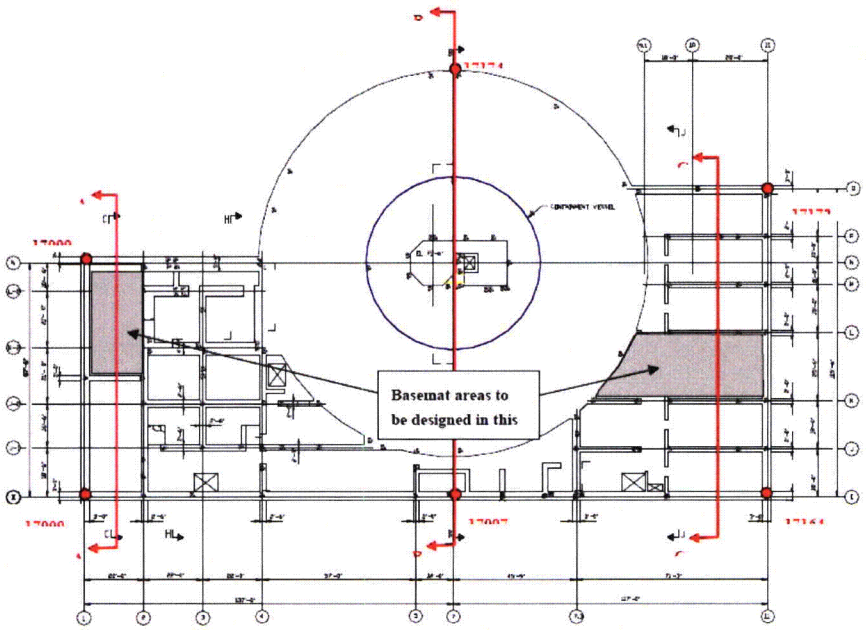

Figure RAI-TR85-SEB1-027-01: Nuclear Island Basemat

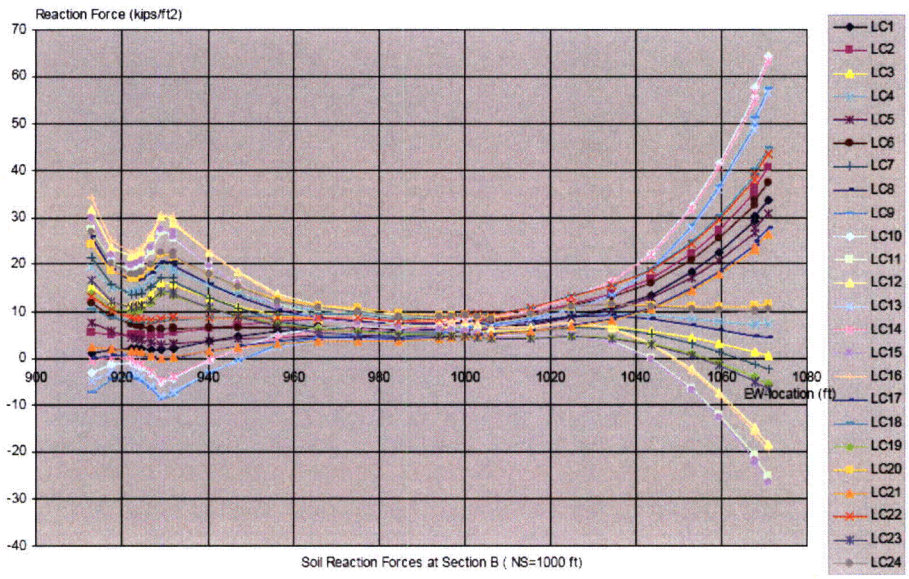

Figure RAI-TR85-SEB1-027-02: Soil Reaction Forces on Section B-B

Westinghouse Response (Revision 2):

DCD subsection 3.7.2.6 describes the use of the 100-40-40 method as follows:

> In analyses with the earthquake components applied separately and in the response spectrum and equivalent static analyses, the effect of the three components of earthquake motion are combined using one of the following methods:
>
> - For seismic analyses with the statistically independent earthquake components applied separately, the time-history responses from the three earthquake components are combined algebraically at each time step to obtain the combined response time-history. This method is used in the SASSI analyses.
> - The peak responses due to the three earthquake components from the response spectrum and equivalent static analyses are combined using the square root of the sum of squares (SRSS) method.
> - The peak responses due to the three earthquake components from the equivalent static analyses are combined directly, using the assumption that when the peak response from one component occurs, the responses from the other two components are 40 percent of the peak (100 percent-40 percent-40 percent method). Combinations of seismic responses from the three earthquake components, together with variations in sign (plus or minus), are considered. This method is used in the nuclear island basemat analyses, the containment vessel analyses and the shield building roof analyses.

The third bullet is clarified to show that the 100/40/40 method is only used to combine the results of linear and non-linear equivalent static analyses.

As stated in the third bullet, the 100/40/40 method is used in the nuclear island basemat analyses, the containment vessel analyses and the shield building roof analyses.

For AP1000 equivalent static analyses Westinghouse carried the 24 combinations of 100/40/40 through the detailed design calculations and then enveloped the results. This is similar to the approach for other load combinations. For the containment vessel detail evaluation, stresses were combined to calculate stress intensity and critical load cases were evaluated for buckling. For the reinforced concrete structures, the required reinforcement was calculated for the combination of member forces. Typical comparisons against time history or response spectrum analyses are provided below for the containment vessel and the shield building roof to demonstrate that the approach taken is conservative. Application to the nuclear island basemat is addressed in the response to RAI-TR85-SEB1-32, Rev 4.

The 100/40/40 method is a conservative extension of methodology used for many years in seismic design. Design for two horizontal direction of input is specified in the UBC as follows:

> The requirement that orthogonal effects be considered may be satisfied by designing such elements for 100 percent of the prescribed design seismic forces in one direction plus 30 percent of the prescribed design seismic forces in the perpendicular direction. The combination requiring the greater component strength shall be used for design. Alternatively, the effects of the two orthogonal directions may be combined on a square-root-sum-of-the squares (SRSS) basis. When the SRSS method of combining directional effects is used, each term computed shall be assigned the sign that will result in the most conservative design.

This methodology was expanded to three directions and the 30% increased to 40% in nuclear plant applications. Note that the UBC recognizes that the 100/40/40 method provides appropriate relative signs for the member forces so that the strength can be evaluated for each of the cases and the maximum value used. The SRSS method requires consideration of the worst combination of signs for each term (or member force).

The combination of the three directions of seismic input in equivalent static analyses is not addressed in either R.G 1.92 or ASCE 4-98. Both R.G 1.92 and ASCE 4-98 provide guidance for response spectrum analyses. This guidance applies to cases where seismic results have already been combined by SRSS so the signs of the individual components have been lost. As a result the variation of the signs needs to be addressed in the detailed design calculation as described in paragraph 3.2.7.1.3 of ASCE 4-98. Part (a) takes the SRSS or envelope of 100/40/40 of all member forces and then all possible signs which is conservative. Part (b) provides a fairly complicated way to reduce this conservatism. This alternate method leads to realistic multiple responses that could occur simultaneously. Such an approach is not necessary for equivalent static analyses combined by the 100/40/40 method since each combination includes appropriate signs on the member force components.

In the Shield Building report Westinghouse did measure the conservatism of the SRSS approach used in design against an application of the 100/40/40 method to the response spectrum analyses. While not directly in accord with the ASCE 4-98 guidance, the degree of conservatism could have been measured against the methods of ASCE 4-98 subsection 3.2.7.1.3 party (b) and a similar degree of conservatism would be expected.

Steel Containment Vessel (SCV)

The design of the steel containment vessel for the analysis of the large penetrations (personnel locks and equipment hatches) utilizes the 100/40/40 combination method. A 3-D finite element model of the steel containment vessel with polar crane is used. For the regions surrounding the large penetrations, the mesh size is very small, for regions away from the major penetrations, the mesh is much coarser.

Seismic analysis is performed in two parts, global equivalent static accelerations, and local equivalent static accelerations. For the global loading, elevation dependent static accelerations are applied to the model. For the local loading, rotational and radial accelerations caused by

the eccentricity of the weight and c.g. locations of the equipment hatches and personnel locks are applied. The combination of the two seismic input loads are algebraically summed (local vertical bending plus North-South direction earthquake, radial acceleration plus East-West direction earthquake, local horizontal bending plus Vertical direction earthquake) for each of the component directions. The resulting stresses from the three directions of seismic loading are combined by the 100/40/40 method and are then combined with dead, pressure, and thermal loading. The critical case is considered for the local buckling evaluation.

The appropriateness of the 100/40/40 combination method is evaluated for the SSE loading condition by a direct comparison of the combined seismic stress results against those from a time history analysis for the regions surrounding the major penetrations. Confirmatory time history and equivalent static analyses were performed on a coarse mesh version of the same finite element model. The time history analysis used 3 orthogonal time history inputs with mode superposition. The resulting stress intensities for both time history and equivalent static with local penetration accelerations were compared from the same model. The results for the 4 major areas are shown in Figures RAI-TR85-SEB1-27-4 through RAI-TR85-SEB1-27-7. The results confirm that the equivalent static accelerations, when applied separately and then combined by 100/40/40 produce conservative results to the more generally accepted time history analysis results.

