Westinghouse Electric Corporation

Energy Systems

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Docket No: STN-52-003

February 12, 1996

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

ATTENTION: T. R. QUAY

SUBJECT: SAMPLE PROBLEM FOR COMPUTER CODE VALIDATION REGARDING THE CONTAINMENT VESSEL DESIGN FOR THE AP600

REFERENCE: NRC letter from Jackson to Liparulo dated October 16, 1995, "Sample Problem For Computer Code Validation Regarding The Containment Vessel Design For The AP600."

Dear Mr. Quay:

The reference letter transmitted sample problems to be used to validate the Chicago Bridge and Iron Company computer code "E0781" and to thereby resolve the staff's concern of DSER open item 3.8.2.4.8. This letter provides the response to the sample problems.

Enclosed is a copy of the CBI generated letter report entitled "VERIFICATION OF CBI AXISYMMETRIC SHELL ANALYSIS COMPUTER PROGRAM 'E0781'," dated February 5, 1996. The report consists of pages 1 through 8, all Revision 0. The report provides the basic input information and a summary of the resulting output for the axisymmetric internal pressure case (n=0 harmonic) when executed by CBI, using CBI RISC 6000 equipment and CBI Computer code 'E0781.' This report is based on the use of a slightly different model than the sample problem provided in the reference letter. This alternate approach was agreed in a telecon between Dr. T. Cheng of the NRC staff and Westinghouse's Richard Orr because the model information provided by Ames Laboratories, included unique modeling features at one of the stiffeners and crane girder which could not be incorporated in the CBI computer code. This difference in modeling features is mainly due to the differences in the analytical approaches used within the two programs. The overall results obtained

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from the two programs should not be significantly different from each other. The alternate is therefore submitted with the understanding that Ames Laboratories can make comparisons against their existing analyses for the internal pressure case. Once these comparisons are found to be acceptable, Westinghouse will have CBI perform the wind load case (n = 1 harmonic) and provide similar information for comparison against Ames Lab's analyses.

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

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

Enclosures

cc: D. J. Jackson, NRC
Ahl, CBI
T. Cheng, NRC
Greisman, Ames Lab
N. J. Liparulo, W

VERIFICATION OF CBI AXISYMMETRIC SHELL ANALYSIS COMPUTER PROGRAM 'E0781'

PROBLEM NO. 1
'n = 0' Harmonic Loading

February 5, 1996

VERIFICATION OF CBI AXISYMMETRIC SHELL ANALYSIS COMPUTER PROGRAM 'E0781'

PROBLEM NO. 1: UNIFORM INTERNAL PRESSURE OF 45 PSIG APPLIED TO AP600CONTAINMENT VESSEL, n = 0 HARMONIC LOADING

ANALYTICAL METHOD AND MODEL

CBI Computer Program 'E0781', "General Shell of Revolution Stress Analysis" based on the method presented by A. Kalnins in the Journal of Applied Mechanics, Vol. 31, September 1964 is used for the analysis.
Model is shown in Figure 1. The stiffeners are modeled as branches. The crane girder is modeled as a closed section using branches and a closed loop.
The radial web plates of the crane girder are considered as the additional orthotropic layers along each of the four sides of the box shaped crane girder. Smeared orthotropic material properties are used with a meridional value for the modulus of elasticity, E equal to Young's modulus factored by the ratio of the radial web thickness divided by the radial web circumferential spacing. The shear modulus is then computed to be one-half the meridional modulus of elasticity and the circumferential modulus of elasticity is zero.

MATERIAL PROPERTIES

Properties are at 320°F.
Parts 1 through 3, 5 through 10, 12, 17, and 19 through 22:
$E = 28.18\times10^6$ psi; $\nu = 0.3$
Part 4:
$E_\varphi = 28.13\times10^9$ psi; $E_\theta = \nu = 0$; $G_{\varphi\theta} = 14.09\times10^9$ psi
Parts 11, 13, through 16, and 18:
Combination of layers with isotropic and orthotropic properties. The layers representing the radial web plates of the crane girder use the orthotropic properties calculated using the method described earlier.

BOUNDARY CONDITIONS

At start of Part 1 (Base):	Fixed
At end of Parts 22 (Crown):	$Q = N_{\varphi\theta} = 0$, $N_\varphi = p \times R_{crown} / 2$, and $M_\varphi = N_\varphi \times t / 2$
At branch ends:	Free

LOADING

Internal pressure of 45 psig on Parts 1 through 3, 7, 10, 14, 15, and 19 through 22.
n = 0 Harmonic loading.

