

Bulletin on Comparison of Marine Drilling Riser Analyses

API BULLETIN 16J (BUL 16J)
FIRST EDITION, AUGUST 1, 1992
(FORMERLY BUL 2J)

American Petroleum Institute
1220 L Street, Northwest
Washington, DC 20005



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API Bulletin on COMPARISON OF ANALYSES OF MARINE DRILLING RISERS

Foreword

a. Recognizing the need for a standard method of analyzing marine drilling risers, the API Committee on the Standardization of Offshore Structures began a program of comparing existing computer programs for such analyses. To make this comparison, a standard set of problems was defined and a Task Group formed by the Committee on Standardization of Offshore Structures obtained computer solutions of this set from various participants. The First Edition of API RP 2J was issued in January 1977. This Edition now under the jurisdiction of the Committee on Standardization of Drilling Well Control Systems and renumbered Bul 16J has added a number of deepwater cases along with some random wave cases. The number of participants has increased from nine to 14. The statistical summaries of these solutions are presented in this bulletin.

b. The purposes of issuing these results are: (1) to show the degree of agreement among a representative group of riser analysis computer programs, and (2) to present data which can be used to help validate other such programs.

c. In cases where the results of a participant differed significantly (some 25% or more) from the consistently clustered results of the majority of the participants, results were omitted. Numerous attempts were made by the committee members to assist participants in correcting input errors, problem definitions, and other

likely sources of disagreement. The omissions were handled on a problem by problem basis, i.e., the number of solutions used to compile the results for each problem varies. The number of solutions included for each individual problem is indicated throughout the tables and figures in parentheses following the problem designation.

d. None of these results have been directly validated by measurements on equivalent real risers, although some of the programs have been partially validated in other applications. Comparisons such as those described here are not intended to replace or lessen the need for such validation.

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Note:

This is the first edition of this bulletin. It was formerly numbered API Bul 2J.

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SECTION 1 DESCRIPTION OF CASES

General

1.1 There are a total of forty cases as shown in Table 1, DESIGNATION OF CASES. All but two are for 500-, 1500-, and 3000-ft water depths.

1.2 Static cases are analyzed for three water depths, two current profiles and two top tensions. Also included are three disconnected cases, one at each depth, and a 6000-ft water depth case.

1.3 Periodic dynamic cases are analyzed for three water depths, two current profile/wave height combinations, and two top tensions. Also included are three disconnected cases, one at each depth, and a 6000-ft water depth case. There are also two cases, 1500-40-1-D2 and 1500-40-2-D2, for which the vessel surge phase angle is 180° greater than that of the other cases, i.e., the peak vessel surge leads the wave crest. These cases are intended to illustrate the importance of phase angle and to provide results that may be more useful for checking hydrodynamic force formulations.

1.4 Random dynamic cases are analyzed for three water depths, one current profile/wave height combination, and two top tensions.

1.5 The input data specifications for the 500-, 1500-, and 3000-ft water depth cases are given in Table 2. Table 3 shows input data specifications for the 6000-ft cases. Figure 1 shows typical riser configurations and Figure 2 shows a cross section of the riser. Figure 3 is the vessel's surge response amplitude operator (RAO) to be used for the random cases.

1.6 The 21-inch and 18 $\frac{3}{4}$ -inch risers are assumed to contain drilling mud only — with no drill pipe or other internal connections. For all cases, the choke and kill lines are assumed to be filled with seawater to the mean water level. The riser is attached at its lower end to a pin connection, the lower ball joint. At its top, it is restrained by another pin connection at the tensioner ring. Both joints are frictionless, and for simplicity, the telescopic joint is assumed to have the same physical properties as the rest of the riser. The riser has no upper, or intermediate, ball joint.

1.7 For disconnected riser cases, the riser is assumed to contain sea water, with the lower marine riser package (LMRP) twenty feet above the sea floor. Included in the LMRP is a pin connection, the lower ball joint, ten feet above its bottom (thirty feet above the sea floor).