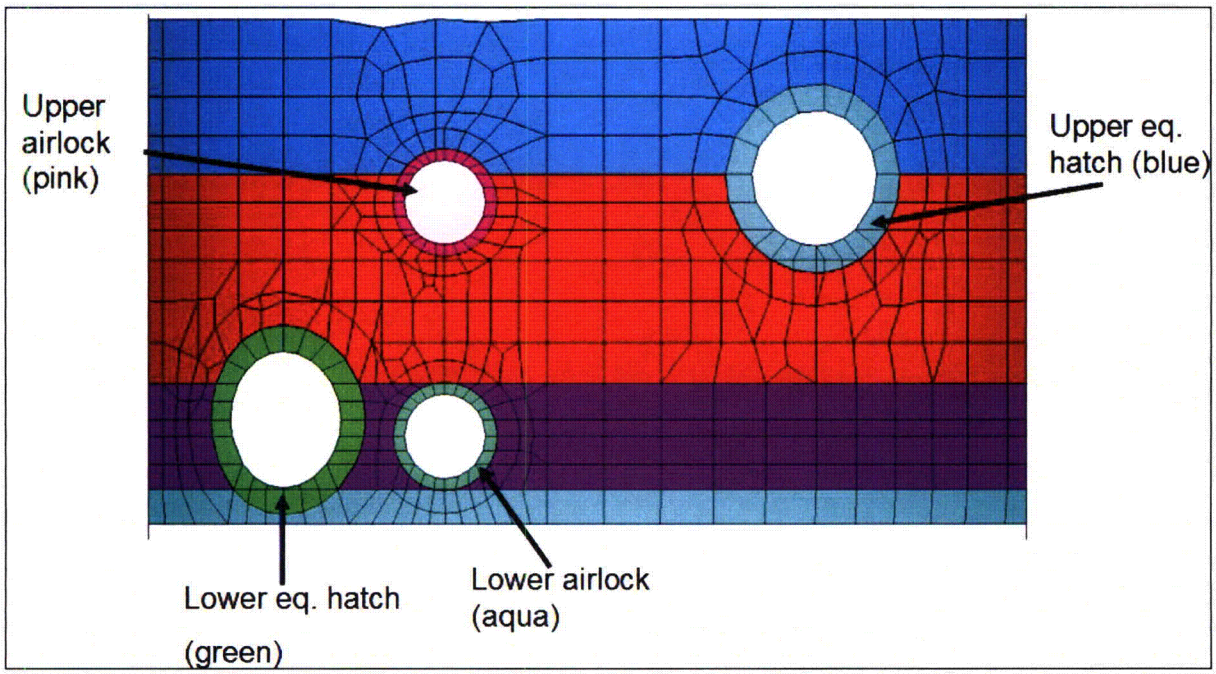

Figure RAI-TR85-SEB1-27-3: SCV 3-D Finite Element Model Large Penetrations

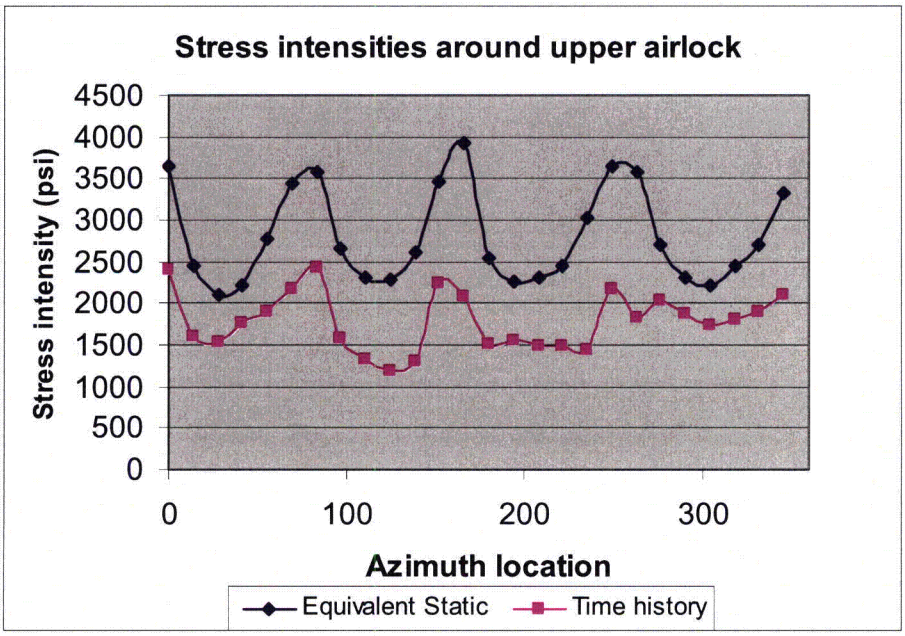

Figure RAI-TR85-SEB1-27-4: SCV 3-D Stress Intensity Comparison for Upper Airlock

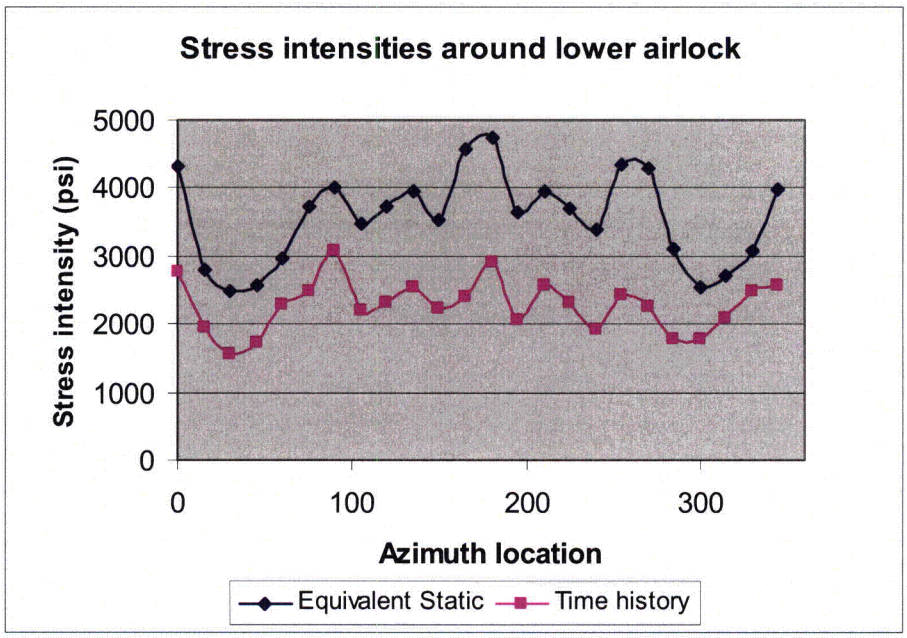

Figure RAI-TR85-SEB1-27-5: SCV 3-D Stress Intensity Comparison for Lower Airlock

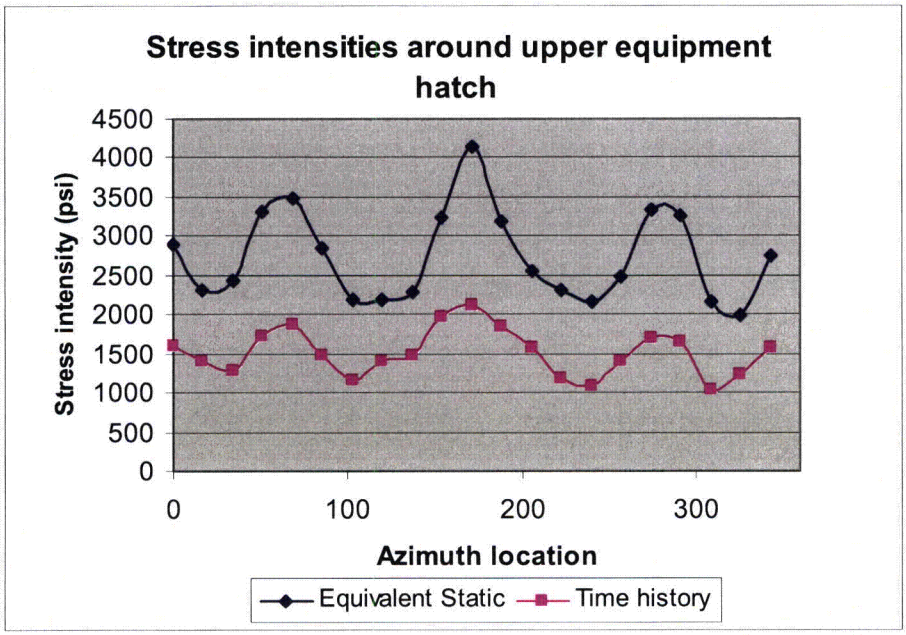

Figure RAI-TR85-SEB1-27-6: SCV 3-D Stress Intensity Comparison for Upper Equipment Hatch

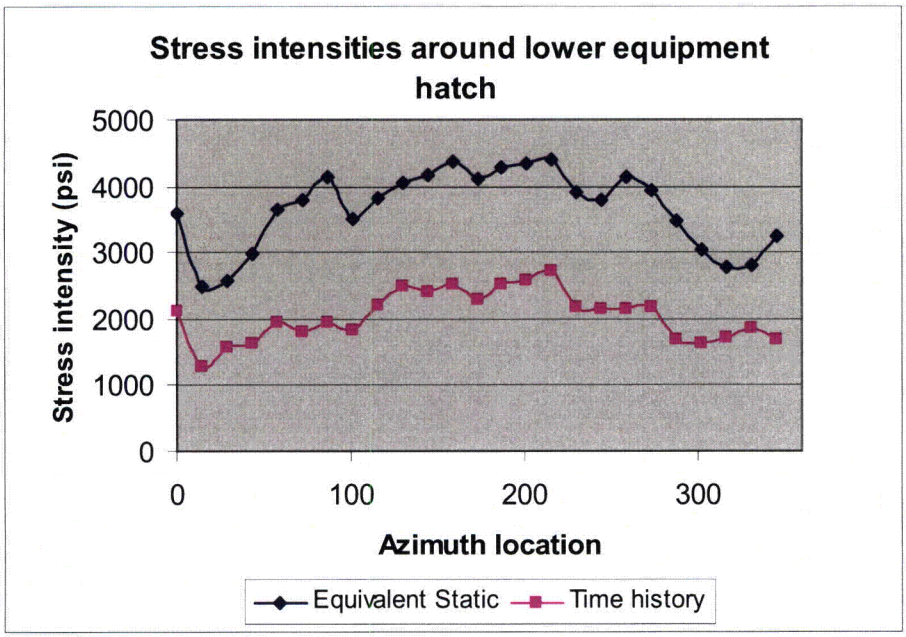

Figure RAI-TR85-SEB1-27-7: SCV 3-D Stress Intensity Comparison for Lower Equipment Hatch