RESULTS

The deflections are summarized in Table 1 and the stresses in Table 2.

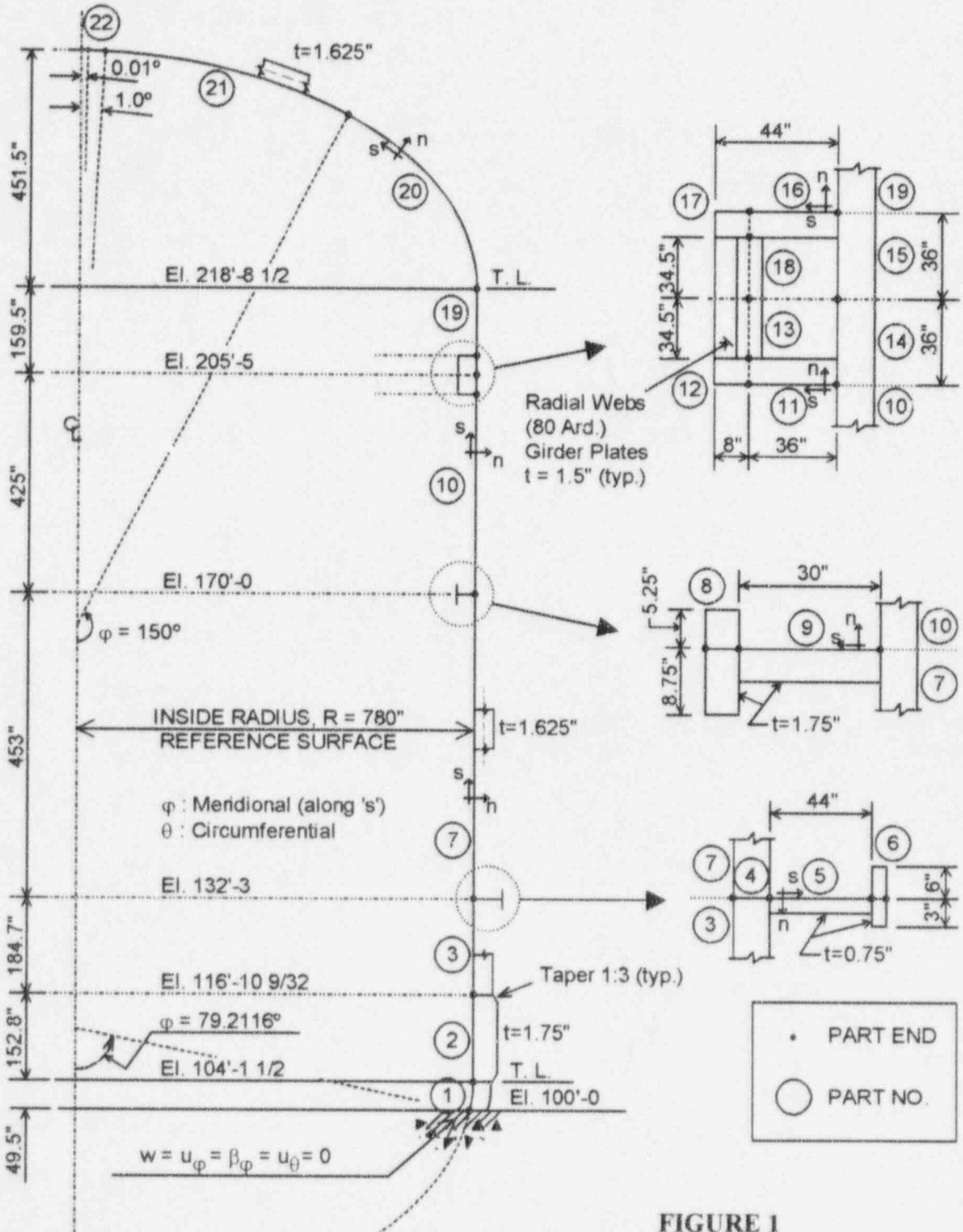

FIGURE 1

SHELL OF REVOLUTION 'E0781' MODEL

TABLE 1: DEFLECTIONS DUE TO INTERNAL PRESSURE OF 45 PSIG

w = Normal (radial) displacement, '+' is in the direction of 'n' in Fig.1;
u_φ = Meridional displacement, '+' is in the direction of 's' in Fig.1.

