Figure 2.2.E	General Description of Caisson N2
Figure 2.2.F	General Description of Caisson N3
Figure 2.2.G	General Description of Caisson Y1
Figure 2.2.H	General Description of Caisson Y2
Figure 2.2.I	General Description of Caisson Y3
Figure 3.1.A	Analysis Models
Figure 3.1.B	Element from a Beam Subjected to Pure Bending
Figure 3.1.C	Interpretation of Ultimate Strength for Fabricated Steel Cylinder Under Bending
Figure 3.1.D(a)	Assumed Elastic-Plastic Behavior of Steel
Figure 3.1.D(b)	Behavior of a Cylindrical Section in Bending
Figure 3.1.E	Behavior of a Cylindrical Section in Bending With Axial Load
Figure 3.1.F	Comparison of Moment Profiles
Figure 3.1.G	Computation of Residual Lean Angle
Figure 3.1.H	Lean at Mudline vs Load Factor
Figure 3.3.A	Residual Lean Angle vs Water Depth
Figure 3.3.B	Residual Lean Angle vs Water Depth
Figure 3.3.C	Residual Lean Angle vs Water Depth
Figure 3.3.D	Residual Lean Angle vs Water Depth
Figure 3.3.E	Residual Lean Angle vs Pile Diameter
Figure 3.3.F	Residual Lean Angle vs Pile Diameter

1.0 Introduction

On August 24, and 25, 1992 Hurricane Andrew passed through a region of the Gulf of Mexico that is densely populated with oil and gas structures. While most of these structures survived with minor or no damage, several structures were severely damaged or collapsed.

According to data gathered by the Mineral Management Service, MMS, about 100 caisson structures were tilted to various degrees during the passage of Hurricane Andrew. The MMS selected Barnett and Casbarian Inc.(BCI) to perform a study to develop an acceptance criteria for those caisson structures tilted by a storm and to develop guidelines for repair of those structures which do not meet the acceptance criteria. This report provides the results of that study.

1.1 Executive Summary

BCI's work scope included the following tasks: 1) data gathering and assimilation, 2) development of an acceptance criteria, and 3) damage assessment and repair guidelines. The primary concern of this study evolved to be the establishment of an acceptance criteria by which caissons which have been exposed to extreme environmental condition may be judged to be acceptable for future operations without any remediation.

A typical caisson structure has an outer caisson which is usually driven 100 to 300 feet into the seabed and has a series of inner production casings. The structural response is dominated by the outer caisson compared to all of the internal casings; thus, unless otherwise noted, caisson will refer to the outer tubular member of the caisson structure.

The data gathering stage was aided by the staff of the MMS in Metairie and resulted in obtaining data on damaged and undamaged caissons from three of the operating companies whose structures where within the path of Hurricane Andrew.

An extreme wave response analysis was performed using data for nine actual caisson structures provided by the operating companies and was performed on several idealized or equivalent caisson structures. The study of the equivalent structures was for various water depths, soil conditions, caisson size and penetration depths. Shown in Figure 1.1.A(a) is the conceptual plot of environmental load versus residual lean angle. As shown in part (b) of the figure, the lean angle may be due to straining of the steel caisson, the failure of the soil, or a combination of both.

The acceptance criteria focuses on structural integrity of the outer member or caisson structure rather than the inner casings and well strings. Except for the condition where massive soil failure occurs, unacceptable strain occurs in the caisson before it occurs in the casings. For the yielding caisson, the fundamental acceptance criteria assumed for this study is that the strain in the caisson be less than that which causes local buckling. An environmentally loaded caisson which is strained less than buckling should be capable of withstanding significant additional environmental loadings.

Based on the analyses of the actual caissons reported herein, the allowable residual lean of a caisson structure ranges from 1 to 6 degrees, depending of the specific design details of the caisson and the soil condition. We believe the analytical tools available to us to perform the analyses and the assumptions utilized, provide conservative results. Since our results could not be calibrated against actual field tests, we recommend that an allowable residual lean of 3 degrees is acceptable. A greater value will require a Level III (Reference 1) type underwater inspection and detailed calculations to show that a greater angle of lean is acceptable.

As revealed in the analysis of equivalent caissons, short, very thick walled caissons may have sufficient strength to not yield before massive soil failure. For this type of failure the operations of the well system is the constraining factor. Those constraints were not addressed in this report.

1.2 Report Layout

The major sections of the report include; 1) data gathering, 2) extreme wave response, 3) acceptance criteria and 4) damage assessment). The figures and tables associated with each section following the text of the section.

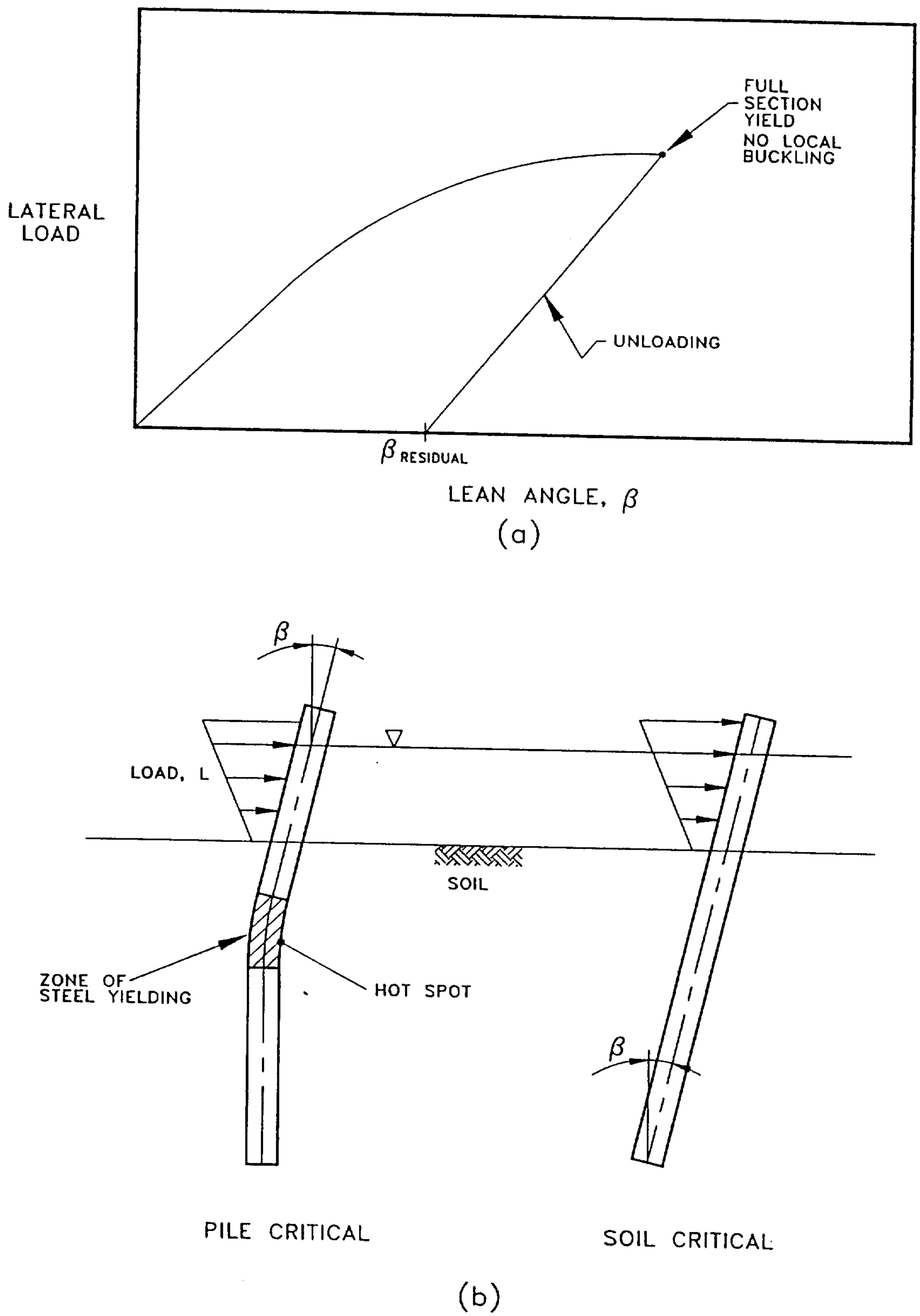


Figure 1.1.A
Overview Of Caisson Failure

\MMS\1-1A 1=1 MW 6/28/94

2.0 Data Gathering

2.1 Structures Within Hurricane Andrew Path

The data in Table 2.1.A is based on data provided by the Minerals Management Service(Ref. 1). It is not intended to be comprehensive, but does indicate the types of caissons that were damaged and the types of damage that were observed. The critical observation from these data was that lean greater than 15 degrees was measured for several of the caissons after Hurricane Andrew.

In order to gain an insight into the impact of Hurricane Andrew on the population of caisson structures, Barnett and Casbarian Inc.'s data base on platforms was interrogated for the resulting data shown in Table 2.1.B. Table 2.1.B lists all minimum structures within a fifty mile distance from the path (Ref. 2) of Hurricane Andrew. (This data base was developed from information obtained from the MMS). Unfortunately, it was not possible to distinguish between single caissons and other minimal structures. The constraints listed at the first of Table 2.1.B were used in the extraction of the caissons and the minimal structures from the structures data base.

The values from Table 2.1.B are used to generate the data shown in Figure 2.1.A. That figure is a plot of minimal structures versus distance from the path. The most significant observation from this plot is that about 40% of the minimal structures within 10 miles of the path were damaged. The fact that many structures in the hurricane path were undamaged indicates that the response of caisson structures is highly variable.

2.2 Structures Selected for Detailed Evaluation

Three operators were requested to supply information on some of their caisson structures which were within the Hurricane Andrew path. Data on both damaged and undamaged structures were received. As the intent of this study was to address structures which are representative of a larger population, the caisson structures listed in Table 2.2.A were selected for analysis. Table 2.2.A lists the general dimensions of the caisson as well as the hurricane damage. In Table 2.2.B are listed the configuration of the inner casings. Some of the data was unavailable. However, it is assumed from the data shown that none of the caissons are grouted to the first inner casing and that only the L1, L2 and L3 structures may have loading on the caisson from the inner casings. In order to make some assessment of the impact of potential loading of the inner casings on the caisson behavior, Ref. 9 was used to obtain the estimate (650 kips) shown in Table 2.2.B. In later reporting of results the caisson evaluations without casing loading are labeled L1, L2 and L3; and the results with loading are labeled as L1*, L2* and L3*.

In Figures 2.2.A-I are the data for each of the nine caissons. Shown are the configuration, the deck loading, the wave load profile, and the soil description that was used for the each of the analyses presented in Section 3.