Shield Building Roof (SBR)

The design of the shield building roof uses results from equivalent static analyses of ¼ finite element (FE) model as well as results from a response spectrum analysis of a linear elastic ANSYS model (Ni05). Figure RAI-TR85-SEB1-27-8 shows the ¼ FEM model and Figure RAI-TR85-SEB1-27-9 shows the roof portion only from the complete Ni05 model. Table RAI-TR85-SEB1-27-1 summarizes the use of each model for seismic (SSE), dead load (DL), and snow for each of the critical sections where the WEC 100/40/40 load combination technique is used for design. For equivalent static analysis, the WEC 100/40/40 combination method is always used. For response spectrum analysis of the shield building roof, the WEC 100/40/40 combination method is used.

Table RAI-TR85-SEB1-27-1: Summary of Building Models Used For Critical Section Design

	Building Model for Analysis		SSE Method	Combination Technique
Roof Area	**Ni05**	**1/4 FE Model**		
Air Inlet		SSE, DL, Snow	Equivalent Static	100/40/40
Tension Ring		SSE, DL, Snow	Equivalent Static	100/40/40
W36 Beam Seat		SSE, DL, Snow	Equivalent Static	100/40/40
W36 Beams Midspan	SSE	DL, Snow	Response Spectrum	100/40/40
Conical Roof	SSE	DL, Snow	Response Spectrum	100/40/40
PCS Tank	SSE	DL, Snow	Response Spectrum	100/40/40

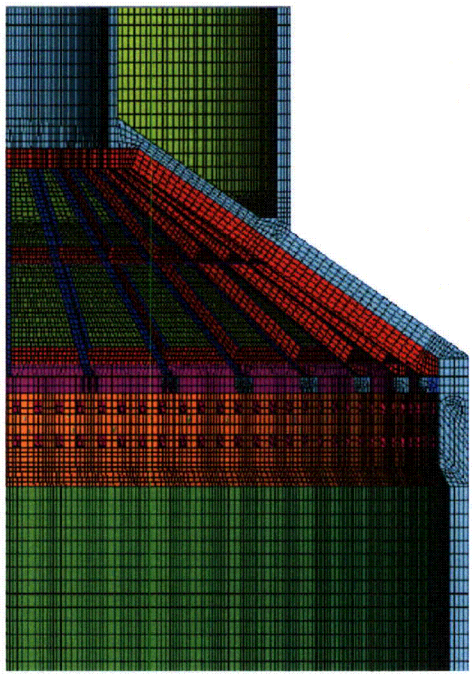

Figure RAI-TR85-SEB1-27-8: ¼ Finite Element Solid Mesh Model of Shield Building Roof

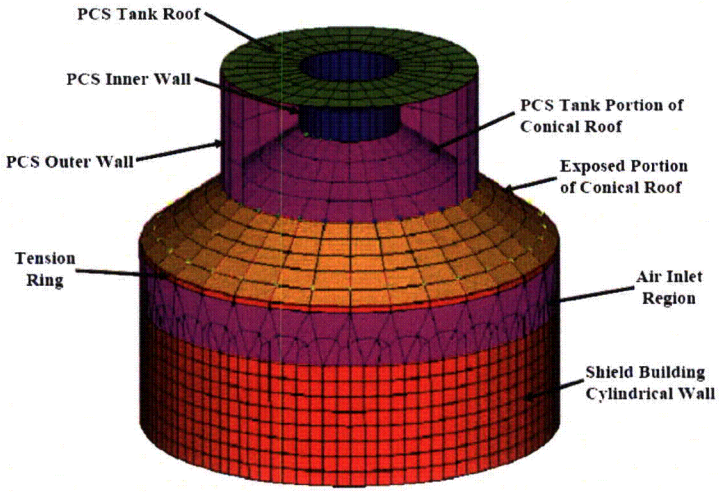

Figure RAI-TR85-SEB1-27-9: Shield Building Roof Portion of Ni05 Finite Element Model

For the loads listed in Table RAI-TR85-SEB1-27-1, only the SSE portion is subject to the WEC 100/40/40 combination. For the SSE analysis of the air inlet, tension ring, and W36 beams, an equivalent static analysis is performed on the ¼ FE model. This is because the FE model, shown in Figure RAI-TR85-SEB1-27-8, has concrete and steel plated sections explicitly modeled with a very fine mesh which is not possible with the coarse building model. For the SSE analysis of the remaining regions, namely the exposed conical roof section and the PCS tank area, the Ni05 nuclear island shell model is used, shown in Figure RAI-TR85-SEB1-27-9.

For SSE analysis, the equivalent static accelerations applied to ¼ FE model were developed from analyses of the NI20 nuclear island model such that the member forces from the equivalent static analysis would envelope those from the response spectrum analysis for all soil site conditions. To accomplish this, a unique amplification factor for each direction of SSE input, ranging from 1.2 to 1.8, was applied to the maximum accelerations from time history analysis to account for the multi-mode dynamic effects.

For SSE analysis of the Ni05 model, a response spectrum analysis is performed for the envelope of soil site conditions and the individual component member force loads (TX, TY, TXY, MX, MY, MXY, NX, and NY) are tabulated.

As identified in the Shield Building Report, the lateral seismic loading from the shield building roof on the air inlet and tension ring sections have a tendency to "ovalize" the circular structure. This effect is shown in Figure TR85-SEB1-27-10.

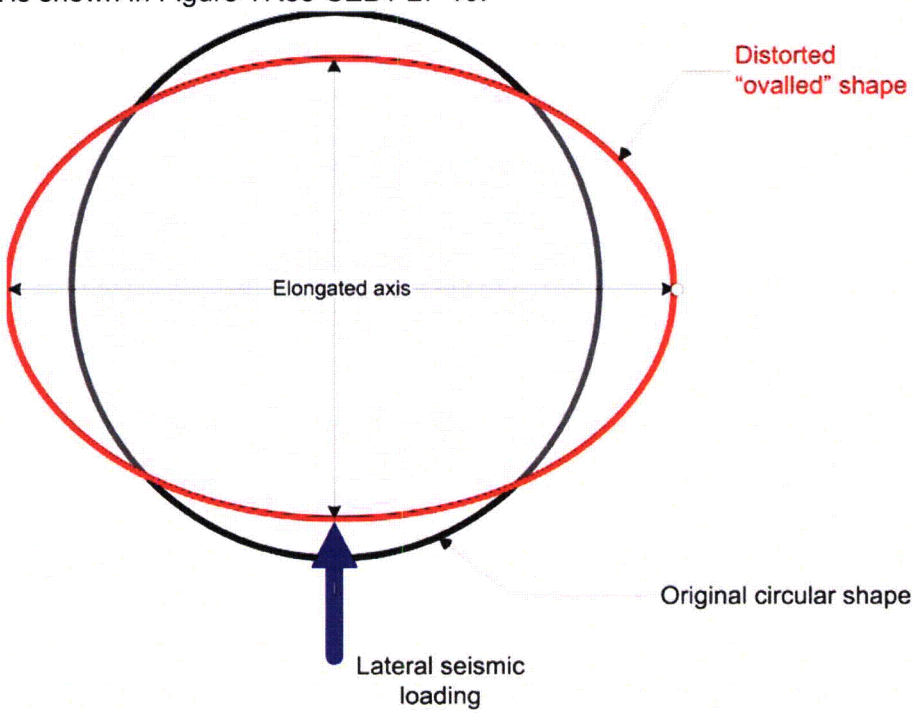

Figure RAI-TR85-SEB1-27-10: Ovalization on the Air Inlet and Tension Ring Sections Due to Lateral Loading

The equivalent static member forces were only post-processed at 4 critical angular locations: 0 degrees, 5.625 degrees, 84.375 degrees and 90 degrees. The 0 degree and 90 degree angles are selected at the location of the peak forces and moments that arise due to the "ovalization" effects caused by the lateral seismic loading, as shown in Figure RAI-TR85-SEB1-27-11.