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	w in	u_φ in
1	79.2116°	100 (Base)	0	0
	81.4°	100.8438	-0.02285	0.0011
	83.5°	101.649	-0.05199	0.007583
	85.7°	102.489	-0.0485	0.01686
	87.8°	103.2885	0.002986	0.02538
2	90°, 1249.5"	104.125 (T. L.)	0.09559	0.02934
	1280.1"	106.675	0.386	0.0327
	1310.6"	109.2167	0.4874	0.03239
	1341.2"	111.7667	0.4845	0.0353
	1371.7"	114.3083	0.4729	0.04001
3	1402.3"	116.8583	0.4895	0.0454
	1433.1"	119.425	0.5099	0.0494
	1463.9"	121.9917	0.5129	0.05393
	1494.6"	124.55	0.515	0.05856
	1525.4"	127.1167	0.5049	0.06244
	1556.2"	129.6833	0.442	0.06568
	1556.2"	129.6833	0.442	0.06568
7	1587"	132.25 (Stfnr)	0.3591	0.07438
	1617.2"	134.7667	0.4409	0.08292
	1647.4"	137.2833	0.5041	0.0861
	1677.6"	139.8	0.5145	0.08983
	1707.8"	142.3167	0.5106	0.09435
	1738"	144.8333	0.5082	0.09905
	1768.2"	147.35	0.5079	0.1037
	1798.4"	149.8667	0.5081	0.1083
	1828.6"	152.3833	0.508	0.113
	1858.8"	154.9	0.5078	0.1176
	1858.8"	154.9	0.5078	0.1176
	1889"	157.4167	0.5083	0.1223

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TABLE 1 (Continued)

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	w in	u_{φ} in
	1919.2"	159.9333	0.5123	0.127
	1949.4"	162.45	0.5185	0.1314
	1979.6"	164.9667	0.4997	0.1346
	2009.8"	167.4833	0.394	0.1369
10	2040"	170 (Stfnr)	0.2692	0.1486
	2072.4"	172.7	0.4166	0.1591
	2104.8"	175.4	0.509	0.1615
	2137.2"	178.1	0.5172	0.1653
	2169.7"	180.8083	0.5103	0.1702
	2202.1"	183.5083	0.5078	0.1753
	2234.5	186.2083	0.5075	0.1803
	2266.9"	188.9083	0.5078	0.1853
	2299.3	191.6083	0.511	0.1904
	2331.7"	194.3083	0.5191	0.1953
	2364.2"	197.0167	0.5069	0.1988
	2396.6"	199.7167	0.3919	0.2008
14	2429"	202.4167†	0.2294	0.2134
	2447"	203.9167†	0.2347	0.2176
15	2465"	205.4167†	0.2369	0.2218
	2483"	206.9167†	0.2355	0.226
19	2501"	208.4167†	0.2311	0.2302
	2525.7"	210.475	0.3544	0.2421
	2550.4"	212.5333	0.4972	0.2441
	2575.1"	214.5917	0.5315	0.2434
	2599.8"	216.65	0.403	0.2408
20	2624.5", 90°	218.708 (T. L.)	0.06658	0.2416
	95°	220.6113	-0.2231	0.2638
	100°	222.5287	-0.3266	0.3064
	105°	224.475	-0.2969	0.349

†Part of the crane girder.

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TABLE 1 (Continued)

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	w in	u_φ in
	110°	226.465	-0.2166	0.3847
	115°	228.5132	-0.1261	0.4126
	120°	230.6341	-0.03206	0.4334
	125°	232.8414	0.0708	0.4469
	130°	235.1467	0.1866	0.4525
	135°	237.5573	0.3162	0.4491
	140°	240.0732	0.4589	0.4363
	145°	242.6812	0.6132	0.4133
21	150°	245.3476	0.7769	0.3801
	151.9°	246.3641	0.842	0.3645
	153.9°	247.4282	0.9076	0.3473
	155.8°	248.4275	0.9732	0.3287
	157.7°	249.4084	1.038	0.3086
	159.7°	250.4124	1.102	0.2871
	161.6°	251.3301	1.165	0.2643
	163.5°	252.2025	1.225	0.2402
	165.5°	253.0606	1.281	0.2149
	167.4°	253.8072	1.333	0.1886
	169.3°	254.4759	1.381	0.1613
	171.3°	255.0837	1.422	0.1333
	173.2°	255.5595	1.456	0.1045
	175.1°	255.9273	1.482	0.07517
	177.1°	256.19	1.5	0.04547
22	179°	256.3162	1.509	0.01553
	180°	256.333 (Pole)	1.51 (up)	0.0003736