TABLE 2.1.A
WELL STRUCTURES DAMAGED BY HURRICANE ANDREW
Type
C - Caisson, Damaged
J - Minimal Structure, Damaged
- Undamaged

	Type	Area	Block	W.D. ft	Structure Name	Installed Year	Distance to Path, Miles	Damage Description	Operator
1	J	PL	0019	30	WG#14	81	11	Leaning 25°	Murphy
2	J	PL	0020	29	WG#13	67	11	0° to 1° Lean	Murphy
3	J	SS	0093	25	WG#12	77	4	Leaning 30°	Murphy
4	J	SS	0093	32	#53	87	4	Toppled	Murphy
5	J	SS	0108	20	SAT#10	61	7	Leaning 5°	Chevron
6	J	SS	0112	47	#5	86	0	Leaning 6°	Murphy
7	J	SS	0114	46	#50	84	2	Toppled	Murphy
8	J	SS	0114	50	#57	86	2	Toppled	Murphy
9	J	SS	0114	51	#60	85	3	Leaning 80°	Murphy
10	J	SS	0114	53	#61	86	3	Leaning 10°	Murphy
11	J	SS	0117	53	#3	82	2	Leaning 20°	Murphy
12	J	SS	0119	43	WG#5	73	2	Leaning 2.5°	Murphy
13	J	SS	0134	60	20	85	8	Toppled	Murphy
14	J	SS	0136	56	#1	83	4	Leaning 30°	Murphy
15	J	ST	0086	110	#20	83	22	Toppled	Odeco
16	J	ST	143	?	A1,A2,A3	?	1?	Toppled	Hall-Hous
17	J	ST	144	?	A1,A2	?	1?	Toppled	Hall-Hous
18	C	PL	0009	40	WG#4	80	15	Leaning 5°	Mobil
19	C	PL	0009	40	9	85	14	Toppled	Mobil
20	C	PL	0010	35	#18	87	12	Toppled	Mobil
21	C	PL	0010	40	17	84	13	Leaning 12°	Mobil
22	C	PL	0011	37	#22	84	13	Leaning 2°	Mobil
23	C	PL	0012	25	#12, 15	64	12	Toppled	Murphy
24	C	PL	0012	25	#18	85	14	Leaning 2°	Murphy
25	C	PL	0012	26	WG#7	63	12	Toppled	Murphy
26	C	PL	0012	28	#43	87	12	Leaning 7°	Murphy
27	C	PL	0012	36	#23	78	13	Leaning 3°	Murphy
28	C	PL	0019	28	WG#37	81	12	Leaning 4°	Murphy
29	C	PL	0019	30	#33,39,42	81	11	Leaning 8°	Murphy
30	C	PL	0019	30	#35	81	12	Leaning 5°	Murphy
31	C	PL	0019	32	#44	85	11	Leaning 5°	Murphy
32	C	PL	0019	?	48	?	11?	Leaning 20°	Murphy
33	C	PL	0020	28	WG#15&27	68	11	Leaning 15°-27°	Murphy
34	C	PL	0020	28	38	85	11	Leaning 3°	Murphy
35	C	PL	0020	29	#33	85	11	Leaning 7°	Murphy
36	C	PL	0020	30	#28&29	81	11	Leaning 7°	Murphy
37	C	PL	0020	30	#36	85	11	Leaning 5°	Murphy
38	C	PL	0020	30	#32	85	11	Leaning 4°	Murphy
39	C	PL	0020	30	#35	86	11	Leaning 2°	Murphy
40	C	PL	0020	30	40,42,46	86	11	Leaning 9°	Murphy
41	C	PL	0020	30	39	87	11	Leaning 5°	Murphy
42	C	PL	0020	32	WG 8 &25	63	11	Toppled	Murphy
43	C	SS	0069	30	#8	84	10	Leaning 10°	Chevron
44	C	SS	0090	33	#2	86	6	Leaning 2°	Murphy
45	C	SS	0090	?	56	?	9?	Leaning 10°	Murphy
46	C	SS	0092	24	#3 & #5	90	8	Leaning 3°	Murphy
47	C	SS	0092	?	7	?	8?	Leaning 25°	Murphy
48	C	SS	0092	?	8	?	8?	Leaning 2°	Murphy
49	C	SS	0093	20	#49	88	6	Leaning 1°	Murphy
50	C	SS	0093	25	33	78	5	Leaning 4°	Murphy
51	C	SS	0093	25	#32	78	5	Leaning 5°	Murphy
52	C	SS	0093	25	#38	83	6	Leaning 3°	Murphy

TABLE 2.1.A

WELL STRUCTURES DAMAGED BY HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

	Type	Area	Block	W.D. ft	Structure Name	Installed Year	Distance to Path, Miles	Damage Description	Operator
53	C	SS	0093	28	47	85	6	Leaning 3°	Murphy
54	C	SS	0093	28	0	89	5	Leaning 3°	Murphy
55	C	SS	0093	28	#45 CAISSON	90	6	Leaning 1°	Murphy
56	C	SS	0093	30	#37	84	4	Leaning 5°	Murphy
57	C	SS	0093	45	#39	82	5	Leaning 4°	Murphy
58	C	SS	0094	22	#23 or S	87	4	Leaning 4°	Murphy
59	C	SS	0094	30	19	81	4	Leaning 4°	Murphy
60	C	SS	0094	32	#17	79	3	Leaning 4°	Murphy
61	C	SS	0094	50	WG#20	79	4	Leaning 4°	Murphy
62	C	SS	0099	21	#2	61	7	Broken at Mudline	Chevron
63	C	SS	0112	48	S(S1&S2)	86	0	Leaning 5°	Murphy
64	C	SS	0112	48	#6	87	0	Leaning 5°	Murphy
65	C	SS	0112	?	4&7	?	1?	Leaning 5°	Murphy
66	C	SS	0113	39	WG#19	67	3	Toppled	Murphy
67	C	SS	0113	40	WG #35	80	3	Leaning 15°	Murphy
68	C	SS	0113	41	WG#41	85	2	Leaning 10°	Murphy
69	C	SS	0113	45	45	90	1	Toppled	Murphy
70	C	SS	0113	46	#40	84	2	Leaning 10°	Murphy
71	C	SS	0113	47	#47 - 49	89	1	Leaning 48°	Murphy
72	C	SS	0113	47	48	89	1	Toppled	Murphy
73	C	SS	0113	?	51	?	3?	Leaning 15°	Murphy
74	C	SS	0113	?	52	?	3?	Leaning 5°	Murphy
75	C	SS	0113	49	29,32	78	2	Leaning 2.5°	Murphy
76	C	SS	0113	50	#46	86	2	Toppled	Murphy
77	C	SS	0114	40	#55	81	2	Leaning 45°	Murphy
78	C	SS	0114	40	WG#43	81	4	Leaning 45°	Murphy
79	C	SS	0114	41	WG #41	80	3	Leaning 30°	Murphy
80	C	SS	0114	50	WG38	76	3	Toppled	Murphy
81	C	SS	0114	50	WG#39&9	79	2	Leaning 5°	Murphy
82	C	SS	0114	?	1	?	4?	Toppled	Murphy
83	C	SS	0114	?	36	?	4?	Toppled	Murphy
84	C	SS	0114	50	#51	82	3	Leaning 30°	Murphy
85	C	SS	0114	50	#46	83	2	Leaning 35°	Murphy
86	C	SS	0114	51	#12 WELL	67	2	Leaning 15°	Murphy
87	C	SS	0114	52	#9	65	2	Toppled	Murphy
88	C	SS	0114	55	#47	82	2	Leaning 4°	Murphy
89	C	SS	0117	50	#2	81	2	Leaning 30°	Murphy
90	C	SS	0117	55	#5&#6	89	2	Leaning 10°	Murphy
91	C	SS	0117	55	#7	90	1	Leaning 45°	Murphy
92	C	SS	0118	50	NO.3	79	0	Leaning 5°	Murphy
93	C	SS	0118	50	WG #4	79	0	Leaning 10°	Murphy
94	C	SS	0118	?	9	?	1?	Toppled	Murphy
95	C	SS	0119	45	14	82	2	Leaning 10°	Murphy
96	C	SS	0119	47	#9	82	2	Leaning 5°	Murphy
97	C	SS	0119	48	#21	86	3	Leaning 10°	Murphy
98	C	SS	0119	50	WG#15	76	2	Leaning 3°	Murphy
99	C	SS	0120	35	3	84	6	Leaning 5°	Murphy
100	C	SS	0120	35	WG#2	83	5	Leaning 5°	Murphy
101	C	SS	0120	40	NO.4	79	4	Leaning 2°	Murphy
102	C	SS	0120	40	4	83	4	Leaning 20°	Murphy
103	C	SS	0120	40	#1	83	4	Leaning 5°	Murphy
104	C	SS	0120	41	NO.5	79	3	Leaning 2°	Murphy
105	C	SS	0120	42	#3	78	3	Leaning 5°	Murphy
106	C	SS	0120	42	#13	87	3	Leaning 15°	Murphy

TABLE 2.1.A
WELL STRUCTURES DAMAGED BY HURRICANE ANDREW
Type
C - Caisson, Damaged
J - Minimal Structure, Damaged
- Undamaged

	Type	Area	Block	W.D. ft	Structure Name	Installed Year	Distance to Path, Miles	Damage Description	Operator
107	C	SS	0120	47	#5	84	5	Leaning 2°	Murphy
108	C	SS	0134	43	1	83	9	Leaning 5°	Murphy
109	C	SS	0134	43	3	83	7	Leaning 5°	Murphy
110	C	SS	0134	43	4	83	9	Leaning 5°	Murphy
111	C	SS	0134	44	6	83	8	Leaning 3°	Murphy
112	C	SS	0134	45	2	83	8	Leaning 5°	Murphy
113	C	SS	0134	45	5	83	7	Leaning 5°	Murphy
114	C	SS	0134	45	9	84	8	Leaning 5°	Murphy
115	C	SS	0134	45	#8	84	7	Leaning 5°	Murphy
116	C	SS	0134	45	#10	84	9	Leaning 5°	Murphy
117	C	SS	0134	60	#7	83	8	Leaning 45°	Murphy
118	C	SS	0134	60	#11	84	9	Leaning 5°	Murphy
119	C	SS	0134	60	#12	84	9	Leaning 5°	Murphy
120	C	SS	0134	60	#13	84	8	Leaning 5°	Murphy
121	C	SS	0134	60	#14	84	7	Leaning 5°	Murphy
122	C	SS	0134	?	#15	?	7?	Leaning 5°	Murphy
123	C	SS	0134	?	#17	?	7?	Leaning 5°	Murphy
124	C	SS	0134	60	#18	84	9	Leaning 5°	Murphy
125	C	SS	0134	60	16	84	8	Leaning 5°	Murphy
126	C	SS	0135	44	#10	83	7	Leaning 10°	Murphy
127	C	SS	0135	45	#5	82	6	Leaning 5°	Murphy
128	C	SS	0135	45	#4	83	7	Leaning 5°	Murphy
129	C	SS	0135	46	6	83	7	Leaning 5°	Murphy
130	C	SS	0135	50	#3	82	5	Leaning 5°	Murphy
131	C	SS	0135	55	#12	83	6	Leaning 5°	Murphy
132	C	SS	0135	55	#13	84	8	Leaning 5°	Murphy
133	C	SS	0135	65	7	83	6	Leaning 3°	Murphy
134	C	SS	0135	113	WG#8	83	6	Leaning 5°	Murphy
135	C	SS	0136	50	#2	87	4	Leaning 20°	Murphy
136	C	SS	0136	50	3	87	6	Toppled	Murphy
137	C	SS	0166	60	#2	84	8	Leaning 20°	Murphy
138	C	SS	0166	60	#1	85	9	Leaning 12°	Murphy
139	C	SS	0166	?	#3	?	9?	Leaning 2°	Murphy
140	C	SS	0167	50	#8 PLATFORM	90	10	Leaning 8°	Murphy
141	C	SS	0167	80	#5	70	10	Leaning 7°	Murphy
142	C	SS	0167	80	#7	78	10	Leaning 7°	Murphy
143	C	SS	0167	?	#9	?	10?	Leaning 35°	Murphy
144	C	ST	0052	60	12,14,15	77	17	Severed 5' above Mud Line	Chevron
145	C	ST	0086	92	12	84	23	Toppled	Odeco