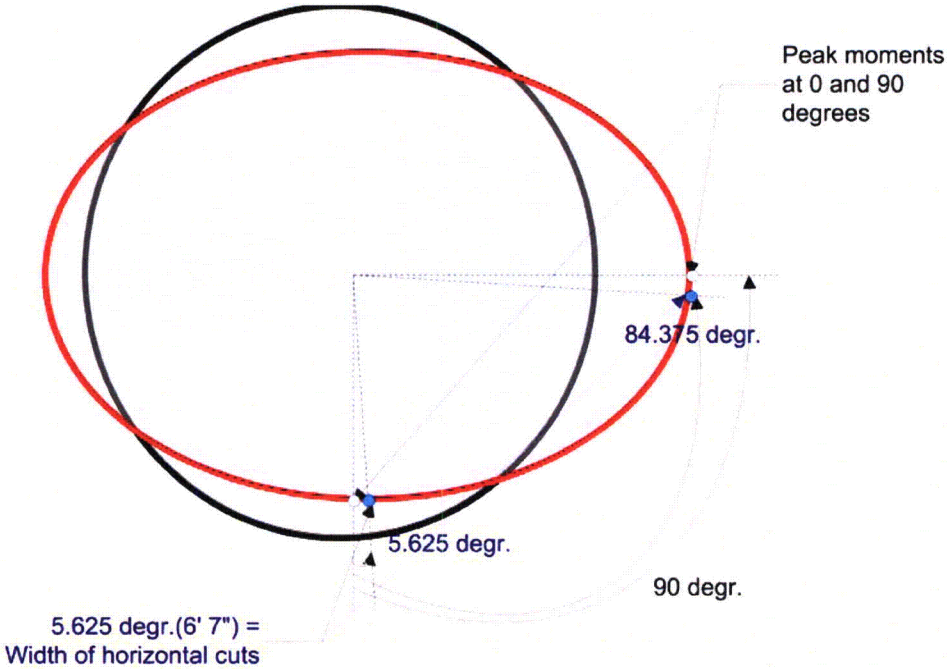

Figure RAI-TR85-SEB1-27-11: Plan View of Critical Angular Locations based on Lateral Load Application

The WEC 100/40/40 method was applied for all sections of the shield building roof for reinforcement design. Three examples are provided in the following paragraphs; one for the air inlet section, one for the tension ring, and one for the radial W36 columns.

An example section for the air inlet region (Section 9) is shown in Figure RAI-TR85-SEB1-27-12. The member forces are tabulated for each element in this cross section for the region between 0 to 5.625 degrees (where the highest ovalization occurs). The following paragraphs summarize the resulting member forces using the WEC 100/40/40 combination as it is used in design compared to the ASCE 100/40/40 method, as well as the same unfactored member forces combined by square root sum of the squares (SRSS method). The resulting member forces are then combined following the equations for strength design given in ACI 349. It will be shown that the required reinforcement area (in in^2/ft) will be less than the provided reinforcement area for the design (WEC 100/40/40) as well as the ASCE 100/40/40 and SRSS cases, assuring an adequate design.

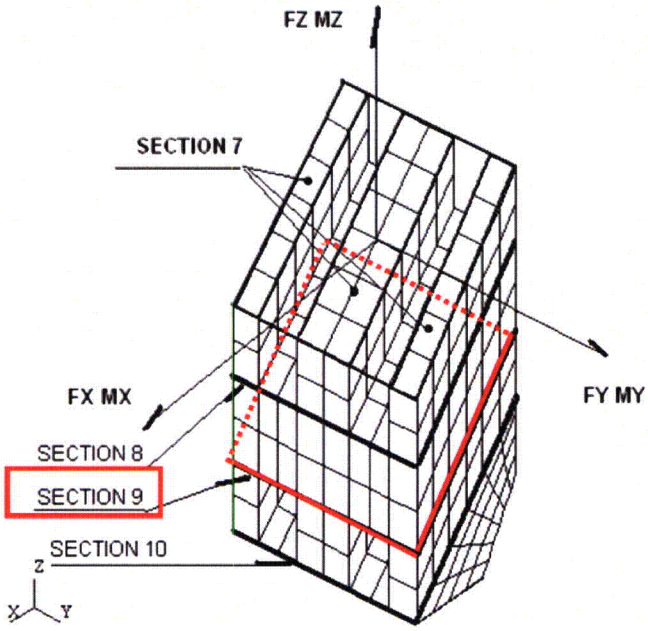

Figure RAI-TR85-SEB1-27-12: Cross Section of Air Inlet Region from ¼ FE Model (Section 9)

The member forces developed from the SSE and DL analysis of the ¼ FE model (unfactored) are summarized in Table RAI-TR85-SEB1-27-2. An example calculation is performed for a single load combination from the 24 possible summarized in Table RAI-TR85-SEB1-27-3 and demonstrated in Equation 1. A summary of all such load combinations for the WEC 100/40/40 method is shown in Table RAI-TR85-SEB1-27-4. The minimum and maximum signed results are also summarized. It is noted that the WEC 100/40/40 method will use the results from each of the 24 combinations separately for evaluation and the ASCE 4-98 100/40/40 method would conservatively use the maximum values from each of the individual components

Table RAI-TR85-SEB1-27-2: Air Inlet Section 9 Unfactored Loads from ¼ FE Model Analysis

Section 9 - Basic Loads - Horizontal Section - AIS						
		DEAD	SNOW	E_z	E_x North - South	E_y East - West
FX	KIP	144.89	4.88	241.41	288.8	11.16
FY	KIP	0.33	0.01	0.56	-64.25	1028.69
FZ	KIP	-394.6	-12.42	-649.5	-821.59	-31.69
MX	KIP*FT	1.01	0.04	1.74	3.38	-17.72
MY	KIP*FT	133.59	1.43	231.34	164.91	7.25
MZ	KIP*FT	4.42	0.16	7.88	-19.38	448.11

Table RAI-TR85-SEB1-27-3: 24 Load Factor Table for WEC 100/40/40 Combination Technique

Seismic L/C	Dead	Snow	E_z	E_x North - South	E_y East - West
1	1.00	1.00	1.00	0.40	0.40
2	1.00	1.00	1.00	0.40	-0.40
3	1.00	1.00	1.00	-0.40	0.40
4	1.00	1.00	1.00	-0.40	-0.40
5	1.00	0.00	-1.00	0.40	0.40
6	1.00	0.00	-1.00	0.40	-0.40
7	1.00	0.00	-1.00	-0.40	0.40
8	1.00	0.00	-1.00	-0.40	-0.40
9	1.00	1.00	0.40	1.00	0.40
10	1.00	1.00	0.40	1.00	-0.40
11	1.00	1.00	0.40	-1.00	0.40
12	1.00	1.00	0.40	-1.00	-0.40
13	1.00	0.00	-0.40	1.00	0.40
14	1.00	0.00	-0.40	1.00	-0.40
15	1.00	0.00	-0.40	-1.00	0.40
16	1.00	0.00	-0.40	-1.00	-0.40
17	1.00	1.00	0.40	0.40	1.00
18	1.00	1.00	0.40	0.40	-1.00
19	1.00	1.00	0.40	-0.40	1.00
20	1.00	1.00	0.40	-0.40	-1.00
21	1.00	0.00	-0.40	0.40	1.00
22	1.00	0.00	-0.40	0.40	-1.00
23	1.00	0.00	-0.40	-0.40	1.00
24	1.00	0.00	-0.40	-0.40	-1.00

1) LC 1: 1.00 * 144.89 + 1.00 * 4.88 + 1.00 * 241.41 + 0.4 * 288.8 + 0.4 * 11.16 = $\boxed{511.2}$

Table RAI-TR85-SEB1-27-4: Final Factored Loads for Air Inlet Section 9 for the 24 Individual WEC 100/40/40 Combinations and ASCE 4-98 100/40/40 Combination (Min/Max)

Member Forces - Section 9 - Kip, Kip*ft						
Load combination	FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
1	511.2	386.7	-1397.8	-2.9	435.2	184.0
2	502.2	-436.3	-1372.5	11.2	429.4	-174.5
3	280.1	438.1	-740.6	-5.7	303.3	199.5
4	271.2	-384.9	-715.2	8.5	297.5	-159.0
5	23.5	385.5	-86.4	-6.5	-28.9	168.0
6	14.5	-437.4	-61.1	7.7	-34.7	-190.5
7	-207.6	436.9	570.9	-9.2	-160.8	183.5
8	-216.5	-386.0	596.2	5.0	-166.6	-175.0
9	539.6	347.8	-1501.1	-2.0	395.4	167.6
10	530.7	-475.2	-1475.7	12.2	389.6	-190.9
11	-38.0	476.3	142.1	-8.7	65.5	206.4
12	-46.9	-346.7	167.4	5.5	59.7	-152.1
13	341.6	347.3	-969.1	-3.4	208.9	161.1
14	332.7	-475.6	-943.7	10.8	203.1	-197.4
15	-236.0	475.8	674.1	-10.2	-121.0	199.9
16	-244.9	-347.1	699.5	4.0	-126.8	-158.6
17	373.0	1003.6	-1027.1	-14.6	300.8	448.1
18	350.7	-1053.8	-963.8	20.8	286.3	-448.1
19	142.0	1055.0	-369.9	-17.3	168.8	463.6
20	119.7	-1002.4	-306.5	18.1	154.3	-432.6
21	175.0	1003.1	-495.1	-16.1	114.3	441.6
22	152.7	-1054.3	-431.7	19.4	99.8	-454.6
23	-56.0	1054.5	162.1	-18.8	-17.7	457.1
24	-78.4	-1002.9	225.5	16.7	-32.2	-439.1
Min	-244.9	-1054.3	-1501.1	-18.8	-166.6	-454.6
Max	539.6	1055.0	699.5	20.8	435.2	463.6

For comparison, the unfactored loads from Table RAI-TR85-SEB1-27-2 may be combined by square root sum of the squares (SRSS), as shown in Equation 2 (max) and 3 (min). As such, the same set of member forces compared in Equation 1 may be processed as follows in Equations 4 (max) and 5.