TABLE 2: STRESSES DUE TO INTERNAL PRESSURE OF 45 PSIG

σ_φ, σ_θ: Meridional and circumferential stress, respectively, '+' for tension;

i, m, o: Subscripts used for inside, membrane, and outside stress, respectively

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	$\sigma_{\varphi i}$ psi	$\sigma_{\varphi m}$ psi	$\sigma_{\varphi o}$ psi	$\sigma_{\theta i}$ psi	$\sigma_{\theta m}$ psi	$\sigma_{\theta o}$ psi
1	79.2116°	100 (Base)	-6210	10830	27870	-1863	3250	8362
	81.4°	100.8438	9708	10830	11950	2099	2451	2803
	83.5°	101.6490	19460	10830	2195	3997	1414	-1169
	85.7°	102.4890	23550	10820	-1918	5363	1537	-1290
	87.8°	103.2885	21980	10810	-357.3	6736	3377	18.55
	90°	104.125 (T. L.)	13900	10800	7696	7625	6694	5762
2	1249.5"	104.125 (T. L.)	13900	10800	7696	7625	6694	5762
	1280.1"	106.6750	3364	10030	16690	14980	16980	18980
	1310.6"	109.2167	7173	10030	12890	19760	20620	21470
	1341.2"	111.7667	9927	10030	10130	20480	20510	20540
	1371.7"	114.3083	10880	10030	9182	20350	20090	19840
3	1402.3"	116.8583	9809	10800	11790	20630	20930	21220
	1433.1"	119.4250	10350	10800	11250	21530	21660	21800
	1463.9"	121.9917	10840	10800	10760	21780	21770	21760
	1494.6"	124.5500	10570	10800	11040	21770	21850	21920
	1525.4"	127.1167	9328	10800	12270	21040	21480	21920
	1556.2"	129.6833	9353	10800	12250	18780	19210	19640
	1587"	132.25 (Stfnr)	20650	10800	951	19170	16210	13260
7	1587"	132.25 (Stfnr)	20510	10800	1090	19130	16210	13300
	1617.2"	134.7667	9393	10800	12210	18750	19170	19590
	1647.4"	137.2833	9266	10800	12330	20990	21450	21910
	1677.6"	139.8000	10480	10800	11120	21730	21830	21920
	1707.8"	142.3167	10880	10800	10730	21710	21690	21670
	1738"	144.8333	10860	10800	10740	21620	21600	21580
	1768.2"	147.3500	10810	10800	10790	21590	21590	21590
	1798.4"	149.8667	10790	10800	10810	21590	21600	21600
	1828.6"	152.3833	10790	10800	10810	21590	21590	21600
	1858.8"	154.9000	10820	10800	10780	21590	21590	21580
	1889"	157.4167	10900	10800	10700	21630	21600	21580

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TABLE 2 (Continued)