128 Number of Caissons Damaged
17 Number of Minimal Structures Damaged

145 Total Number of Structures

MMS Caisson Study
Well Structures Within 50 Miles of Hurricane Andrew
Data Base Construction

Data Base from Minerals Management Services, MMS

The filters listed below were used to obtain the final print output:

All data base structures were included between State Plane Coordinates:
X=1,780,205 and X=2,428,144

Structures with heliports were excluded

Structures with living quarters were excluded

Structures with production equipment were excluded

Structures with power generation were excluded

Structures with gas compression were excluded

Structures with storage tanks were excluded

Major structures were excluded

Structures with more than 3 well slots were excluded

Structures with water depths more than 150' were excluded

Structures more than 50 miles from the storm track were excluded

Structures that were listed as being removed were excluded

Table 2.1.B

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
1		BM	0002	40	28	69	40		Chevron
2		BM	0002	45	#42	73	41		Chevron
3		BM	0002	47	1366 #43	73	40		Chevron
4		BM	0002	50	9	61	40		Chevron
5		BM	0002	50	50	84	40		Chevron
6		BM	0003	30	#12	71	39		Chevron
7		BM	0003	42	#28	84	40		Chevron
8		EI	0010	9	4	82	4		Amerada Hess
9		EI	0024	13	7	82	5		Murphy
10		EI	0026	17	5	88	9		Texaco Inc.
11		EI	0026	20	2	80	11		Murphy
12		EI	0026	20	4	86	10		Texaco Inc.
13		EI	0026	20	#6	89	10		Texaco Inc.
14		EI	0026	20	8	90	10		Texaco Inc.
15		EI	0028	12	#2 CAISSON	88	6		Kerr-McGee
16		EI	0032	12	6	64	1		Union Oil
17		EI	0032	12	19	69	1		Union Oil
18		EI	0032	12	8	64	2		Union Oil
19		EI	0032	12	18	65	1		Union Oil
20		EI	0032	12	16	64	2		Union Oil
21		EI	0032	12	17	65	1		Union Oil
22		EI	0032	12	11	57	2		Union Oil
23		EI	0032	12	9	65	2		Union Oil
24		EI	0032	12	20	72	2		Union Oil
25		EI	0032	12	10	65	1		Union Oil
26		EI	0032	12	15	64	2		Union Oil
27		EI	0032	12	5	59	2		Union Oil
28		EI	0032	14	NO. 14	58	1		Union Oil
29		EI	0033	10	1	83	3		Cockrell Oil
30		EI	0033	10	2	86	3		Cockrell Oil
31		EI	0033	10	3 CAISSON	88	3		Cockrell Oil
32		EI	0038	10	1	75	4		Marathon
33		EI	0038	10	2 & 5	76	5		Marathon
34		EI	0038	10	6	76	4		Marathon
35		EI	0038	10	10	78	3		Marathon
36		EI	0038	10	12	78	4		Marathon
37		EI	0038	10	14	78	3		Marathon
38		EI	0038	11	3	76	3		Marathon
39		EI	0041	15	1	83	2		Chevron
40		EI	0042	14	4	83	3		Pennzoil
41		EI	0042	15	6	84	2		Pennzoil
42		EI	0044	21	4	84	6		General Atlantic Resources
43		EI	0045	21	5	85	9		Seagull Energy
44		EI	0045	22	#8	89	9		Seagull Energy
45		EI	0047	21	11	87	10		Murphy
46		EI	0047	23	8	81	11		Murphy
47		EI	0047	23	9	81	11		Murphy
48		EI	0051	20	1	61	8		Mobil
49		EI	0051	21	2	61	8		Mobil
50		EI	0051	22	4	63	8		Mobil
51		EI	0052	25	4	81	5		Pennzoil
52		EI	0052	25	5	82	6		Pennzoil
53		EI	0053	21	2	59	6		Pennzoil

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
54		EI	0053	21	#6	86	4		Pennzoil
55		EI	0056	9	1	82	1		Marathon
56		EI	0056	11	#2	89	2		Marathon
57		EI	0056	11	#3	90	2		Marathon
58		EI	0057	10	1	74	4		Marathon
59		EI	0057	10	2	74	4		Marathon
60		EI	0057	12	4	75	2		Marathon
61		EI	0057	12	6	76	3		Marathon
62		EI	0057	14	3	75	3		Marathon
63		EI	0057	29	12	82	3		Marathon
64		EI	0058	10	1	76	4		Marathon
65		EI	0058	12	2	76	4		Marathon
66		EI	0062	25	3	83	4		Hunt Oil
67		EI	0062	25	4	83	4		Hunt Oil
68		EI	0063	22	2	79	6		Hunt Oil
69		EI	0063	22	5	83	6		Hunt Oil
70		EI	0064	22	4	73	7		Chevron
71		EI	0064	25	1	71	8		Chevron
72		EI	0074	18	3	72	11		Chevron
73		EI	0074	18	#4 & #5	72	11		Chevron
74		EI	0076	22	4	85	7		Hunt Oil
75		EI	0076	28	1	84	6		Hunt Oil
76		EI	0076	28	2	84	6		Hunt Oil
77		EI	0077	22	4	80	5		Hunt Oil
78		EI	0077	22	9	83	7		Hunt Oil
79		EI	0077	22	10	84	5		Hunt Oil
80		EI	0077	23	5	81	5		Hunt Oil
81		EI	0077	25	2 A	56	5		Hunt Oil
82		EI	0077	25	6	83	5		Hunt Oil
83		EI	0089	30	11	67	16		Gulfstream Resources
84		EI	0089	30	19	83	18		Gulfstream Resources
85		EI	0090	22	9	70	19		Gulfstream Resources
86		EI	0090	22	0228-10	82	19		Gulfstream Resources
87		EI	0090	22	11	83	18		Gulfstream Resources
88		EI	0093	20	8	68	19		Gulfstream Resources
89		EI	0093	22	2	59	19		Gulfstream Resources
90		EI	0093	23	9	82	19		Gulfstream Resources
91		EI	0093	25	11	83	19		Gulfstream Resources
92		EI	0093	25	12	84	19		Gulfstream Resources
93		EI	0094	33	1	84	20		Gulfstream Resources
94		EI	0095	17	3	67	17		Gulfstream Resources
95		EI	0095	19	5	70	17		Gulfstream Resources
96		EI	0095	19	12	71	17		Gulfstream Resources
97		EI	0095	20	9	71	17		Gulfstream Resources
98		EI	0095	22	8	71	17		Gulfstream Resources
99		EI	0097	25	#1 CAISSON	89	14		NERCO
100		EI	0100	23	JC19	61	9		Shell
101		EI	0100	23	18/30	61	9		Shell
102		EI	0100	23	JA15	61	8		Shell
103		EI	0100	23	13	60	8		Shell
104		EI	0100	23	7	60	8		Shell
105		EI	0100	23	4	60	8		Shell
106		EI	0105	24	5	61	9		Mobil
107		EI	0105	24	2	61	10		Mobil
108		EI	0105	24	F	79	10		Mobil

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
109		EI	0105	24	3	61	10		Mobil
110		EI	0107	28	4	90	15		NERCO
111		EI	0107	31	3	87	14		Atlantic Richfield
112		EI	0108	26	7	85	15		NERCO
113		EI	0108	26	9	87	15		NERCO
114		EI	0116	48	G	89	20		Mobil
115		EI	0116	50	#10	87	20		Mobil
116		EI	0116	50	#11	88	20		Mobil
117		EI	0116	50	#12	89	20		Mobil
118		EI	0119	33	13	64	13		Mobil
119		EI	0119	34	16	64	13		Mobil
120		EI	0119	35	4	62	14		Mobil
121		EI	0119	35	8	62	14		Mobil
122		EI	0119	35	15	64	13		Mobil
123		EI	0119	36	14	64	13		Mobil
124		EI	0119	36	5	62	14		Mobil
125		EI	0119	36	32	84	14		Mobil
126		EI	0119	36	#30	89	14		Mobil
127		EI	0119	37	7	62	14		Mobil
128		EI	0119	37	12	64	13		Mobil
129		EI	0119	37	26	67	14		Mobil
130		EI	0119	38	M-4	89	14		Mobil
131		EI	0119	38	11	63	13		Mobil
132		EI	0119	45	27	68	14		Mobil
133		EI	0120	36	3	66	13		Mobil
134		EI	0120	36	7	69	13		Mobil
135		EI	0120	36	11 CAISSON	88	13		Mobil
136		EI	0125	40	3 & 4	72	14		Mobil
137		EI	0125	40	#5	89	14		Mobil
138		EI	0125	41	2	60	15		Mobil
139		EI	0126	40	5	64	15		Mobil
140		EI	0126	40	7	70	15		Mobil
141		EI	0128	52	5	84	20		Mobil
142		EI	0128A	51	3	59	21		Shell
143		EI	0128A	51	4	59	21		Shell
144		EI	0128A	51	5	59	21		Shell
145		EI	0128A	56	6	59	21		Shell
146		EI	0128A	60	19	87	21		Shell
147		EI	0129	52	1	59	20		Mobil
148		EI	0159	70	#1	81	30		Amerada Hess
149		EI	0189	65	1	56	22		Shell
150		EI	0189	65	2	59	22		Shell
151		EI	0189	65	3	59	22		Shell
152		EI	0189	65	4	59	22		Shell
153		EI	0189	65	6	59	22		Shell
154		EI	0189	65	8	60	22		Shell
155		EI	0199	113	4	66	40		DelMar Operating, Inc.
156		EI	0214	107	2	76	33		Chevron
157		EI	0224	135	#2	89	45		Amoco
158		EI	0230	123	CC	76	37		Chevron
159		GI	0026	24	SAT#14	73	42		Chevron
160		GI	0026	42	SAT#1	57	43		Chevron
161		GI	0037	50	#22	69	40		Chevron
162		PL	0009	35	#7	81	14		Mobil
163	C	PL	0009	40	WG#4	80	15	Leaning 5°	Mobil