1.8 Furthermore, it is assumed that all cases are for a semisubmersible drilling vessel with the upper end of the riser exposed to wave forces. Wave and current forces are assumed to act in the same direction as the positive offset. Choke and kill lines are broadside to waves and current, as shown in Figure 2, and are assumed to contribute no stiffness to the riser.

Static Cases

1.9 The static cases are for current plus offset only — no wave forces. The remaining input data, including current profiles, are given in Tables 2 and 3.

1.10 Note that the 500- and 1500-ft cases are with a 20-inch unbuoyed riser, the 3000-ft cases with a 21-inch buoyed riser, and the 6000-ft case with an 18 $\frac{3}{4}$ -inch buoyed riser.

Dynamic Cases

1.11 The dynamic cases are similar to the static cases, with the addition of time-varying wave forces. Dynamic cases are for combined wave and current. Wave propagation is in the direction of positive offset. Input data specifications for the two periodic waves and the random waves are included in Tables 2 and 3. The periodic wave model is not specified. Top tension is assumed to be constant throughout the wave cycle.

1.12 For the periodic wave cases, horizontal motion (surge) is assumed to be sinusoidal with the same period as the wave. For those dynamic cases with the designation "D," the surge motion lags the wave crest. For "D2" cases, the surge motion leads the crest. For the random wave cases, the vessel's surge response amplitude operator (RAO) is shown in Figure 3.

TABLE 1
DESIGNATION OF CASES

Water Depth (Feet)	Top Tension (Kips)	Current Profile A		Current Profile B			Random Dynamic (Significant Wave Height 21.5 Ft)
		Static	Periodic Dynamic (Wave Height 20 Ft)	Static	Periodic Dynamic (Wave Height 40 Ft)		
500	170	500-A-1-S	500-20-1-D	500-B-1-S	500-40-1-D	500-21.5-1-R	
	240	500-A-2-S	500-20-2-D	500-B-2-S	500-40-2-D	500-21.5-2-R	
	Disconnected			500-B-FREE-S	500-40-FREE-D		
1500	370	1500-A-1-S	1500-20-1-D	1500-B-1-S	1500-40-1-D	1500-21.5-1-R	
	600	1500-A-2-S	1500-20-2-D	1500-B-2-S	1500-40-2-D	1500-21.5-2-R	
	Disconnected			1500-B-FREE-S	1500-40-2-D2 1500-40-FREE-D		
3000	500	3000-A-1-S	3000-20-1-D	3000-B-1-S	3000-40-1-D	3000-21.5-1-R	
	650	3000-A-2-S	3000-20-2-D	3000-B-2-S	3000-40-2-D	3000-21.5-2-R	
	Disconnected			3000-B-FREE-S	3000-40-FREE-D		
6000	700	Current Profile C					
				6000-C-1-S	6000-40-1-D		