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	$\sigma_{\varphi i}$ psi	$\sigma_{\varphi m}$ psi	$\sigma_{\varphi o}$ psi	$\sigma_{\theta i}$ psi	$\sigma_{\theta m}$ psi	$\sigma_{\theta o}$ psi
	1919.2"	159.9333	10910	10800	10690	21780	21750	21720
	1949.4"	162.4500	10240	10800	11360	21800	21970	22140
	1979.6"	164.9667	8251	10800	13350	20530	21290	22060
	2009.8"	167.4833	8732	10800	12840	16860	17470	18090
	2040"	170.0 (Stfnr)	27760	10800	-6162	18050	12960	7876
10	2040"	170.0 (Stfnr)	25200	10800	-3596	17280	12960	8646
	2072.4"	172.7000	8062	10800	13540	17470	18290	19110
	2104.8"	175.4000	8753	10800	12850	21020	21630	22250
	2137.2"	178.1000	10570	10800	11030	21860	21930	22000
	2169.7"	180.8083	10940	10800	10660	21720	21680	21640
	2202.1"	183.5083	10850	10800	10750	21600	21590	21570
	2234.5"	186.2083	10800	10800	10800	21580	21580	21580
	2266.9"	188.9083	10870	10800	10730	21600	21590	21570
	2299.3"	191.6083	10960	10800	10640	21750	21700	21650
	2331.7"	194.3083	10470	10800	11130	21890	21990	22090
	2364.2"	197.0167	8267	10800	13330	20790	21550	22310
	2396.6"	199.7167	7866	10800	13730	16520	17400	18280
	2429"	202.4167†	29750	10800	-8154	17210	11530	5840
14	2429"	202.4167‡	9855	10010	10160	11240	11290	11330
	2447"	203.9167‡	10010	10260	10510	11480	11560	11630
15	2465"	205.4167‡	10060	10340	10620	11580	11660	11750
	2483"	206.9167‡	10010	10260	10510	11510	11590	11660
	2501"	208.4167‡	9854	10000	10150	11300	11350	11390
19	2501"	208.4167§	30380	10800	-8780	17460	11590	5714
	2525.7"	210.4750	10270	10800	11340	15880	16040	16200
	2550.4"	212.5333	6199	10800	15400	19820	21200	22580
	2575.1"	214.5917	4241	10800	17360	20480	22440	24410
	2599.8"	216.6500	1245	10800	20360	14930	17800	20670
	2624.5"	218.708 (T. L.)	11160	10800	10440	5753	5646	5538

†Just below the crane girder. ‡Part of the crane girder. §Just above the crane girder.

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TABLE 2 (Continued)

Shell Part No. (See Fig. 1)	Coordinate deg or in	Elevation ft	$\sigma_{\varphi i}$ psi	$\sigma_{\varphi m}$ psi	$\sigma_{\varphi o}$ psi	$\sigma_{\theta i}$ psi	$\sigma_{\theta m}$ psi	$\sigma_{\theta o}$ psi
20	90°	218.708 (T. L.)	11160	10800	10440	5753	5646	5539
	95°	220.6113	20730	10830	921.6	-2652	-5649	-8645
	100°	222.5287	16870	10900	4931	-8552	-10350	-12150
	105°	224.4750	12780	11040	9305	-9954	-10460	-10970
	110°	226.4650	11280	11240	11210	-8987	-8976	-8965
	115°	228.5132	11380	11510	11630	-7389	-7325	-7261
	120°	230.6341	11880	11830	11780	-5749	-5733	-5717
	125°	232.8414	12320	12220	12110	-4035	-4028	-4021
	130°	235.1467	12740	12680	12620	-2117	-2087	-2057
	135°	237.5573	13220	13220	13220	41.81	98.42	155
	140°	240.0732	13790	13830	13880	2413	2490	2566
	145°	242.6812	14440	14510	14590	4947	5039	5132
	150°	245.3476	15130	15250	15380	7555	7666	7777
21	150°	245.3476	15160	15250	15350	7582	7685	7788
	151.9°	246.3641	15450	15550	15650	8612	8719	8825
	153.9°	247.4282	15750	15850	15960	9639	9749	9859
	155.8°	248.4275	16050	16160	16270	10660	10770	10880
	157.7°	249.4084	16350	16460	16570	11650	11770	11890
	159.7°	250.4124	16640	16760	16870	12620	12740	12860
	161.6°	251.3301	16930	17050	17170	13560	13680	13800
	163.5°	252.2025	17210	17330	17450	14440	14560	14690
	165.5°	253.0606	17470	17590	17710	15270	15390	15520
	167.4°	253.8072	17710	17830	17960	16030	16150	16280
	169.3°	254.4759	17930	18050	18180	16700	16830	16950
	171.3°	255.0837	18120	18240	18370	17290	17410	17540
	173.2°	255.5595	18280	18400	18530	17770	17890	18020
	175.1°	255.9273	18400	18530	18650	18130	18260	18390
	177.1°	256.1900	18480	18610	18730	18390	18510	18640
	179°	256.3162†	18540	18640	18750	18520	18660	18800
22	179°	256.3162†	18530	18650	18770	18510	18640	18760

†Very close to pole. Stresses at pole can not be determined due to numerical problem. Using formula, $\sigma_{\varphi} = \sigma_{\theta} = (p \times R_{crown}) / (2 \times t) = (45 \times 1347.5) / (2 \times 1.625) = 18658$ psi.