TABLE 2.1.B
WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type
C - Caisson, Damaged
J - Minimal Structure, Damaged
- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
164		PL	0009	40	WG#6	80	13		Mobil
165		PL	0009	40	8	82	15		Mobil
166	C	PL	0009	40	9	85	14	Toppled	Mobil
167		PL	0010	35	15	83	14		Mobil
168		PL	0010	35	#19	83	12		Mobil
169	C	PL	0010	35	#18	87	12	Toppled	Mobil
170		PL	0010	40	#11	80	14		Mobil
171		PL	0010	40	14	81	14		Mobil
172		PL	0010	40	2924#2	81	14		Mobil
173	C	PL	0010	40	17	84	13	Leaning 12°	Mobil
174		PL	0010	40	WG #20	88	14		Mobil
175		PL	0011	24	WG#15	69	11		Mobil
176		PL	0011	28	WG#7	66	12		Mobil
177		PL	0011	35	WG#10	67	12		Mobil
178		PL	0011	35	#24	85	12		Mobil
179	C	PL	0011	37	#22	84	13	Leaning 2°	Mobil
180		PL	0011	40	17	78	11		Mobil
181		PL	0011	40	#18	78	12		Mobil
182	C	PL	0012	25	#12, 15	64	12	Toppled	Mobil
183		PL	0012	25	#16/17	80	13		Murphy
184	C	PL	0012	25	#18	85	14	Leaning 2°	Murphy
185	C	PL	0012	26	WG#7	63	12	Toppled	Murphy
186	C	PL	0012	28	#43	87	12	Leaning 7°	Murphy
187		PL	0012	30	#25	81	13		Murphy
188		PL	0012	30	#32	84	14		Murphy
189		PL	0012	30	#19	85	14		Murphy
190		PL	0012	30	20	85	13		Murphy
191		PL	0012	32	NO.29	79	14		Murphy
192		PL	0012	32	NO.30	79	13		Murphy
193		PL	0012	32	C-1	85	14		Murphy
194		PL	0012	34	WG #28	84	13		Murphy
195		PL	0012	35	22	78	13	Leaning 2°	Murphy
196		PL	0012	35	#31	79	14		Murphy
197		PL	0012	35	#26	79	13		Murphy
198		PL	0012	35	WG #33 & #42	79	13		Murphy
199		PL	0012	35	F (35)	84	13		Murphy
200	C	PL	0012	36	#23	78	13	Leaning 3°	Murphy
201		PL	0012	36	#24-C	79	14		Murphy
202		PL	0012	36	#27	79	13		Murphy
203		PL	0012	36	37	85	14		Murphy
204		PL	0019	27	21&52	73	11		Murphy
205		PL	0019	28	#22/#38	73	11		Murphy
206		PL	0019	28	WG#6/#7	61	11		Murphy
207	C	PL	0019	28	WG#37	81	12	Leaning 4°	Murphy
208	J	PL	0019	30	WG#14	81	11	Leaning 25°	Murphy
209	C	PL	0019	30	#33,39,42	81	11	Leaning 8°	Murphy
210	C	PL	0019	30	#35	81	12	Leaning 5°	Murphy
211		PL	0019	32	25,26 WG	75	11		Murphy
212	C	PL	0019	32	#44	85	11	Leaning 5°	Murphy
213		PL	0019	45	29	80	10		Murphy
214		PL	0019	45	34	80	10		Murphy
215	C	PL	0019	117	48	?		Leaning 20°	Murphy
216	C	PL	0020	28	WG#15&27	68	11	Leaning 15°-27°	Murphy
217	C	PL	0020	28	38	85	11	Leaning 3°	Murphy
218	J	PL	0020	29	WG#13	67	11	0° to 1° Lean	Murphy

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
219		PL	0020	29	WG#9(12)	67	11		Murphy
220	C	PL	0020	29	#33	85	11	Leaning 7°	Murphy
221		PL	0020	30	WG#24	71	11		Murphy
222	C	PL	0020	30	#28&29	81	11	Leaning 7°	Murphy
223	C	PL	0020	30	#36	85	11	Leaning 5°	Murphy
224	C	PL	0020	30	#32	85	11	Leaning 4°	Murphy
225	C	PL	0020	30	#35	86	11	Leaning 2°	Murphy
226	C	PL	0020	30	40,42,46	86	11	Leaning 9°	Murphy
227	C	PL	0020	30	39	87	11	Leaning 5°	Murphy
228		PL	0020	31	WG#17	70	11		Murphy
229	C	PL	0020	32	WG 8 &25	83	11	Toppled	Murphy
230		PL	0023	61	1238#1	62	10		Stone Petroleum
231		PL	0023	61	1244#1	62	10		Stone Petroleum
232		SM	0011	62	11	66	34		Forcenergy Gas
233		SM	0011	68	29	70	34		Forcenergy Gas
234		SM	0011	68	21	67	34		Forcenergy Gas
235		SM	0011	68	17	67	33		Forcenergy Gas
236		SM	0011	68	15	67	34		Forcenergy Gas
237		SM	0011	68	14	67	33		Forcenergy Gas
238		SM	0011	68	13	67	33		Forcenergy Gas
239		SM	0011	68	24	68	34		Forcenergy Gas
240		SM	0011	68	50	86	34		Forcenergy Gas
241		SM	0011	70	16	67	34		Forcenergy Gas
242		SM	0011	70	48	72	34		Forcenergy Gas
243		SM	0011	70	1	62	34		Forcenergy Gas
244		SM	0048	100	5	87	42		Pennzoil
245		SM	0229	20	141	88	13		Texaco
246		SM	0236	14	#144	89	14		Texaco
247		SM	0236	14	#160	89	15		Texaco
248		SM	0236	14	#161	89	14		Texaco
249		SM	0236	18	128	85	14		Texaco
250		SM	0236	18	139	87	14		Texaco
251		SM	0236	18	142	88	15		Texaco
252		SM	0236	20	100	83	14		Texaco
253		SM	0236	20	101	83	13		Texaco
254		SM	0236	20	107	84	14		Texaco
255		SM	0236	20	138	88	15		Texaco
256		SM	0236	20	1	82	15		Texaco
257		SM	0238	18	133	85	10		Texaco
258		SM	0238	18	129/130	85	10		Texaco
259		SM	0238	18	137	85	10		Texaco
260		SM	0239	17	143	88	9		Texaco
261		SM	0239	18	91	85	10		Texaco
262		SM	0239	18	132	85	10		Texaco
263		SM	0241	23	301	82	13		Texaco
264		SM	0241	23	302	83	12		Texaco
265		SM	0242	20	111	84	15		Texaco
266		SM	0256	25	1	87	20		Pennzoil
267		SS	0014	10	#2	85	6		Kerr-McGee
268		SS	0014	12	WG#1	66	6		Kerr-McGee
269		SS	0026	8	WG#4	69	9		Four Star Oil & Gas
270		SS	0026	9	#9	75	9		Four Star Oil & Gas
271		SS	0026	10	10	79	9		Four Star Oil & Gas
272		SS	0026	10	NO.12	79	9		Four Star Oil & Gas
273		SS	0026	10	#13	82	9		Four Star Oil & Gas

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
274		SS	0026	10	#1	87	10		Phillips
275		SS	0027	9	#2	81	8		Kerr-McGee
276		SS	0027	15	#4	82	8		Kerr-McGee
277		SS	0028	12	#6-(I-1)	59	5		Kerr-McGee
278		SS	0028	12	WG#23	65	5		Kerr-McGee
279		SS	0028	12	WG#29	67	5		Kerr-McGee
280		SS	0028	12	#4-(G-1)	58	5		Kerr-McGee
281		SS	0028	12	WG#30	67	5		Kerr-McGee
282		SS	0028	12	#34	78	5		Kerr-McGee
283		SS	0029	12	#3-(U-1)	62	5		Kerr-McGee
284		SS	0029	12	WG#8	66	5		Kerr-McGee
285		SS	0029	13	WG#6	65	5		Kerr-McGee
286		SS	0030	18	#11 CAISSON	88	1		Kerr-McGee
287		SS	0032	15	#19	85	1		Kerr-McGee
288		SS	0032	15	#20	89	1		Kerr-McGee
289		SS	0032	18	#14	75	3		Kerr-McGee
290		SS	0032	19	1	64	1		Kerr-McGee
291		SS	0032	19	#15	75	3		Kerr-McGee
292		SS	0032	19	WG#18	77	3		Kerr-McGee
293		SS	0033	15	#8	76	2		Kerr-McGee
294		SS	0033	17	D	50	0		Kerr-McGee
295		SS	0033	19	WG #11	78	2		Kerr-McGee
296		SS	0037	9	#2	89	8		Aquila Energy
297		SS	0063	25	#21	85	7		Mobil
298		SS	0063	33	#9	82	6		Mobil
299		SS	0063	33	#10	83	7		Mobil
300		SS	0064	25	#1	82	10		Mobil
301		SS	0066	26	#5	89	11		Chevron
302		SS	0066	28	#3	85	11		Chevron
303		SS	0066	30	#1	85	10		Chevron
304		SS	0066	30	#2	85	10		Chevron
305		SS	0068	40	#1	79	11		Mobil
306		SS	0069	26	#10	85	9		Chevron
307		SS	0069	27	#4	83	11		Chevron
308		SS	0069	27	#5	84	10		Chevron
309		SS	0069	27	#7	84	10		Chevron
310		SS	0069	29	#6	84	10		Chevron
311	C	SS	0069	30	#8	84	10	Leaning 10°	Chevron
312		SS	0069	30	#9	84	10		Chevron
313		SS	0069	30	#11	85	9		Chevron
314		SS	0069	35	#13	89	10		Chevron
315		SS	0072	30	23	84	5		Mobil
316		SS	0072	32	#13	77	4		Mobil
317		SS	0072	40	#17	78	4		Mobil
318	C	SS	0090	33	#2	86	6	Leaning 2°	Murphy
319	C	SS	0090	97	56	?		Leaning 10°	Murphy
320	C	SS	0092	24	#3 & #5	90	8	Leaning 3°	Murphy
321	C	SS	0092	87	7	?		Leaning 25°	Murphy
322	C	SS	0092	87	8	?		Leaning 2°	Murphy
323		SS	0093	20	44	83	6		Murphy
324	C	SS	0093	20	#49	88	6	Leaning 1°	Murphy
325		SS	0093	22	WG#13	72	6		Murphy
326		SS	0093	22	M-1	84	6		Murphy
327		SS	0093	23	#40	83	6		Murphy
328		SS	0093	24	WG#22	72	7		Murphy

TABLE 2.1.B
WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW
Type
C - Caisson, Damaged ? - Distance uncertain
J - Minimal Structure, Damaged
- Undamaged