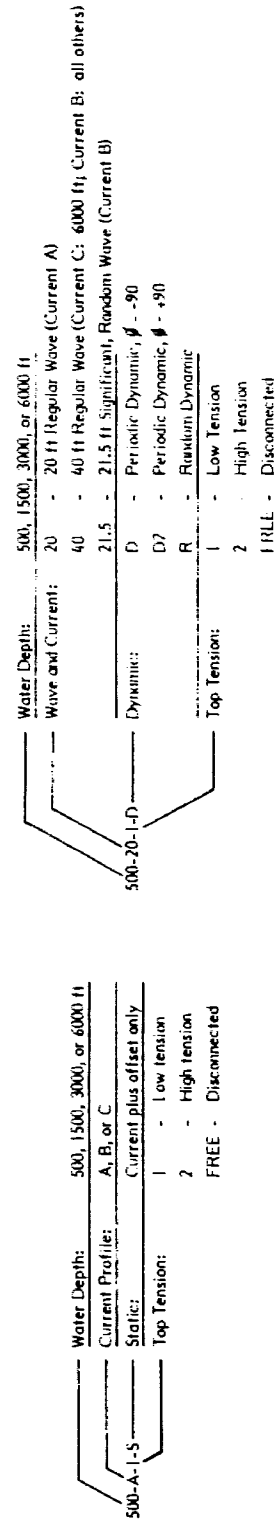


TABLE 2
INPUT DATA SPECIFICATIONS
500, 1500, AND 3000-FT CASES

I. CONSTANT WITH WATER DEPTH		II. VARYING WITH WATER DEPTH	
<u>Vertical Distances, Feet</u>		<u>D, water depth, feet</u>	
Mean water level to riser tensioner ring		500	
Sea floor to lower ball joint		520	
<u>Riser Data¹</u>		<u>L, riser length, feet⁴</u>	
		170	
		<u>T, top tension, Kips⁴</u>	
		240	
		<u>O_s, static offset, feet</u>	
		15	
		45	
		3000	
		3020	
		500	
		650	
		90	
<u>Diameters, Inches</u>		<u>H₁, wave height, peak to trough, feet</u>	
<u>r_o, riser pipe outside diameter</u>		20	
<u>r_i, riser pipe inside diameter</u>		9	
<u>c_o & c_i, choke and kill line inside diameters</u>		<u>T, wave period, seconds</u>	
<u>b_o, buoyant material outside diameter</u>		4	
<u>b_i, buoyant material inside diameter</u>		<u>V, vessel surge amplitude (peak to peak), ft</u>	
<u>b_o, (3000-ft water depth cases only)</u>		-90	
		<u>φ, vessel surge phase angle, degrees</u>	
		A	
		Current profile	
		21.5	
		12.8	
		26.7	
		-90	
		B	
<u>Choke and Kill Lines Offset (Centerline to Centerline of Riser), Inches</u>		<u>Current profile</u>	
		21.5	
		12.8	
		26.7	
		-90	
		B	
<u>Modulus of Elasticity of Riser Pipe, E_r, psi x 10⁶</u>		<u>Current profile</u>	
		21.5	
		12.8	
		26.7	
		-90	
		B	
<u>Densities, pounds/ cubic foot</u>		<u>Current profile</u>	
<u>Seawater</u>		21.5	
<u>Drilling mud²</u>		12.8	
		26.7	
		-90	
		B	
<u>Hydraulic Force Constants</u>		<u>Current profile</u>	
<u>C_d, drag coefficient³</u>		21.5	
<u>C_m, mass coefficient³</u>		12.8	
<u>d_e, effective diameter for current and wave forces, inches - unbuoyed riser</u>		26.7	
<u>d_e, effective diameter for current and wave forces, inches - buoyed riser</u>		-90	
		B	
<u>Weight, pounds, of 50-foot joint, complete with all associated lines, couplings, and buoyant material, if any</u>		<u>Current profile</u>	
		21.5	
		12.8	
		26.7	
		-90	
		B	
		<u>Current profile</u>	
		21.5	
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		<u>Current profile</u>	
		21.5	
		12.8	

TABLE 3

INPUT DATA SPECIFICATIONS

6000-FT CASES

Vertical Distances, Feet

Mean water level to riser tensioner ring	50
Sea floor to lower ball joint	30

Riser Data¹Diameters, Inches

r_o , riser pipe outside diameter	18.63
r_i , riser pipe inside diameter	17.63
c_o & k_o , choke and kill line outside diameters	4.0
c_i & k_i , choke and kill line inside diameters	3.0
b_o , buoyant material outside diameter	38.0

Choke and Kill Lines Offset (Centerline to Centerline of Riser), Inches

14.75

Modulus of Elasticity of Riser Pipe, E , psi $\times 10^6$

30

Densities, Pounds/Cubic Foot

Seawater	64.0
Drilling Mud ²	89.8 (12 ppq)

Hydraulic Force Constants

C_d , drag coefficient ³	0.7
C_m , mass coefficient	1.5
d_e , effective diameter for current and wave forces, inches	38.0

Weight, Pounds, of 50-foot joint, complete with all associated lines, couplings, and buoyant material,

	<u>W_a, in air</u>	<u>W_p, in seawater</u>
18-5/8-in, buoyed	16350	1300

Current Profile

- C. Linear, 2 knot at mean water level, 1 knot at 150 ft below MWL, 0.4 knot at lower ball joint.