2) $MAX = DL + SN + \sqrt{(E_X^2 + E_Y^2 + E_z^2)}$

3) $MIN = DL + SN - \sqrt{(E_X^2 + E_Y^2 + E_z^2)}$

4) Load Combination 1 (for SRSS): $144.89 + 4.88 + \sqrt{(241.41^2 + 288.8^2 + 11.16^2)} = \boxed{526.3}$

5) Load Combination 2 (for SRSS): $144.89 + 4.88 - \sqrt{(241.41^2 + 288.8^2 + 11.16^2)} = \boxed{-226.7}$

The results for the air inlet region (Section 9) for both ASCE 4-98 100/40/40 and SRSS combination techniques for the component FX are summarized in Figure RAI-TR85-SEB1-27-13. The remaining member forces for each load combination are summarized in Table RAI-TR85-SEB1-27-5.

ASCE 4-98 100/40/40 - FX

24	-78.4
Min	-244.9
Max	539.6

SRSS - FX

$+ 288.8^2 + 11.16^2) = \boxed{526.3}$

$288.8^2 + 11.16^2) = \boxed{-226.7}$

Figure RAI-TR85-SEB1-27-13: Summary of Maximum Member Force Results (FX) for Air Inlet Region from ¼ FE Model (Section 9)

Table RAI-TR85-SEB1-27-5: Comparison of Final Factored Loads for Air Inlet Section 9 by ASCE 4-98 100/40/40 and SRSS Combination Methods

Member Forces - Section 9 - Kip, Kip*ft							
Load combination		FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
100/40/40	MIN	-244.9	-1054.3	-1501.1	-18.8	-166.6	-454.6
SRSS	MIN	-226.8	-1030.4	-1454.8	-17.1	-149.2	-444.0
Ratio		1.08	1.02	1.03	1.10	1.12	1.02
100/40/40	MAX	539.6	1055.0	699.5	20.8	435.2	463.6
SRSS	MAX	526.3	1031.0	640.8	19.2	419.2	453.2
Ratio		1.03	1.02	1.09	1.09	1.04	1.02

For the reinforcement design of the air inlet, the concrete cross section is subject to the following forces:

1) In Plane Shear (FY)
2) Axial Force (FZ)
3) Bending Moment (MY)
4) Out-of-plane shear (FX)

A macro is used to develop the resulting required steel reinforcement area. The equations for reinforcement demand are directly from the ACI 349 strength requirements and are summarized for the maximum for each case in Table RAI-TR85-SEB1-27-6. As shown in the Table, the maximum required reinforcement for any of the WEC 24 load combinations (2.10 in^2/ft) is less than the provided value (12 in^2/ft).

Table RAI-TR85-SEB1-27-6: Comparison of Final Required Steel Area for WEC 100/40/40 Combination Technique

Reinforcing Steel - Section # 9 - AIS								
Load combination	FZ Kip	FY Kip	MY Kip*ft	FX Kip	Steel Area (Z dir.) Required [in^2/ft]		Provided [in^2/ft]	
1	-1397.8	386.7	435.2	511.2	0.15	Max		
2	-1372.5	-436.3	429.4	502.2	0.19			
3	-740.6	438.1	303.3	280.1	0.19			
4	-715.2	-384.9	297.5	271.2	0.15			
5	-86.4	385.5	-28.9	23.5	0.15			
6	-61.1	-437.4	-34.7	14.5	0.19			
7	570.9	436.9	-160.8	-207.6	1.79			
8	596.2	-386.0	-166.6	-216.5	1.87			
9	-1501.1	347.8	395.4	539.6	0.12			
10	-1475.7	-475.2	389.6	530.7	0.22			
11	142.1	476.3	65.5	-38.0	0.64			
12	167.4	-346.7	59.7	-46.9	0.72		Liner 1"	12
13	-969.1	347.3	208.9	341.6	0.12	2.10		
14	-943.7	-475.6	203.1	332.7	0.22			
15	674.1	475.8	-121.0	-236.0	2.02			
16	699.5	-347.1	-126.8	-244.9	2.10			
17	-1027.1	1003.6	300.8	373.0	0.61			
18	-963.8	-1053.8	286.3	350.7	0.64			
19	-369.9	1055.0	168.8	142.0	0.64			
20	-306.5	-1002.4	154.3	119.7	0.61			
21	-495.1	1003.1	114.3	175.0	0.61			
22	-431.7	-1054.3	99.8	152.7	0.64			
23	162.1	1054.5	-17.7	-56.0	1.12			
24	225.5	-1002.9	-32.2	-78.4	1.32			

For the ASCE 4-98 100/40/40 or SRSS combinations for required area, a maximum area for reinforcement demand could occur for any combination of a minimum or maximum component value for FY, FZ, MY, and FX. As such, there are 16 possible combinations as shown in Table RAI-TR85-SEB1-27-7 where a minimum is represented by a "Min" and the maximum response is represented by a "Max."

Table RAI-TR85-SEB1-27-7: 16 Component Combinations for Detailed Reinforcement Design for ACI 349 for ASCE 4-98 100/40/40 and SRSS Load Combinations

Case #	Component	FY	FZ	MY	FX
1	Min or Max	Max	Max	Max	Max
2		Max	Max	Max	Min
3		Max	Max	Min	Max
4		Max	Min	Max	Max
5		Max	Min	Min	Min
6		Max	Min	Min	Max
7		Max	Min	Max	Min
8		Max	Max	Min	Min
9		Min	Min	Min	Min
10		Min	Min	Min	Max
11		Min	Min	Max	Min
12		Min	Max	Min	Min
13		Min	Max	Max	Max
14		Min	Max	Max	Min
15		Min	Max	Min	Max
16		Min	Min	Max	Max

As shown in Table RAI-TR85-SEB1-27-8 and Table RAI-TR85-SEB1-27-9, the maximum required demand for any of the 16 component member force combinations for either the ASCE 4-98 100/40/40 or the SRSS combination technique result in a lower required reinforcement area (2.49 and 2.31 in^2/ft respectively) than the provided value (12 in^2/ft). The required reinforcement demand for each method is summarized in Table RAI-TR85-SEB1-27-10.

Table RAI-TR85-SEB1-27-8: Comparison of Final Required Steel Area for ASCE 4-98 100/40/40 Combination

Reinforcing Steel - Section # 9 - AIS							
Component Combination (ASCE 4-98 100/40/40)	FY Kip	FZ Kip	MY Kip*ft	FX Kip	Steel Area		
					Total Required [in^2/ft]	Provided [in^2/ft]	
1	1055.0	699.5	435.2	539.6	2.49	Liner 1"	12
2	1055.0	699.5	435.2	-244.9	2.49		
3	1055.0	699.5	-166.6	539.6	2.47		
4	1055.0	-1501.1	435.2	539.6	0.64		
5	1055.0	-1501.1	-166.6	-244.9	0.64		
6	1055.0	-1501.1	-166.6	539.6	0.64		
7	1055.0	-1501.1	435.2	-244.9	0.64		
8	1055.0	699.5	-166.6	-244.9	2.47		
9	-1054.3	-1501.1	-166.6	-244.9	0.64		
10	-1054.3	-1501.1	-166.6	539.6	0.64		
11	-1054.3	-1501.1	435.2	-244.9	0.64		
12	-1054.3	699.5	-166.6	-244.9	2.47		
13	-1054.3	699.5	435.2	539.6	2.49		
14	-1054.3	699.5	435.2	-244.9	2.49		
15	-1054.3	699.5	-166.6	539.6	2.47		
16	-1054.3	-1501.1	435.2	539.6	0.64		

Table RAI-TR85-SEB1-27-9: Comparison of Final Required Steel Area for SRSS Combination

Reinforcing Steel - Section # 9 - AIS							
Component Combination (SRSS)	FY Kip	FZ Kip	MY Kip*ft	FX Kip	Steel Area		
					Total Required [in^2/ft]	Provided [in^2/ft]	
1	1031.0	640.8	419.2	526.3	2.31	Liner 1"	12
2	1031.0	640.8	419.2	-226.8	2.31		
3	1031.0	640.8	-149.2	526.3	2.29		
4	1031.0	-1454.8	419.2	526.3	0.63		
5	1031.0	-1454.8	-149.2	-226.8	0.63		
6	1031.0	-1454.8	-149.2	526.3	0.63		
7	1031.0	-1454.8	419.2	-226.8	0.63		
8	1031.0	640.8	-149.2	-226.8	2.29		
9	-1030.4	-1454.8	-149.2	-226.8	0.63		
10	-1030.4	-1454.8	-149.2	526.3	0.63		
11	-1030.4	-1454.8	419.2	-226.8	0.63		
12	-1030.4	640.8	-149.2	-226.8	2.29		
13	-1030.4	640.8	419.2	526.3	2.31		
14	-1030.4	640.8	419.2	-226.8	2.31		
15	-1030.4	640.8	-149.2	526.3	2.29		
16	-1030.4	-1454.8	419.2	526.3	0.63		

Table RAI-TR85-SEB1-27-10: Comparison of Final Required Steel Area for Different Combination Methods

Reinforcing Steel - Section # 9 - AIS			
Load Combination	Steel Area		
	Required [in^2/ft]	Provided [in^2/ft]	
WEC 100/40/40	2.10	Liner 1"	12
ASCE 4-98 100/40/40	2.49		
SRSS	2.31		

Figure RAI-TR85-SEB1-27-13 shows an example cross-section from the tension ring in the ¼ FE model. As with the example for the air inlet section, the basic loads are developed from the equivalent static analysis of the ¼ FE model and summarized in Table RAI-TR85-SEB1-27-11. The member forces are tabulated for each element in this cross section for the region between 0 to 5.625 degrees (where the highest ovalization occurs). The maximum resulting combinations based on the WEC 100/40/40 combination technique are summarized in Table RAI-TR85-SEB1-27-12. As with the air inlet example, Table RAI-TR85-SEB1-27-13 summarizes the maximum member forces developed for both the ASCE 4-98 100/40/40 and the SRSS combination techniques.