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
329		SS	0093	24	WG#17	72	7		Murphy
330		SS	0093	24	WG#16	72	7		Murphy
331		SS	0093	24	29	77	5		Murphy
332		SS	0093	24	#35	79	5		Murphy
333		SS	0093	25	WG18(28)	72	7		Murphy
334	C	SS	0093	25	33	78	5	Leaning 4°	Murphy
335	C	SS	0093	25	#32	78	5	Leaning 5°	Murphy
336	J	SS	0093	25	WG#12	77	4	Leaning 30°	Murphy
337	C	SS	0093	25	#38	83	6	Leaning 3°	Murphy
338		SS	0093	25	48	85	6		Murphy
339		SS	0093	26	WG#9	70	5		Murphy
340		SS	0093	28	WG#6	69	4		Murphy
341		SS	0093	28	#31	82	5		Murphy
342	C	SS	0093	28	47	85	6	Leaning 3°	Murphy
343	C	SS	0093	28	0	89	5	Leaning 3°	Murphy
344	C	SS	0093	28	#45 CAISSON	90	6	Leaning 1°	Murphy
345	C	SS	0093	30	#37	84	4	Leaning 5°	Murphy
346		SS	0093	32	#51	86	6		Murphy
347	J	SS	0093	32	#53	87	4	Toppled	Murphy
348	C	SS	0093	45	#39	82	5	Leaning 4°	Murphy
349	C	SS	0094	22	#23 or S	87	4	Leaning 4°	Murphy
350		SS	0094	29	WG#8	70	4		Murphy
351	C	SS	0094	30	19	81	4	Leaning 4°	Murphy
352	C	SS	0094	32	#17	79	3	Leaning 4°	Murphy
353	C	SS	0094	50	WG#20	79	4	Leaning 4°	Murphy
354		SS	0094	50	N	88	3		Murphy
355		SS	0098	17	#1	86	4		Murphy
356		SS	0099	20	SAT #7	76	6		Chevron
357	C	SS	0099	21	#2	61	7	Broken at Mudline	Chevron
358		SS	0100	23	#1	87	7		Chevron
359		SS	0108	20	SAT#22	62	7		Chevron
360		SS	0108	20	SAT#27	63	7		Chevron
361		SS	0108	20	SAT#34	65	7		Chevron
362		SS	0108	20	SAT#9	61	7		Chevron
363		SS	0108	20	SAT#20	62	7		Chevron
364	J	SS	0108	20	SAT#10	61	7	Leaning 5°	Chevron
365		SS	0108	20	SAT #12	61	7		Chevron
366		SS	0108	20	SAT#15	61	7		Chevron
367		SS	0108	20	CB	60	7		Chevron
368		SS	0108	20	CP	86	7		Chevron
369		SS	0108	21	SAT#19	62	8		Chevron
370		SS	0108	21	SAT#23	62	8		Chevron
371		SS	0108	21	SAT#25	63	8		Chevron
372		SS	0108	21	SAT#32	64	7		Chevron
373		SS	0108	21	SAT #39	69	7		Chevron
374		SS	0108	22	SAT#16	61	7		Chevron
375		SS	0108	22	SAT#21	62	8		Chevron
376		SS	0108	22	SAT#28	63	8		Chevron
377		SS	0108	22	SAT#31	64	7		Chevron
378		SS	0108	22	SAT#36	67	7		Chevron
379		SS	0108	25	#41	89	7		Chevron
380		SS	0108	25	#42	89	7		Chevron
381	J	SS	0112	47	#5	86	0	Leaning 6°	Chevron
382	C	SS	0112	48	S(S1&S2)	86	0	Leaning 5°	Murphy
383	C	SS	0112	48	#6	87	0	Leaning 5°	Murphy

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
384	C	SS	0112	1?	4&7	?		Leaning 5°	Murphy
385	C	SS	0113	39	WG#19	67	3	Toppled	Murphy
386	C	SS	0113	40	WG #35	80	3	Leaning 15°	Murphy
387	C	SS	0113	41	WG#41	85	2	Leaning 10°	Murphy
388	C	SS	0113	45	45	90	1	Toppled	Murphy
389	C	SS	0113	46	#40	84	2	Leaning 10°	Murphy
390	C	SS	0113	47	#47 - 49	89	1	Leaning 48°	Murphy
391	C	SS	0113	47	48	89	1	Toppled	Murphy
392	C	SS	0113	3?	51	?		Leaning 15°	Murphy
393	C	SS	0113	3?	52	?		Leaning 5°	Murphy
394		SS	0113	48	WG16(17&18)	67	2		Murphy
395	C	SS	0113	49	29,32	78	2	Leaning 2.5°	Murphy
396	C	SS	0113	50	#46	86	2	Toppled	Murphy
397	C	SS	0114	40	#55	81	2	Leaning 45°	Murphy
398	C	SS	0114	40	WG#43	81	4	Leaning 45°	Murphy
399	C	SS	0114	41	WG #41	80	3	Leaning 30°	Murphy
400		SS	0114	42	WG#11	66	4		Murphy
401	J	SS	0114	46	#50	84	2	Toppled	Murphy
402		SS	0114	47	#49	85	2		Murphy
403		SS	0114	49	WG#15	69	3		Murphy
404	C	SS	0114	50	WG38	76	3	Toppled	Murphy
405	C	SS	0114	50	WG#39&9	79	2	Leaning 5°	Murphy
406	C	SS	0114	4?	1	?		Toppled	Murphy
407	C	SS	0114	4?	36	?		Toppled	Murphy
408	C	SS	0114	50	#51	82	3	Leaning 30°	Murphy
409	C	SS	0114	50	#46	83	2	Leaning 35°	Murphy
410	J	SS	0114	50	#57	86	2	Toppled	Murphy
411	C	SS	0114	51	#12 WELL	67	2	Leaning 15°	Murphy
412	J	SS	0114	51	#60	85	3	Leaning 80°	Murphy
413	C	SS	0114	52	#9	65	2	Toppled	Murphy
414	J	SS	0114	53	#61	86	3	Leaning 10°	Murphy
415	C	SS	0114	55	#47	82	2	Leaning 4°	Murphy
416		SS	0115	50	NO.2	78	5		Mesa
417	C	SS	0117	50	#2	81	2	Leaning 30°	Murphy
418	J	SS	0117	53	#3	82	2	Leaning 20°	Murphy
419	C	SS	0117	55	#5&#6	89	2	Leaning 10°	Murphy
420	C	SS	0117	55	#7	90	1	Leaning 45°	Murphy
421	C	SS	0118	50	NO.3	79	0	Leaning 5°	Murphy
422	C	SS	0118	50	WG #4	79	0	Leaning 10°	Murphy
423		SS	0118	50	#6	80	0		Murphy
424	C	SS	0118	1?	9	?		Toppled	Murphy
425	J	SS	0119	43	WG#5	73	2	Leaning 2.5°	Murphy
426		SS	0119	45	WG-12	75	1		Murphy
427	C	SS	0119	45	14	82	2	Leaning 10°	Murphy
428	C	SS	0119	47	#9	82	2	Leaning 5°	Murphy
429	C	SS	0119	48	#21	86	3	Leaning 10°	Murphy
430	C	SS	0119	50	WG#15	76	2	Leaning 3°	Murphy
431	C	SS	0120	35	3	84	6	Leaning 5°	Murphy
432	C	SS	0120	35	WG#2	83	5	Leaning 5°	Murphy
433	C	SS	0120	40	NO.4	79	4	Leaning 2°	Murphy
434		SS	0120	40	NO.7	79	6		Murphy
435	C	SS	0120	40	4	83	4	Leaning 20°	Murphy
436	C	SS	0120	40	#1	83	4	Leaning 5°	Murphy
437	C	SS	0120	41	NO.5	79	3	Leaning 2°	Murphy
438	C	SS	0120	42	#3	78	3	Leaning 5°	Murphy

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
439	C	SS	0120	42	#13	87	3	Leaning 15°	Murphy
440	C	SS	0120	47	#5	84	5	Leaning 2°	Murphy
441		SS	0133	37	#4	85	10		W & T Offshore
442		SS	0133	40	#3	85	9		W & T Offshore
443	C	SS	0134	43	1	83	9	Leaning 5°	Murphy
444	C	SS	0134	43	3	83	7	Leaning 5°	Murphy
445	C	SS	0134	43	4	83	9	Leaning 5°	Murphy
446	C	SS	0134	44	6	83	8	Leaning 3°	Murphy
447	C	SS	0134	45	2	83	8	Leaning 5°	Murphy
448	C	SS	0134	45	5	83	7	Leaning 5°	Murphy
449	C	SS	0134	45	9	84	8	Leaning 5°	Murphy
450	C	SS	0134	45	#8	84	7	Leaning 5°	Murphy
451	C	SS	0134	45	#10	84	9	Leaning 5°	Murphy
452	C	SS	0134	60	#7	83	8	Leaning 45°	Murphy
453	C	SS	0134	60	#11	84	9	Leaning 5°	Murphy
454	C	SS	0134	60	#12	84	9	Leaning 5°	Murphy
455	C	SS	0134	60	#13	84	8	Leaning 5°	Murphy
456	C	SS	0134	60	#14	84	7	Leaning 5°	Murphy
457	C	SS	0134	7?	#15	?		Leaning 5°	Murphy
458	C	SS	0134	7?	#17	?		Leaning 5°	Murphy
459	C	SS	0134	60	#18	84	9	Leaning 5°	Murphy
460	J	SS	0134	60	20	85	8	Toppled	Murphy
461	C	SS	0134	60	16	84	8	Leaning 5°	Murphy
462	C	SS	0135	44	#10	83	7	Leaning 10°	Murphy
463	C	SS	0135	45	#5	82	6	Leaning 5°	Murphy
464	C	SS	0135	45	#4	83	7	Leaning 5°	Murphy
465	C	SS	0135	46	6	83	7	Leaning 5°	Murphy
466	C	SS	0135	50	#3	82	5	Leaning 5°	Murphy
467	C	SS	0135	55	#12	83	6	Leaning 5°	Murphy
468	C	SS	0135	55	#13	84	8	Leaning 5°	Murphy
469	C	SS	0135	65	7	83	6	Leaning 3°	Murphy
470	C	SS	0135	113	WG#8	83	6	Leaning 5°	Murphy
471	C	SS	0136	50	#2	87	4	Leaning 20°	Murphy
472	C	SS	0136	50	3	87	6	Toppled	Murphy
473	J	SS	0136	56	#1	83	4	Leaning 30°	Murphy
474		SS	0146	45	#3	85	11		Phillips
475		SS	0154	60	#22	88	19		Pennzoil
476	C	SS	0166	60	#2	84	8	Leaning 20°	Murphy
477	C	SS	0166	60	#1	85	9	Leaning 12°	Murphy
478	C	SS	0166	9?	#3	?		Leaning 2°	Murphy
479	C	SS	0167	50	#8 PLATFORM	90	10	Leaning 8°	Murphy
480	C	SS	0167	80	#5	70	10	Leaning 7°	Murphy
481	C	SS	0167	80	#7	78	10	Leaning 7°	Murphy
482	C	SS	0167	10?	#9	?		Leaning 35°	Murphy
483		SS	0169	65	WG #9	78	13		Chevron
484		SS	0176	98	#7 CAISSON	90	27		Pennzoil
485		SS	0177	92	#5	84	26		Amoco
486		SS	0177	92	#7 CAISSON	90	25		Amoco
487		SS	0181	45	C	83	18		Chevron
488		SS	0183	66	F	83	15		Chevron
489		SS	0205	107	WG#4&#5	71	24		Torch Operating
490		SS	0209	100	3	66	15		Union Oil
491		SS	0216	107	WG#4	69	20		Torch Operating
492		SS	0239	130	#4	85	23		Kerr-McGee
493		ST	0021	34	WG#78	65	35		Chevron