Model

D , water depth feet	6000
L , riser length, feet ⁴	6020
T , top tension, Kips	700
O_s , static offset, feet	180
H_s , wave height, peak to trough, feet	40
T , wave period, seconds	12.8
V , vessel surge amplitude (peak to peak), feet	26.7
ϕ , vessel surge phase angle, degrees	-90
Current Profile	C

¹ Assume constant properties over entire length. Choke and kill lines are on opposite sides of riser. Riser is oriented so tubes are broadside to current/wave. Weight or other effects above tensioner ring are ignored.

² Riser is filled with drilling mud to top of riser. For simplicity, assume choke and kill lines filled with seawater to mean water level.

³ This is the mass coefficient used in Morison's equation and defined in his original paper on the subject. Morison, J. R., O'Brien, M. P., Johnson, J. W., and Schaaf, S. A. (1950). "The Force Exerted by Surface Waves on Piles", Petroleum Transactions of AIME, Vol. 189, pages 149-154.

⁴ Assume constant (with time) top tension.

⁵ Negative phase angle is peak vessel surge after wave crest. (Assume surge has same period as wave.)



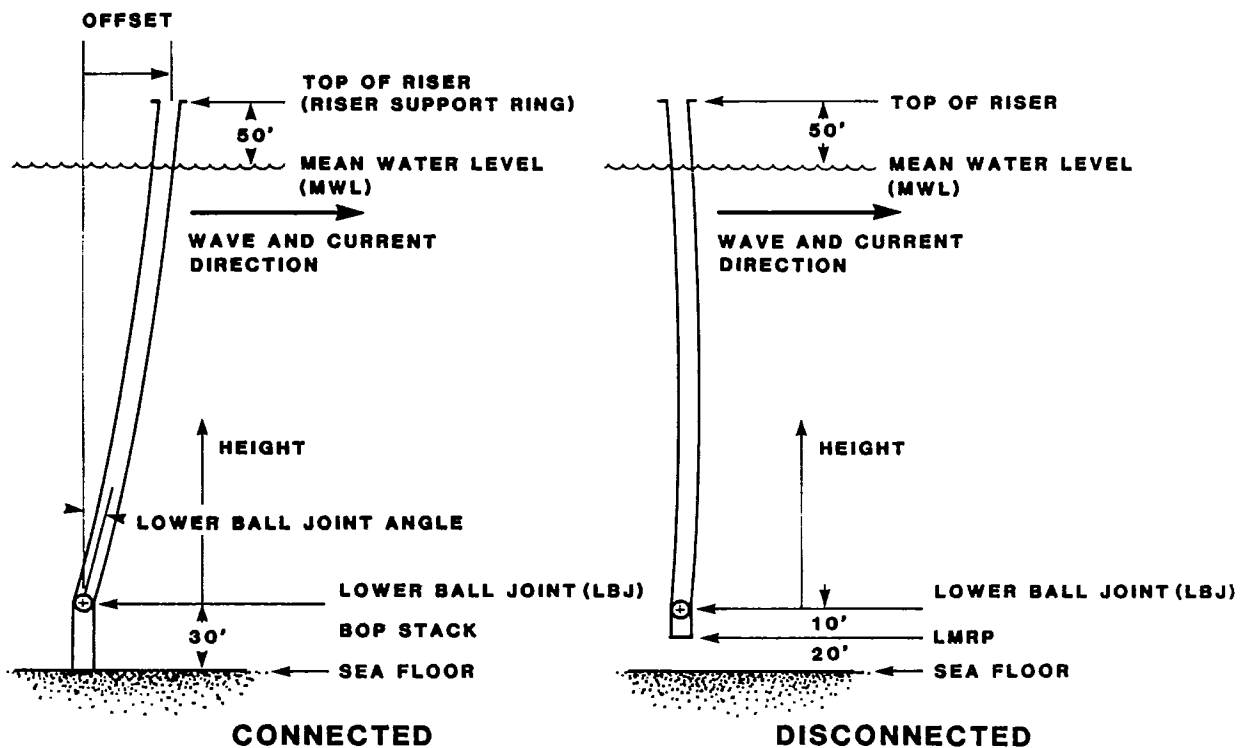


FIGURE 1
TYPICAL RISER CONFIGURATIONS

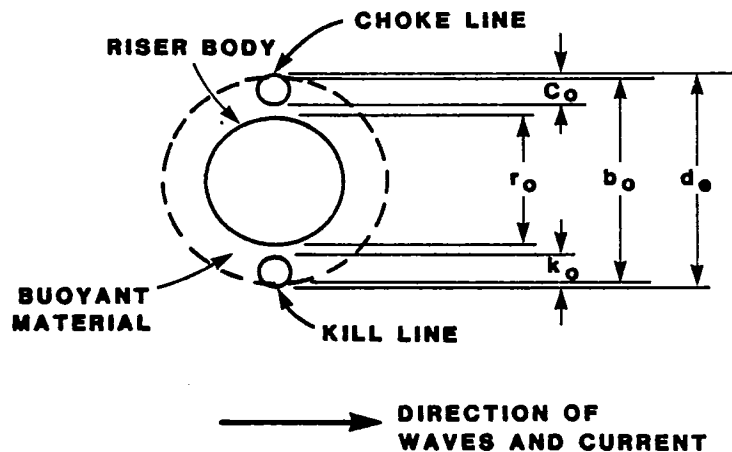
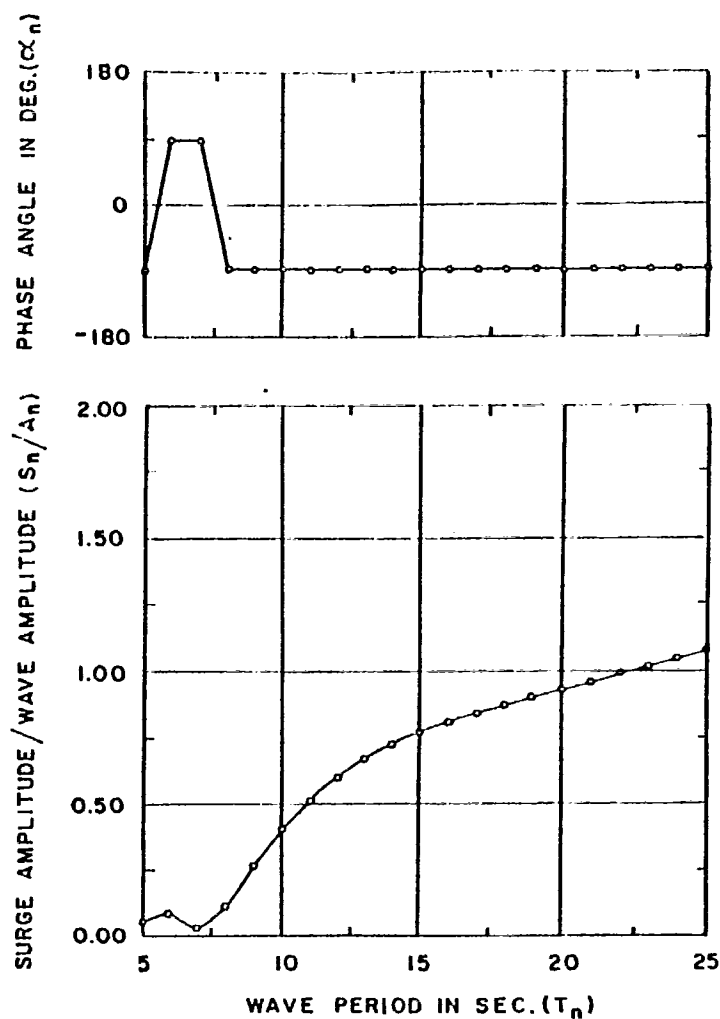


FIGURE 2
CROSS SECTION OF RISER



T_n (sec)	S_n/A_n	α_n (deg)
5	.06	-90
6	.09	+90
7	.04	+90
8	.12	-90
9	.26	-90
10	.40	-90
11	.51	-90
12	.60	-90
13	.67	-90
14	.72	-90
15	.76	-90
16	.80	-90
17	.84	-90
18	.87	-90
19	.91	-90
20	.94	-90
21	.96	-90
22	.99	-90
23	1.02	-90
24	1.06	-90
25	1.09	-90

FIGURE 3
VESSEL RESPONSE OPERATOR*

NOTE: Negative phase angles are for peak vessel surge after the wave crest.