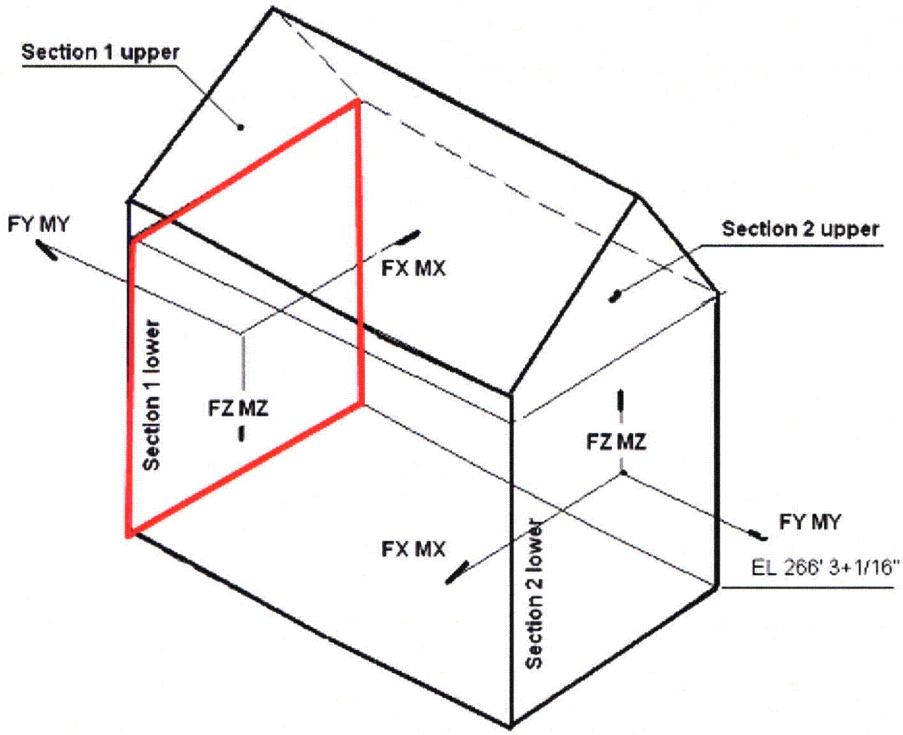

Figure RAI-TR85-SEB1-27-13: Cross Section of Air Inlet Region from ¼ FE Model (Section 1 Lower)

Table RAI-TR85-SEB1-27-11: Tension Ring Section 1 Lower Unfactored Loads from ¼ FE Model Analysis

Section 1 lower - Basic Loads - Vertical Section - Tension Ring						
		DEAD	SNOW	E_z	E_x North - South	E_y East - West
FX	KIP	-46.47	-1.61	-84.18	-88.88	-43.07
FY	KIP	861.33	28.38	1582.1	2472.9	-1.12
FZ	KIP	47.2	1.82	84.63	83.44	474.94
MX	KIP*FT	37.64	2.61	50.58	-23.89	136.97
MY	KIP*FT	166.08	6.18	294.95	305.47	48.51
MZ	KIP*FT	224.45	8.57	399.01	528.87	25.49

Table RAI-TR85-SEB1-27-12: Final Factored Loads for Tension Ring Section 1 Lower for 24 WEC 100/40/40 Combinations

Member Forces - Section 1 lower - Kip, Kip*ft						
Load combination	FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
1	-185.0	3460.5	357.0	136.1	608.8	853.8
2	-150.6	3461.4	-23.0	26.5	570.0	833.4
3	-113.9	1482.2	290.3	155.2	364.4	430.7
4	-79.5	1483.1	-89.7	45.6	325.6	410.3
5	-15.1	267.9	185.9	32.3	12.7	47.2
6	19.4	268.8	-194.0	-77.3	-26.1	26.8
7	56.0	-1710.4	119.2	51.4	-231.7	-375.9
8	90.5	-1709.5	-260.8	-58.2	-270.5	-396.3
9	-187.9	3995.0	356.3	91.4	615.1	931.7
10	-153.4	3995.9	-23.7	-18.2	576.3	911.3
11	-10.1	-950.8	189.4	139.2	4.2	-126.1
12	24.4	-949.9	-190.5	29.6	-34.6	-146.4
13	-118.9	2700.9	286.8	48.3	373.0	603.9
14	-84.5	2701.8	-93.2	-61.3	334.2	583.5
15	58.9	-2244.9	119.9	96.1	-238.0	-453.8
16	93.3	-2244.0	-260.1	-13.5	-276.8	-474.2
17	-160.4	2510.6	591.2	187.9	460.9	629.7
18	-74.2	2512.8	-358.7	-86.0	363.9	578.7
19	-89.3	532.3	524.4	207.0	216.6	206.6
20	-3.1	534.5	-425.4	-66.9	119.5	155.6
21	-91.4	1216.5	521.7	144.8	218.8	301.9
22	-5.3	1218.8	-428.2	-129.1	121.8	250.9
23	-20.3	-761.8	454.9	163.9	-25.6	-121.2
24	65.8	-759.6	-495.0	-110.0	-122.6	-172.2
Min	-187.9	-2244.9	-495.0	-129.1	-276.8	-474.2
Max	93.3	3995.9	591.2	207.0	615.1	931.7

Table RAI-TR85-SEB1-27-13: Comparison of Final Factored Loads for Tension Ring Section 1 Lower by ASCE 4-98 100/40/40 and SRSS Combination Methods

Member Forces - Section 1 Lower - Kip, Kip*ft							
Load combination		FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
100/40/40	MIN	-187.9	-2244.9	-495.0	-129.1	-276.8	-474.2
SRSS	MIN	-177.9	-2046.0	-440.6	-107.7	-255.1	-430.0
Ratio		1.06	1.10	1.12	1.20	1.08	1.10
100/40/40	MAX	93.3	3995.9	591.2	207.0	615.1	931.7
SRSS	MAX	81.7	3825.4	538.6	188.2	599.6	896.0
Ratio		1.14	1.04	1.10	1.10	1.03	1.04

As the tension ring is considered a steel structure, it is evaluated in accordance with ANSI/AISC N690. For the vertical sections, such as Section 1 Lower, two evaluations are performed: Axial plus bending, and shear plus torsional effects. The stresses from axial load (denoted $f_{y,FY}$), and bending about each axis (denoted $f_{y,MX}$ and $f_{y,MZ}$) are summed algebraically against the allowable per ANSI/AISC N690. The stresses from shear load along each axis (denoted $f_{y,FX}$ and $f_{y,FZ}$), and torsion (denoted $f_{y,My}$) are summed algebraically against the allowable per ANSI/AISC N690. The resulting stress is evaluated against the allowable and summarized in Table RAI-TR85-SEB1-27-14 for axial plus bending and Table RAI-TR85-SEB1-27-15 for shear plus torsion for the WEC 100/40/40 combination technique.

Table RAI-TR85-SEB1-27-14: Comparison of Maximum Calculated Stress to Allowable for WEC 100/40/40 Combination Technique – Axial Force plus Bending

Tension Ring - Axial force and Bending Verification - Section 1 lower										
Load combination	FY Kip	MX Kip*ft	MZ Kip*ft	f_{yFY} ksi	f_{yMX} ksi	f_{yMZ} ksi	Sum ksi	F_y ksi	Design Ratio (Sum/0.66*F_y)	Verification (Verified if Design Ratio<1)
1	3460.5	136.1	853.8	10.17	0.34	2.14	12.65	50	0.38	Verified
2	3461.4	26.5	833.4	10.18	0.07	2.09	12.33	50	0.37	Verified
3	1482.2	155.2	430.7	4.36	0.39	1.08	5.82	50	0.18	Verified
4	1483.1	45.6	410.3	4.36	0.11	1.03	5.50	50	0.17	Verified
5	267.9	32.3	47.2	0.79	0.08	0.12	0.99	50	0.03	Verified
6	268.8	-77.3	26.8	0.79	0.19	0.07	1.05	50	0.03	Verified
7	-1710.4	51.4	-375.9	5.03	0.13	0.94	6.10	50	0.18	Verified
8	-1709.5	-58.2	-396.3	5.03	0.15	0.99	6.16	50	0.19	Verified
9	3995.0	91.4	931.7	11.75	0.23	2.33	14.31	50	0.43	Verified
10	3995.9	-18.2	911.3	11.75	0.05	2.28	14.08	50	0.43	Verified
11	-950.8	139.2	-126.1	2.80	0.35	0.32	3.46	50	0.10	Verified
12	-949.9	29.6	-146.4	2.79	0.07	0.37	3.23	50	0.10	Verified
13	2700.9	48.3	603.9	7.94	0.12	1.51	9.57	50	0.29	Verified
14	2701.8	-61.3	583.5	7.94	0.15	1.46	9.56	50	0.29	Verified
15	-2244.9	96.1	-453.8	6.60	0.24	1.14	7.98	50	0.24	Verified
16	-2244.0	-13.5	-474.2	6.60	0.03	1.19	7.82	50	0.24	Verified
17	2510.6	187.9	629.7	7.38	0.47	1.58	9.43	50	0.29	Verified
18	2512.8	-86.0	578.7	7.39	0.22	1.45	9.05	50	0.27	Verified
19	532.3	207.0	206.6	1.56	0.52	0.52	2.60	50	0.08	Verified
20	534.5	-66.9	155.6	1.57	0.17	0.39	2.13	50	0.06	Verified
21	1216.5	144.8	301.9	3.58	0.36	0.76	4.69	50	0.14	Verified
22	1218.8	-129.1	250.9	3.58	0.32	0.63	4.53	50	0.14	Verified
23	-761.8	163.9	-121.2	2.24	0.41	0.30	2.95	50	0.09	Verified
24	-759.6	-110.0	-172.2	2.23	0.28	0.43	2.94	50	0.09	Verified