TABLE 2.1.B
WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type
C - Caisson, Damaged
J - Minimal Structure, Damaged
- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
494		ST	0021	35	WG#20	60	34		Chevron
495		ST	0021	35	WG#24	61	35		Chevron
496		ST	0021	36	WG#80	65	35		Chevron
497		ST	0021	36	WG#79	66	35		Chevron
498		ST	0021	36	WG-8	58	34		Chevron
499		ST	0021	36	WG#58	63	34		Chevron
500		ST	0021	36	WG#31	61	34		Chevron
501		ST	0021	37	WG#6	58	34		Chevron
502		ST	0021	37	WG#1	58	34		Chevron
503		ST	0021	37	WG#5	58	34		Chevron
504		ST	0021	38	WG#95	66	33		Chevron
505		ST	0021	38	WG#85	82	35		Chevron
506		ST	0021	38	WG#28	61	35		Chevron
507		ST	0021	38	WG#59	82	35		Chevron
508		ST	0021	39	WG#10	59	34		Chevron
509		ST	0021	39	#111	66	34		Chevron
510		ST	0021	39	WG#2	58	34		Chevron
511		ST	0021	40	WG#15	59	34		Chevron
512		ST	0021	40	WG#12	59	34		Chevron
513		ST	0021	40	WG#13	59	34		Chevron
514		ST	0021	40	WG#17	59	34		Chevron
515		ST	0021	40	WG#21	60	33		Chevron
516		ST	0021	40	WG#27	61	34		Chevron
517		ST	0021	40	WG#32	61	34		Chevron
518		ST	0021	40	#124	89	34		Chevron
519		ST	0021	43	WG#40	62	33		Chevron
520		ST	0021	43	WG#108	70	34		Chevron
521		ST	0021	44	WG#47	62	33		Chevron
522		ST	0021	45	WG#92	66	33		Chevron
523		ST	0021	45	WG#110	71	34		Chevron
524		ST	0021	45	WG#66	65	34		Chevron
525		ST	0021	46	WG#100	67	33		Chevron
526		ST	0021	46	WG#94	66	33		Chevron
527		ST	0021	46	WG#91	66	33		Chevron
528		ST	0021	46	WG#90	67	34		Chevron
529		ST	0021	46	WG#69	64	33		Chevron
530		ST	0021	46	WG#67	64	34		Chevron
531		ST	0021	46	116&51	63	33		Chevron
532		ST	0021	46	WG#54	63	34		Chevron
533		ST	0021	46	88,89,93	66	34		Chevron
534		ST	0021	47	WG#109	70	34		Chevron
535		ST	0021	47	WG#75	65	34		Chevron
536		ST	0021	47	WG#55	63	33		Chevron
537		ST	0021	48	WG#99	67	33		Chevron
538		ST	0021	48	WG#86	65	33		Chevron
539		ST	0021	48	WG82&98	67	34		Chevron
540		ST	0021	48	WG#81	65	34		Chevron
541		ST	0021	48	71,72,7	65	34		Chevron
542		ST	0021	48	WG#97	67	33		Chevron
543		ST	0021	48	WG#87	65	34		Chevron
544		ST	0021	49	WG#84	65	33		Chevron
545		ST	0021	49	WG76&77	65	33		Chevron
546		ST	0021	49	WG#63	63	33		Chevron
547		ST	0021	49	WG#68	64	33		Chevron
548		ST	0021	50	WG#101	67	33		Chevron

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
549		ST	0021	50	WG#102	67	34		Chevron
550		ST	0022	48	WG#7	73	34		Chevron
551		ST	0023	46	16	65	38		Chevron
552		ST	0023	50	9&20	64	37		Chevron
553		ST	0024	47	#20	84	40		Chevron
554		ST	0024	48	18	80	39		Chevron
555		ST	0027	48	SAT#8	66	34		Chevron
556		ST	0027	48	WG#5	66	34		Chevron
557		ST	0027	48	WG#2	66	34		Chevron
558		ST	0027	48	WG#12	66	34		Chevron
559		ST	0027	48	WG#9	66	34		Chevron
560		ST	0027	48	WG#4	66	34		Chevron
561		ST	0027	48	WG#3	66	34		Chevron
562		ST	0027	48	WG#7&#13	66	34		Chevron
563		ST	0027	48	WG#1	66	34		Chevron
564		ST	0027	49	WG#17	68	34		Chevron
565		ST	0027	50	WG#11	66	34		Chevron
566		ST	0027	50	WG#16	67	34		Chevron
567		ST	0027	51	WG-24	77	34		Chevron
568		ST	0027	57	WG#18	71	33		Chevron
569		ST	0028	50	WG#10	66	33		Chevron
570		ST	0028	50	WG#1	64	33		Chevron
571		ST	0028	50	WG#6	65	33		Chevron
572		ST	0028	50	WG#8	65	32		Chevron
573		ST	0028	50	WG#5	65	33		Chevron
574		ST	0028	50	WG#13	67	32		Chevron
575		ST	0028	50	WG#3	64	33		Chevron
576		ST	0028	50	WG#2	64	33		Chevron
577		ST	0028	50	WG#4	64	33		Chevron
578		ST	0028	50	WG#12	67	33		Chevron
579		ST	0034	50	#8	83	22		Chevron
580		ST	0034	52	#2/#3	83	21		Kerr-McGee
581		ST	0034	52	#4	83	21		Kerr-McGee
582		ST	0034	52	#6	83	20		Kerr-McGee
583		ST	0034	52	#11	89	21		Kerr-McGee
584		ST	0034	53	#9	84	20		Kerr-McGee
585		ST	0035	48	#5	87	23		Kerr-McGee
586		ST	0035	50	#3 CAISSON	88	21		Chevron
587		ST	0035	50	#6	87	22		Chevron
588		ST	0050	55	#4	80	21		Chevron
589		ST	0050	58	C	80	19		Kerr-McGee
590		ST	0050	58	#6	81	21		Kerr-McGee
591		ST	0051	58	SAT #4	67	18		Kerr-McGee
592		ST	0051	58	SAT#3	76	18		Chevron
593		ST	0051	58	#4	86	20		Chevron
594		ST	0051	58	5	87	20		Chevron
595		ST	0051	60	9&12(1240)	85	20		Chevron
596		ST	0051	60	#5,#7,#8	77	18		Chevron
597		ST	0051	60	#10&#11	84	18		Chevron
598		ST	0051	60	#23	86	19		Chevron
599		ST	0052	50	SAT.#3	72	17		Chevron
600		ST	0052	54	#20	83	17		Chevron
601		ST	0052	58	10,16,18	77	18		Chevron
602		ST	0052	60	CB	75	16		Chevron
603	C	ST	0052	60	12,14,15	77	17	Severed 5' above Mud Line	Chevron

TABLE 2.1.B

WELL STRUCTURES WITHIN 50 MILES OF HURRICANE ANDREW

Type

C - Caisson, Damaged

J - Minimal Structure, Damaged

- Undamaged

? - Distance uncertain

	Type	Area	Block	W.D. ft.	Structure Name	Installed Year	Distance to Path, miles	Damage Description	Operator
604		ST	0052	60	17	82	17		Chevron
605		ST	0052	61	#21	89	17		Chevron
606		ST	0053	60	#5	87	17		Union Oil
607		ST	0053	65	#4	83	17		Union Oil
608		ST	0063	84	WG#2	69	25		Murphy
609		ST	0063	86	WG#1	90	25		Odeco
610		ST	0063	87	WG#3	71	25		Murphy
611		ST	0063	90	WG#13	71	24		Murphy
612		ST	0063	90	WG#14	70	25		Murphy
613		ST	0063	92	#9 CAISSON	90	24		Murphy
614		ST	0067	61	WG#2	67	17		Exxon
615		ST	0072	62	#3	63	9		Gas Transportation
616	C	ST	0086	92	12	84	23	Toppled	Odeco
617		ST	0086	92	3	82	22		Odeco
618		ST	0086	100	#24	85	23		Odeco
619	J	ST	0086	110	#20	83	22	Toppled	Odeco
620	J	ST	143	1?	A1,A2,A3	?		Toppled	Hall-Hous
621	J	ST	144	1?	A1,A2	?		Toppled	Hall-Hous
622		ST	0145	90	A	88	2		Hughes Eastern Petroleum

128 Number of Damaged Caissons

17 Number of Damaged Minimal Structures

622 Total Number of Structures

TABLE 2.2.A

SUMMARY OF CHARACTERISTICS OF SELECTED ACTUAL CAISSONS

No.	I.D. No.	Water Depth ft	Diameter in	Thickness in	Yield Stress ksi	Penetration Below Mud ft	Hurricane Damage
1	L1	37.5	33	1.250	42	118.5	20 deg lean*
2	L2	36	30	1.750	42	195	Failed 30' below mudline
3	L3	34	30	1.750	42	119	11 deg lean*
4	N1	40	48	1.875	42	108	None
5	N2	17	72	0.750	42	75	None
6	N3	60	96	1.250	55	100	Severed 5' above Mudline
7	Y1	46	48	1.750	42	100	Toppled
8	Y2	53	48	2.000	42	100	15 deg. lean
9	Y3	53	72	2.250	42	130	After repair

Notes:

1. * - damage during Hurrican Camille
   Other damage during Hurricane Andrew

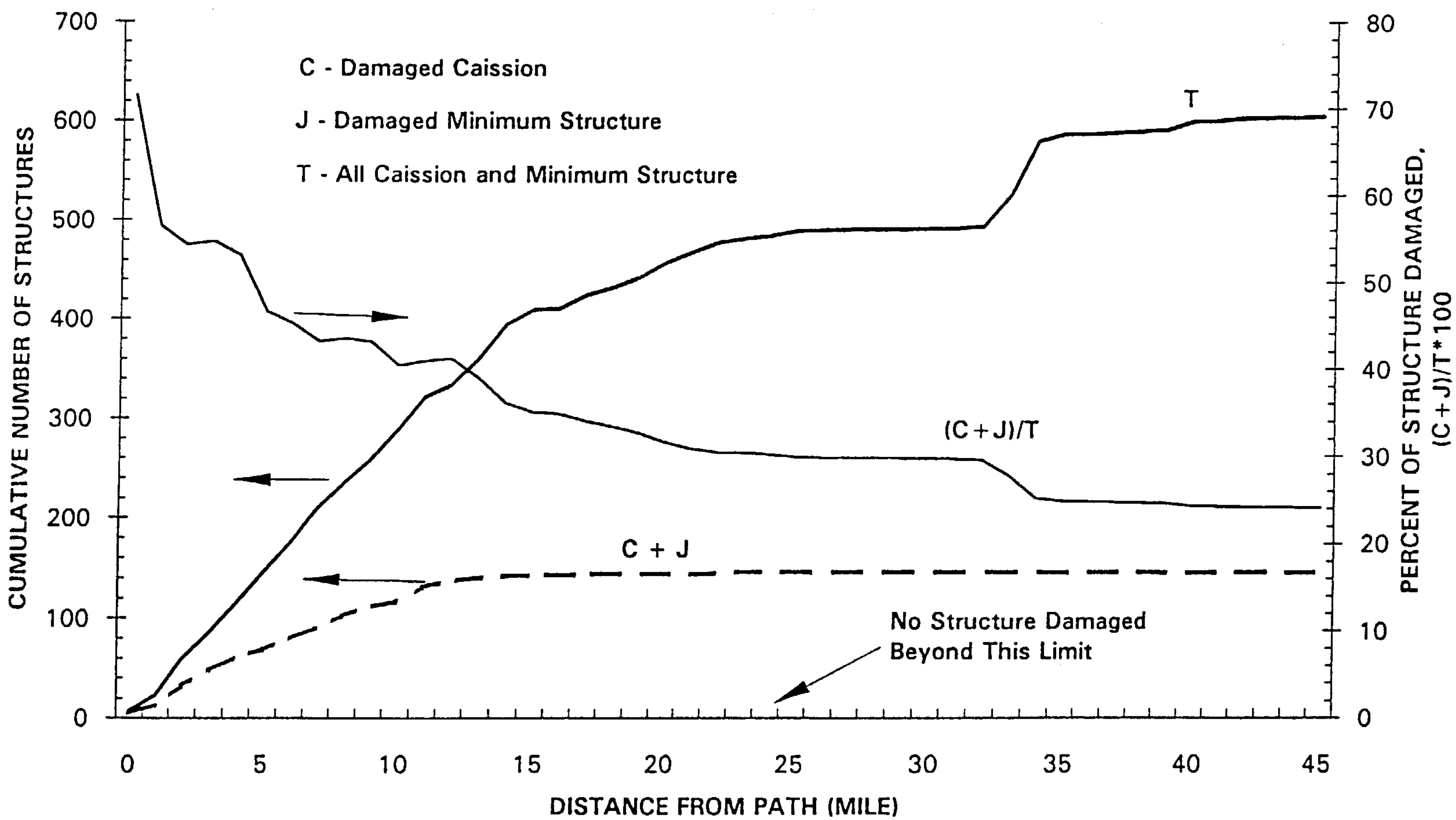
TABLE 2.2.B

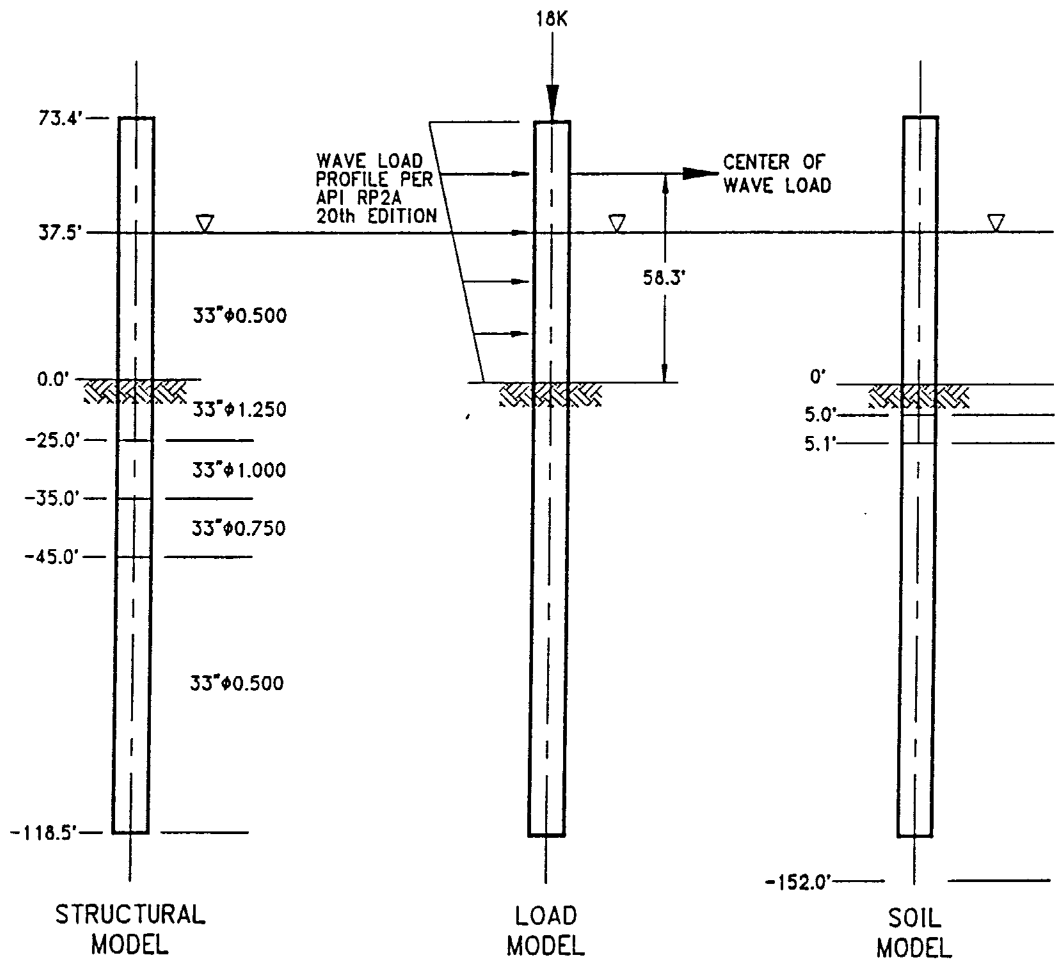
SUMMARY OF CHARACTERISTICS OF INNER CASING CHARACTERISTICS
OF SELECTED ACTUAL CAISSONS

	CAISSON I.D.	L1, L1*	L2, L2*	L3, L3*	N1	N2	N3	Y1	Y2	Y3
Casing										
No.										
0	Diameter, in	33	30	30	48	72	72	48	48	72
0/1	Grouted	@Caisson Tip Only(a)	@Caisson Tip Only(a)	@Caisson Tip Only(a)	?	No	No	No	No	No
1	Driven	No	No	No	Yes?	Yes?	Yes?	Yes	Yes	Yes
1	Diameter, in	20	20	20	?	?	?	30	30	48
1	Thickness,in	0.438	0.438	0.438	?	?	?	0.75	0.5	?
1	Length,ft	1012	1012	1012	?	?	?	328	460	150
2	Diameter, in	13.375	13.375	13.375	?	?	?	16	16	30
2	Weight, lb/ft	68	68	68	?	?	?	65	65	157
2	Length,ft	4508	4508	4508	?	?	?	695	750	328
3	Diameter, in	9.625	9.625	9.625	?	?	?	10.75	10.75	16
3	Weight, lb/ft	47	47	47	?	?	?	40	40	65
3	Length,ft	11500	11500	11500	?	?	?	4284	2000	695
4	Diameter, in							7.625	7.625	10.75
4	Weight, lb/ft							33	26	40
4	Length,ft							10761	5722	4284
	Caisson Axial Load from Casings, kip*	650 for L1* 0 for L1	650 for L2* 0 for L2	650 for L3* 0 for L3	0	0	0	0	0	0

a - Assumed to be ungrouted

FIGURE 2.1.A
DAMAGED CAISSIONS AND MINIMUM STRUCTURES
vs.
DISTANCE FROM PATH OF HURRICANE ANDREW



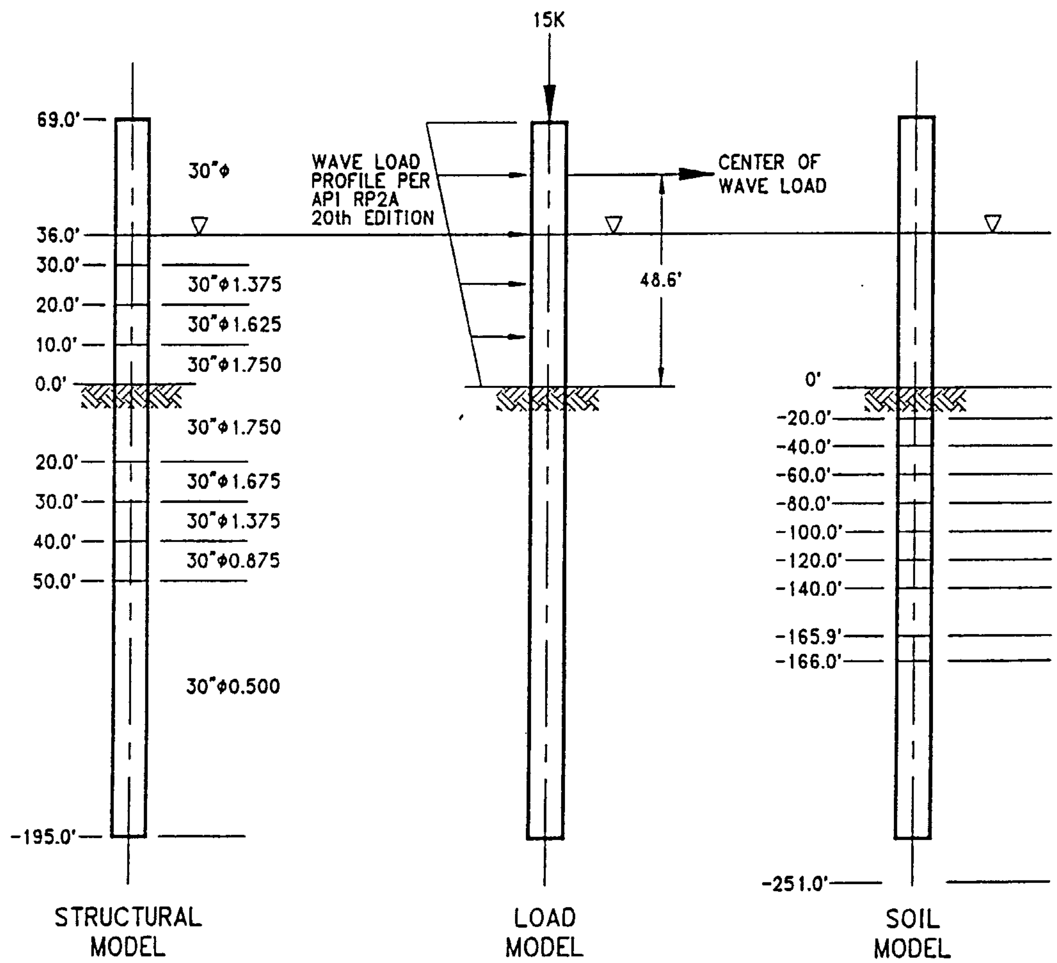


SOIL TYPE	EFFECTIVE WEIGHT PCF	SHEAR STRENGTH KSF	FRICTION ANGLE DEGREES
SAND	60	-	25
SAND	60	-	25
CLAY	35	0.400	-
CLAY	35	1.600	-

NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.A
GENERAL DESCRIPTION OF CAISSON L1