* Sexton, R.M. and Agbezuge, L.K. (1979), Random Wave and Vessel Motion Effects on Drilling Riser Dynamics, Offshore Technology Conference, Paper No. OTC-2650.

SECTION 2 RESULTS

General

2.1 The computer programs used to obtain the results described here were developed by different organizations, using varying modeling and mathematical techniques. The programs are all based on the concept of a laterally loaded vertical beam with axial tension varying over its length. Some programs simulate static or steady state conditions only while others simulate dynamic or time-varying effects. The dynamic programs use either frequency or time domain solutions.

2.2 For dynamic cases with periodic waves, maximum and minimum deflection and bending stress were the parameters chosen for comparative purposes. For random waves, mean and RMS values were used. All dynamic cases compare top and bottom angles as well. For static cases, maximum bending stress, maximum total stress, and top and bottom riser angles were chosen. The premise was that agreement among these parameters would indicate the degree of similarity of the various solutions.

Static Analyses

2.3 Fourteen participants submitted solutions to the static cases. Since the general character of the deflection and stress profiles were basically similar for all solutions, results are conveniently presented in tabular form in Table 4.

2.4 Table 4 provides a statistical analysis of maximum bending stress, maximum total stress, and angles at the lower ball joint and the top of the riser. The statistical parameters are defined in Appendix A.

Periodic Dynamic Analyses

2.5 Fourteen participants submitted solutions to the periodic dynamic cases. Unlike the static solutions, the dynamic deflection and stress profiles varied too much for a simple tabular comparison to be meaningful. Therefore, the one-standard-deviation envelopes of the computed profiles have been plotted and are presented as Figures 4 through 39. The purpose of these plots is to show what is judged to be the correct solution along with the general level of agreement among the various solutions, rather than compare specific solutions.

2.6 The envelopes plotted bracket the parameter (deflection or stress) through one or more wave cycles. For example, in case 500-20-1-D, the top deflection is specified as 15 feet (static) with a dynamic oscillation of four feet ($\pm$ two feet) about this static value. An examination of the deflection profile for this case (Figure 4) shows that, at the top of the riser, the deflection profiles do converge within the specified oscillation limits of ± 2 feet. Each solution consists of two envelopes which describe the left and right hand excursions of the parameter plotted.

2.7 The top and bottom riser angle extremes are tabulated in Table 5.

Random Dynamic Analyses

2.8 Six participants submitted solutions to the random dynamic cases. Profile envelopes are presented in Figures 40 through 51. Note, as pointed out in Section 1, that mean and RMS values have been substituted for the minimum and maximum values used in the periodic dynamic runs.