Table RAI-TR85-SEB1-27-15: Comparison of Maximum Calculated Stress to Allowable for WEC 100/40/40 Combination Technique – Shear plus Torsion

Tension Ring - Shear force and Torsion Verification - Section 1 lower										
Load combination	FX Kip	FZ Kip	MY Kip*ft	f_{vFX} ksi	f_{vFZ} ksi	f_{vMY} ksi	Sum ksi	F_y ksi	Design Ratio (Sum/0.4*F_y)	Verification (Verified if Design Ratio<1)
1	-185.0	357.0	608.8	1.17	1.95	0.76	3.89	50	0.19	Verified
2	-150.6	-23.0	570.0	0.96	0.13	0.71	1.80	50	0.09	Verified
3	-113.9	290.3	364.4	0.72	1.59	0.46	2.77	50	0.14	Verified
4	-79.5	-89.7	325.6	0.50	0.49	0.41	1.40	50	0.07	Verified
5	-15.1	185.9	12.7	0.10	1.02	0.02	1.13	50	0.06	Verified
6	19.4	-194.0	-26.1	0.12	1.06	0.03	1.22	50	0.06	Verified
7	56.0	119.2	-231.7	0.36	0.65	0.29	1.30	50	0.06	Verified
8	90.5	-260.8	-270.5	0.57	1.43	0.34	2.34	50	0.12	Verified
9	-187.9	356.3	615.1	1.19	1.95	0.77	3.91	50	0.20	Verified
10	-153.4	-23.7	576.3	0.97	0.13	0.72	1.82	50	0.09	Verified
11	-10.1	189.4	4.2	0.06	1.04	0.01	1.11	50	0.06	Verified
12	24.4	-190.5	-34.6	0.15	1.04	0.04	1.24	50	0.06	Verified
13	-118.9	286.8	373.0	0.75	1.57	0.47	2.79	50	0.14	Verified
14	-84.5	-93.2	334.2	0.54	0.51	0.42	1.46	50	0.07	Verified
15	58.9	119.9	-238.0	0.37	0.66	0.30	1.33	50	0.07	Verified
16	93.3	-260.1	-276.8	0.59	1.42	0.35	2.36	50	0.12	Verified
17	-160.4	591.2	460.9	1.02	3.24	0.58	4.83	50	0.24	Verified
18	-74.2	-358.7	363.9	0.47	1.96	0.46	2.89	50	0.14	Verified
19	-89.3	524.4	216.6	0.57	2.87	0.27	3.71	50	0.19	Verified
20	-3.1	-425.4	119.5	0.02	2.33	0.15	2.50	50	0.12	Verified
21	-91.4	521.7	218.8	0.58	2.86	0.27	3.71	50	0.19	Verified
22	-5.3	-428.2	121.8	0.03	2.34	0.15	2.53	50	0.13	Verified
23	-20.3	454.9	-25.6	0.13	2.49	0.03	2.65	50	0.13	Verified
24	65.8	-495.0	-122.6	0.42	2.71	0.15	3.28	50	0.16	Verified

Unlike the air inlet section where the required area is developed from signed component loads (FZ, FY, MX, and FX) the design of the tension ring is performed against an allowable stress which is unsigned. As such, the absolute value of each component load is calculated for both the ASCE 4-98 100/40/40 and SRSS combinations. The resulting stress is evaluated against the allowable and summarized in Table RAI-TR85-SEB1-27-16 for axial plus bending and Table RAI-TR85-SEB1-27-17 for shear plus torsion for the three combination techniques.

Table RAI-TR85-SEB1-27-16: Comparison of Stress Qualification of Tension Ring by Combination Method – Axial Force plus Bending

Tension Ring - Axial force and Bending Verification - Section 1 lower											
Load combination		FY Kip	MX Kip*ft	MZ Kip*ft	f_{yFY} ksi	f_{yMX} ksi	f_{yMZ} ksi	Sum ksi	F_y ksi	Design Ratio (Sum/0.66*F_y)	Verification (Verified if Design Ratio<1.4)
WEC 100/40/40	9	3995.0	91.4	931.7	11.75	0.23	2.33	14.31	50	0.43	Verified
ASCE 4-98 100/40/40	ABS Max	3995.9	207.0	931.7	11.75	0.52	2.33	14.60	50	0.44	Verified
SRSS	ABS Max	3825.4	188.2	896.0	11.25	0.47	2.24	13.96	50	0.42	Verified

Table RAI-TR85-SEB1-27-17: Comparison of Stress Qualification of Tension Ring by Combination Method – Shear plus Torsion

Tension Ring - Shear force and Torsion Verification - Section 1 lower											
Load combination		FX Kip	FZ Kip	MY Kip*ft	f_{yFY} ksi	f_{yMX} ksi	f_{yMZ} ksi	Sum ksi	F_y ksi	Design Ratio (Sum/0.40*F_y)	Verification (Verified if Design Ratio<1.4)
WEC 100/40/40	17	-160.4	591.2	460.9	1.02	3.24	0.58	4.83	50	0.24	Verified
ASCE 4-98 100/40/40	ABS Max	187.9	591.2	615.1	1.19	3.24	0.77	5.20	50	0.26	Verified
SRSS	ABS Max	177.9	538.6	599.6	1.13	2.95	0.75	4.83	50	0.24	Verified

Figure RAI-TR85-SEB1-27-14 shows an example cross-section (Stress Line 5) of a W36x393 radial beam from the conical roof section of the ¼ FE model. The basic loads are summarized in Table RAI-TR85-SEB1-27-18. The member forces are tabulated for each element in this cross section for the radial roof beam at 90 degrees, where the lowest design ratio occurs. The maximum resulting combinations based on the WEC 100/40/40 combination technique are summarized in Table RAI-TR85-SEB1-27-19. As with the other examples, Table RAI-TR85-SEB1-27-20 summarizes the maximum member forces developed for both the ASCE 4-98 100/40/40 and the SRSS combination techniques.

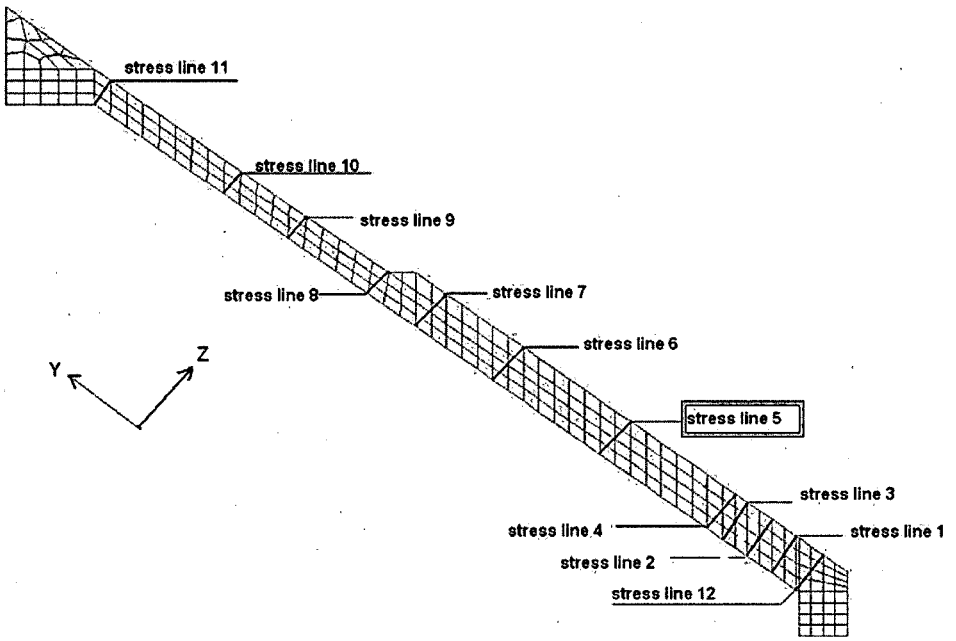

Figure RAI-TR85-SEB1-27-14: Cross Section of Radial W36x393 Beam from ¼ FE Model (Stress Line 5)

Table RAI-TR85-SEB1-27-18: W36x393 Radial Beam Section 5 at 90° Unfactored Loads

Section 5 - SSE Loads - Conical Roof at W36 Beam 90°						
Load		DEAD	SNOW	E_z	E_x North - South	E_y East - West
FX	KIP	640.2	-25.3	238.9	172.2	171.0
FY	KIP	246.4	3.3	2.4	1.9	1.9
FZ	KIP	-20.9	-1.1	145.4	95.1	91.7
MX	KIP*FT	-72.6	-4.4	0.02	0.12	0.11
MY	KIP*FT	-103.4	-5.5	663.5	410.3	479.7
MZ	KIP*FT	0.0	0.0	12.0	8.4	9.5

Table RAI-TR85-SEB1-27-19: Final Factored Loads for W36x393 Radial Beam Section 5 at 90° WEC 100/40/40 Combinations