2.9 The top and bottom riser angle results are tabulated in Table 5.

TABLE 4
RESULTS — STATIC ANALYSES

CASE	MAX BENDING STRESS		MAX TOTAL STRESS		ANGLE FROM VERTICAL	
	VALUE	LOC	VALUE	LOC	LBJ	TOP
500-A-1-S (10)						
MEAN	2.05	127.40	5.69	444.90	2.51	1.00
STANDARD DEVIATION	0.09	6.22	0.15	27.22	0.03	0.04
COEF. OF VARIATION%	4.53	4.88	2.61	6.12	1.24	3.62
RANGE	0.36	21.00	0.52	90.00	0.10	0.12
500-A-2-S (11)						
MEAN	1.14	126.27	7.75	470.91	2.17	1.22
STANDARD DEVIATION	0.05	6.99	0.08	19.62	0.02	0.02
COEF. OF VARIATION%	4.77	5.53	1.02	4.17	0.71	1.45
RANGE	0.23	26.00	0.31	75.00	0.04	0.06
500-B-FREE-S (5)						
MEAN	1.59	391.20	7.19	413.20	-0.03	-1.04
STANDARD DEVIATION	0.03	14.04	0.08	21.53	0.02	0.03
COEF. OF VARIATION%	1.63	3.59	1.16	5.21	-55.90	-3.12
RANGE	0.07	34.00	0.22	54.00	0.04	0.09
500-B-1-S (9)						
MEAN	3.59	168.00	7.53	369.67	3.28	0.19
STANDARD DEVIATION	0.09	9.68	0.08	14.14	0.05	0.03
COEF. OF VARIATION%	2.44	5.76	1.01	3.83	1.42	17.15
RANGE	0.31	26.00	0.27	42.00	0.17	0.11
500-B-2-S (10)						
MEAN	2.17	352.80	8.92	420.00	2.62	0.67
STANDARD DEVIATION	0.06	38.23	0.14	13.94	0.02	0.02
COEF. OF VARIATION%	2.75	10.84	1.62	3.32	0.64	2.97
RANGE	0.18	132.00	0.50	44.00	0.06	0.07
1500-A-1-S (13)						
MEAN	3.91	122.45	11.49	1504.65	4.57	0.64
STANDARD DEVIATION	0.18	8.46	0.05	14.49	0.07	0.01
COEF. OF VARIATION%	4.58	6.91	0.47	0.96	1.64	1.45
RANGE	0.76	36.00	0.22	50.10	0.31	0.04

TABLE 4 (Continued)
RESULTS — STATIC ANALYSES

CASE	MAX BENDING STRESS		MAX TOTAL STRESS		ANGLE FROM VERTICAL	
	VALUE	LOC	VALUE	LOC	LBJ	TOP
1500-A-2-S (13)						
MEAN	0.71	118.15	18.66	1499.88	2.52	1.14
STANDARD DEVIATION	0.09	10.65	0.09	12.36	0.01	0.01
COEF. OF VARIATION%	12.46	9.01	0.51	0.82	0.51	0.49
RANGE	0.34	47.00	0.37	50.10	0.05	0.02
1500-B-FREE-S (10)						
MEAN	0.98	1342.60	11.04	1429.94	-0.02	-1.91
STANDARD DEVIATION	0.06	20.05	0.98	18.59	0.01	0.07
COEF. OF VARIATION%	5.66	1.49	8.89	1.30	-57.52	-3.64
RANGE	0.22	63.00	3.30	73.40	0.03	0.28
1500-B-1-S (12)						
MEAN	6.04	125.12	11.93	1430.87	6.63	-0.77
STANDARD DEVIATION	0.28	8.12	0.21	30.19	0.12	0.03
COEF. OF VARIATION%	4.64	6.49	1.72	2.11	1.75	-4.15
RANGE	1.21	32.00	0.62	123.50	0.45	0.12
1500-B-2-S (11)						
MEAN	1.00	121.35	18.95	1449.26	3.12	0.36
STANDARD DEVIATION	0.09	6.43	0.19	13.97	0.02	0.01
COEF. OF VARIATION%	9.23	5.30	1.02	0.96	0.58	4.09
RANGE	0.35	20.00	0.78	37.30	0.08	0.06
3000-A-1-S (9)						
MEAN	1.03	150.70	15.49	3021.67	3.45	0.80
STANDARD DEVIATION	0.09	18.35	0.08	36.74	0.06	0.02
COEF. OF VARIATION%	8.98	12.18	0.53	1.22	1.71	2.77
RANGE	0.31	50.80	0.24	140.00	0.21	0.08
3000-A-2-S (8)						
MEAN	0.44	140.72	20.15	3028.13	2.64	1.06
STANDARD DEVIATION	0.03	26.06	0.11	33.37	0.03	0.03
COEF. OF VARIATION%	6.07	18.52	0.55	1.10	1.10	2.47
RANGE	0.09	68.80	0.32	100.00	0.09	0.07