Member Forces - Section 5 Conical Roof at W36 Beam - 90°						
Load combination	FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
1	991.1	253.6	198.2	-76.9	910.6	19.1
2	854.3	252.1	124.8	-77.0	526.8	11.6
3	853.4	252.1	122.1	-77.0	582.4	12.4
4	716.6	250.6	48.7	-77.1	198.6	4.9
5	538.5	245.5	-91.6	-72.5	-410.9	-4.9
6	401.7	244.0	-165.0	-72.6	-794.7	-12.4
7	400.8	244.0	-167.7	-72.6	-739.1	-11.6
8	264.0	242.5	-241.1	-72.7	-1122.9	-19.1
9	951.1	253.3	168.0	-76.8	758.6	17.0
10	814.2	251.8	94.6	-76.9	374.9	9.4
11	606.7	249.5	-22.3	-77.1	-61.9	0.2
12	469.9	248.0	-95.6	-77.2	-445.6	-7.4
13	785.2	248.1	52.7	-72.4	233.3	7.4
14	648.4	246.6	-20.6	-72.5	-150.4	-0.2
15	440.9	244.3	-137.5	-72.7	-587.2	-9.4
16	304.0	242.8	-210.9	-72.8	-970.9	-17.0
17	950.4	253.4	165.9	-76.8	800.3	17.6
18	608.3	249.5	-17.5	-77.1	-159.1	-1.3
19	812.6	251.8	89.8	-76.9	472.1	10.9
20	470.6	248.0	-93.6	-77.2	-487.3	-8.0
21	784.5	248.1	50.7	-72.5	275.0	8.0
22	442.5	244.3	-132.7	-72.7	-684.4	-10.9
23	646.8	246.6	-25.4	-72.5	-53.2	1.3
24	304.7	242.7	-208.8	-72.8	-1012.6	-17.6
Min	264.0	242.5	-241.1	-77.2	-1122.9	-19.1
Max	991.1	253.6	198.2	-72.4	910.6	19.1

Table RAI-TR85-SEB1-27-20: Comparison of Final Factored Loads for W36x393 Radial Beam Section 5 at 90° by ASCE 4-98 100/40/40 and SRSS Combination Methods

Member Forces - Section 5 Conical Roof at W36 Beam - 90°							
Load combination		FX Kip	FY Kip	FZ Kip	MX Kip*ft	MY Kip*ft	MZ Kip*ft
100/40/40	MIN	264.0	242.5	-241.1	-77.2	-1122.9	-19.1
SRSS	MIN	274.3	246.1	-218.5	-77.2	-1024.7	-17.4
Ratio		0.96	0.99	1.10	1.00	1.10	1.10
100/40/40	MAX	991.1	253.6	198.2	-72.4	910.6	19.1
SRSS	MAX	955.5	253.3	174.5	-76.8	806.9	17.4
Ratio		1.04	1.00	1.14	0.94	1.13	1.10

The resulting stress is evaluated against the allowable and summarized in Table RAI-TR85-SEB1-27-21 for axial plus bending and Table RAI-TR85-SEB1-27-22 for shear plus torsion for the WEC 100/40/40 methodology for 24 load combinations.

Table RAI-TR85-SEB1-27-21: Comparison of Maximum Calculated Stress to Allowable for WEC 100/40/40 Combination Technique – Axial plus Bending Stress

Case #	Bending		Axial		Verified if Design Ratio<1
	Allowables		Allowables		
	Compression Bending Stress	-23760	Compression stress	-34783	
	Tension Bending Stress	23760	Tension stress	21600	
	Applied Stress	Ratio Applied/Allowable	Applied Stress	Ratio Applied/Allowable	Total
1	12069	0.51	-4561	0.13	0.64
2	8892	0.37	-3371	0.10	0.47
3	9352	0.39	-3363	0.10	0.49
4	6175	0.26	-2173	0.06	0.32
5	6175	0.26	-2173	0.06	0.32
6	9352	0.39	-3363	0.10	0.49
7	8892	0.37	-3371	0.10	0.47
8	12069	0.51	-4561	0.13	0.64
9	10811	0.46	-4212	0.12	0.58
10	7634	0.32	-3022	0.09	0.41
11	4019	0.17	-1360	0.04	0.21
12	6417	0.27	-2550	0.07	0.34
13	6417	0.27	-2550	0.07	0.34
14	4019	0.17	-1360	0.04	0.21
15	7634	0.32	-3022	0.09	0.41
16	10811	0.46	-4212	0.12	0.58
17	11156	0.47	-4206	0.12	0.59
18	4046	0.17	-1346	0.04	0.21
19	8439	0.36	-3009	0.09	0.44
20	6762	0.28	-2544	0.07	0.36
21	6762	0.28	-2544	0.07	0.36
22	8439	0.36	-3009	0.09	0.44
23	4046	0.17	-1346	0.04	0.21
24	11156	0.47	-4206	0.12	0.59

Table RAI-TR85-SEB1-27-22: Comparison of Maximum Calculated Stress to Allowable for WEC 100/40/40 Combination Technique – Shear plus Torsion Stress

Case #	Shear Allowables		Torsion	Verified if Design Ratio<1
	Shear Stress	14400	Torsion Stress	
	Applied Stress	Ratio Applied/Allowable	Applied Stress	Total
1	2099	0.15	0.0	0.15
2	1461	0.10	0.0	0.10
3	1437	0.10	0.0	0.10
4	799	0.06	0.0	0.06
5	799	0.06	0.0	0.06
6	1437	0.10	0.0	0.10
7	1461	0.10	0.0	0.10
8	2099	0.15	0.0	0.15
9	1836	0.13	0.0	0.13
10	1198	0.08	0.0	0.08
11	187	0.01	0.0	0.01
12	825	0.06	0.0	0.06
13	825	0.06	0.0	0.06
14	187	0.01	0.0	0.01
15	1198	0.08	0.0	0.08
16	1836	0.13	0.0	0.13
17	1819	0.13	0.0	0.13
18	223	0.02	0.0	0.02
19	1157	0.08	0.0	0.08
20	807	0.06	0.0	0.06
21	807	0.06	0.0	0.06
22	1157	0.08	0.0	0.08
23	223	0.02	0.0	0.02
24	1819	0.13	0.0	0.13

Similar to the tension ring, each component load is calculated for both the ASCE 4-98 100/40/40 and SRSS combinations. The resulting stress is evaluated against the allowable and summarized in Table RAI-TR85-SEB1-27-23 for axial plus bending and Table RAI-TR85-SEB1-27-24 for shear plus torsion for the three combination techniques.

Table RAI-TR85-SEB1-27-23: Comparison of Stress Qualification of W36 Beam Section 5 by Combination Method – Axial Force plus Bending

Section 5 - Axial plus Bending Verification - 90°							
Load combination		**Axial**		**Bending**		**Total (Axial + Bending)**	**Verification (Verified if Design**
		Stress (psi)	Raio to Allowable	Stress (psi)	Raio to Allowable		
WEC 100/40/40	1	-4561	0.13	12069	0.51	0.64	Verified
ASCE 4-98 100/40/40	ABS Max	-4561	0.13	12069	0.51	0.64	Verified
SRSS	ABS Max	-4251	0.12	11210	0.47	0.59	Verified

Table RAI-TR85-SEB1-27-24: Comparison of Stress Qualification of W36 Beam Section 5 by Combination Method – Shear plus Torsion

Section 5 - Shear plus Torsion Verification - 90°							
Load combination		**Shear**		**Torsion**		**Total (Shear + Torsion)**	**Verification (Verified if Design**
		Stress (psi)	Raio to Allowable	Stress (psi)	Raio to Allowable		
WEC 100/40/40	8	2099	0.15	0.0	0.00	0.15	Verified
ASCE 4-98 100/40/40	ABS Max	2099	0.15	0.0	0.00	0.15	Verified
SRSS	ABS Max	1893	0.13	0.0	0.00	0.13	Verified

Design Control Document (DCD) Revision:

Revise third bullet of subsection 3.7.2.6 as follows:

- The peak responses due to the three earthquake components from the equivalent static analyses are combined directly, using the assumption that when the peak response from one component occurs, the responses from the other two components are 40 percent of the peak (100 percent-40 percent-40 percent method). Combinations of seismic responses from the three earthquake components, together with variations in sign (plus or minus), are considered. This method is used in the nuclear island basemat analyses, the containment vessel analyses and the shield building roof analyses.

PRA Revision:
None

Technical Report (TR) Revision:

Revise section 2.6.1.4 as follows: The underlined portion is added by Revision 1 of this response.

2.6.1.4 Normal plus seismic reactions

Liftoff analyses were performed for 16 load cases of dead, live and seismic loads for the soil site with subgrade modulus of 520 kcf. Seismic loads are applied with unit factor in one direction and with 0.4 factor in the other two directions. The 16 cases were those having the unit factor applied in the horizontal direction in order to maximize the overturning. Cases with unit factor in the vertical direction <u>were also analyzed in linear analyses and</u> do not control. Maximum bearing reactions at the corners of the auxiliary building and at the west side of the shield building are shown in Table 2.6-3. Bearing pressure contours are shown in Figures 2.6-4 to 2.6-8 for the five load cases resulting in these maximum bearing reactions. The seismic load combination is shown for each figure. Note that the bearing pressures reduce rapidly away from the corners. These figures show lift off for equivalent static loads which are higher than the maximum time history loads as discussed in section 2.4.2. This is particularly the case for load combinations with unit seismic load in the Y direction (East-West) where the footprint dimension is smaller. The results of the equivalent static analyses are used for basemat design. The maximum bearing capacity reactions for defining minimum dynamic soil bearing capacity are based on time history analyses as discussed in Section 2.4.2.