\MMS\2-2A 1=1 MW 7/18/94

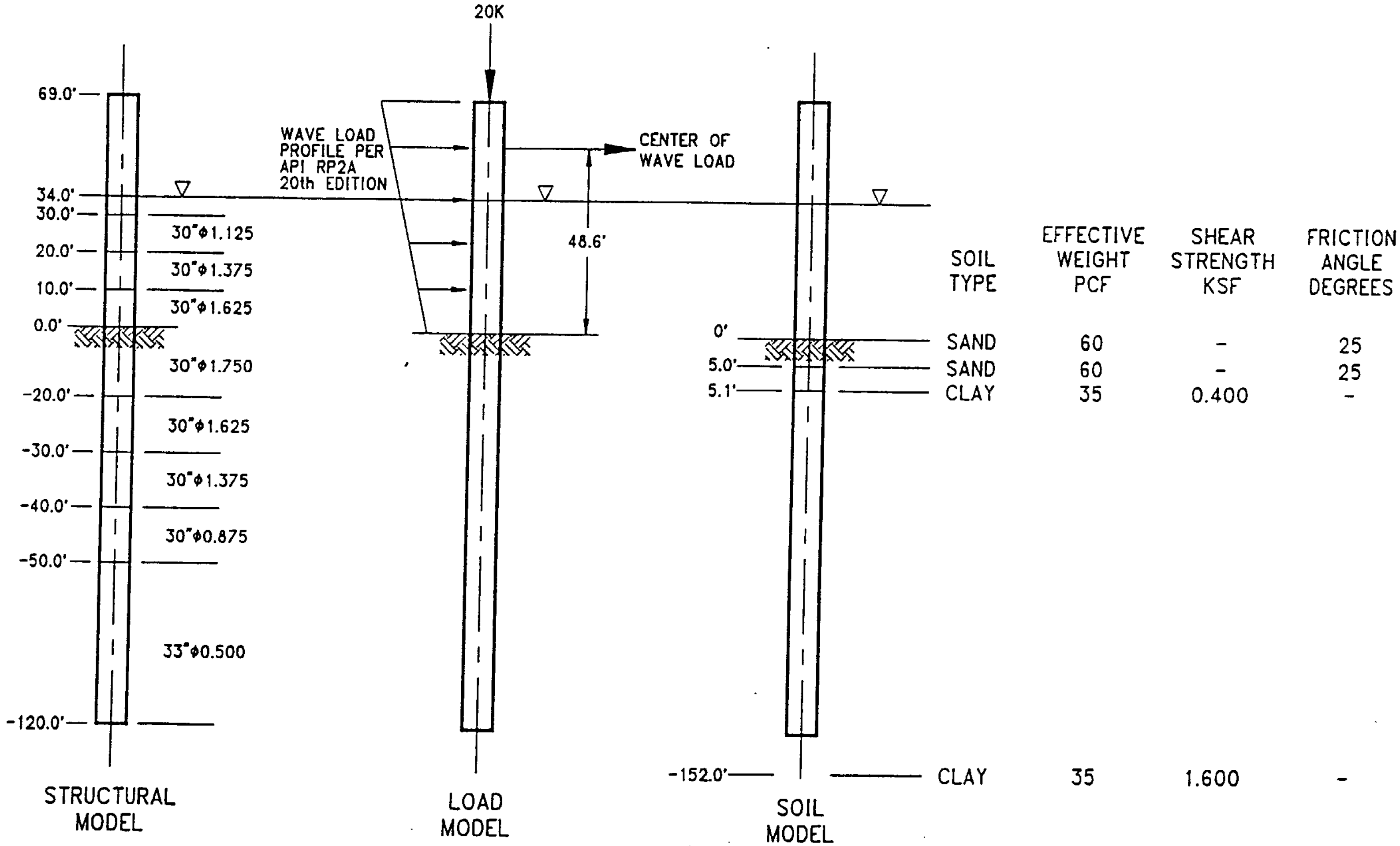


Elevation	SOIL TYPE	EFFECTIVE WEIGHT PCF	SHEAR STRENGTH KSF	FRICTION ANGLE DEGREES
0'	CLAY	33	0.200	-
-20.0'	CLAY	33	0,270	-
-40.0'	CLAY	35	0.339	-
-60.0'	CLAY	35	0.407	-
-80.0'	CLAY	43	0.747	-
-100.0'	CLAY	43	0.540	-
-120.0'	CLAY	43	0.607	-
-140.0'	CLAY	43	0.673	-
-165.9'	CLAY	43	0.760	-
-166.0'	SAND	60	-	35
-251.0'	SAND	60	-	35

NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.B
GENERAL DESCRIPTION OF CAISSON L2

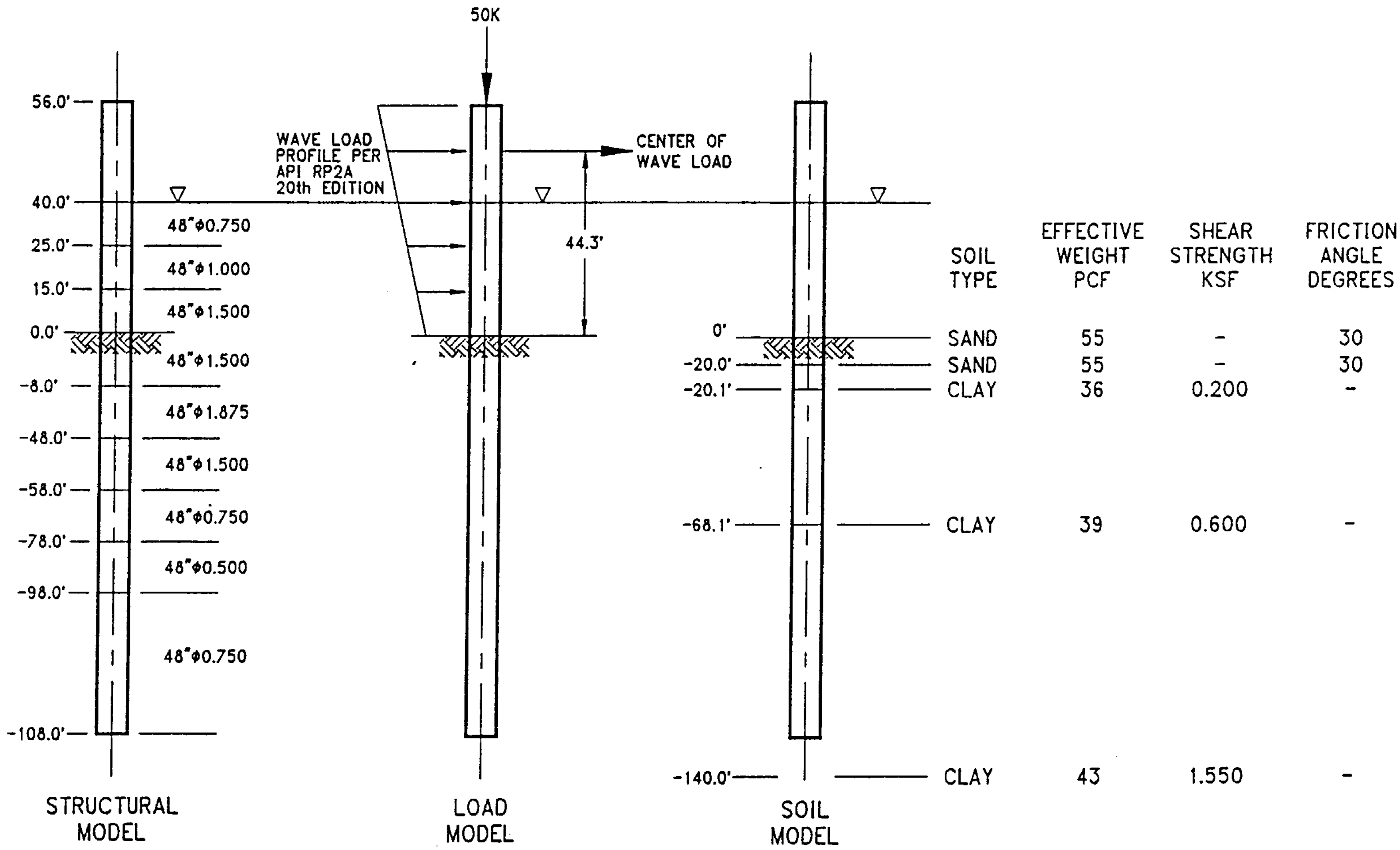
\MMS\2-2B 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.C
GENERAL DESCRIPTION OF CAISSON L3

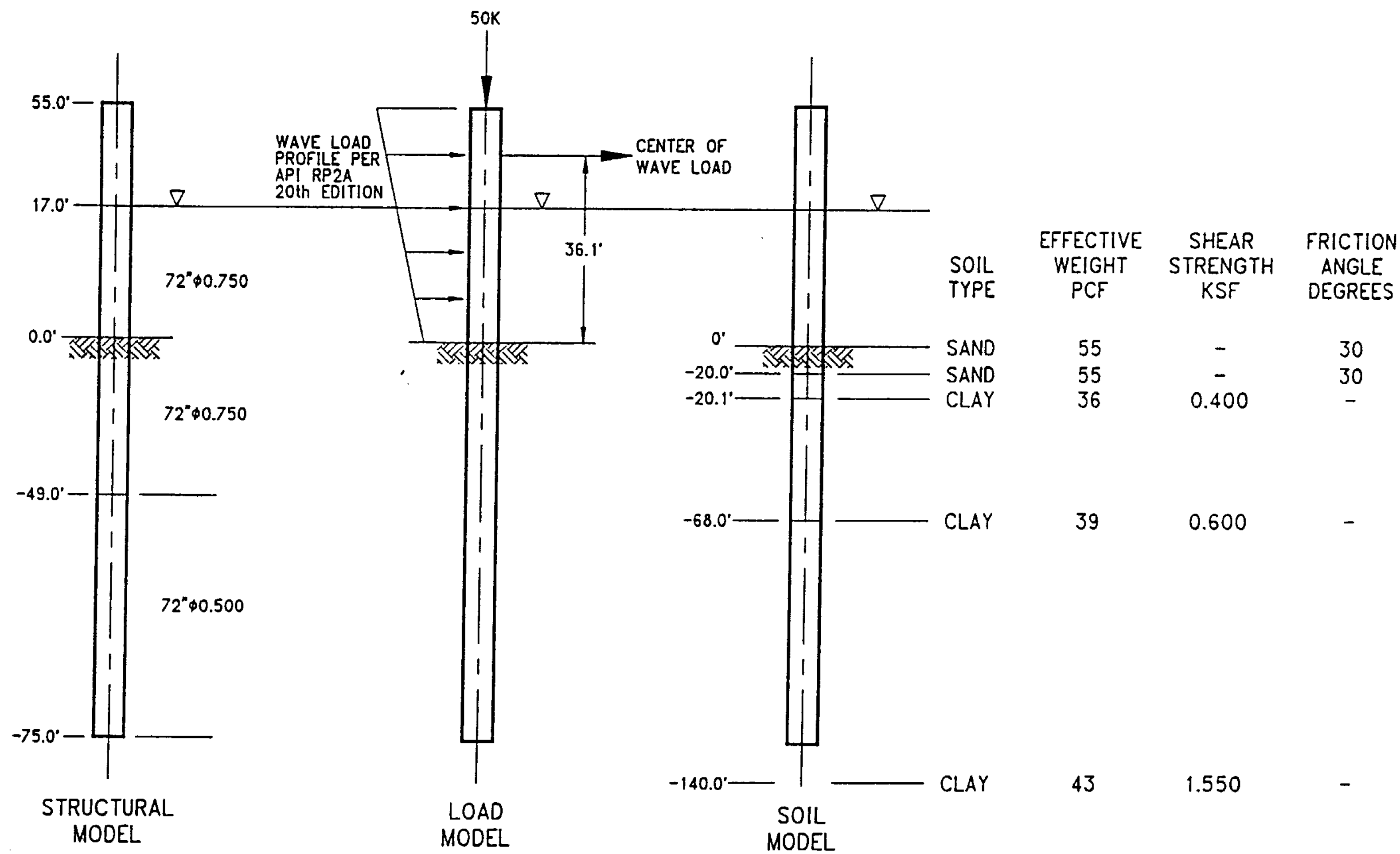
\MMS\2-2C 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.D
GENERAL DESCRIPTION OF CAISSON N1

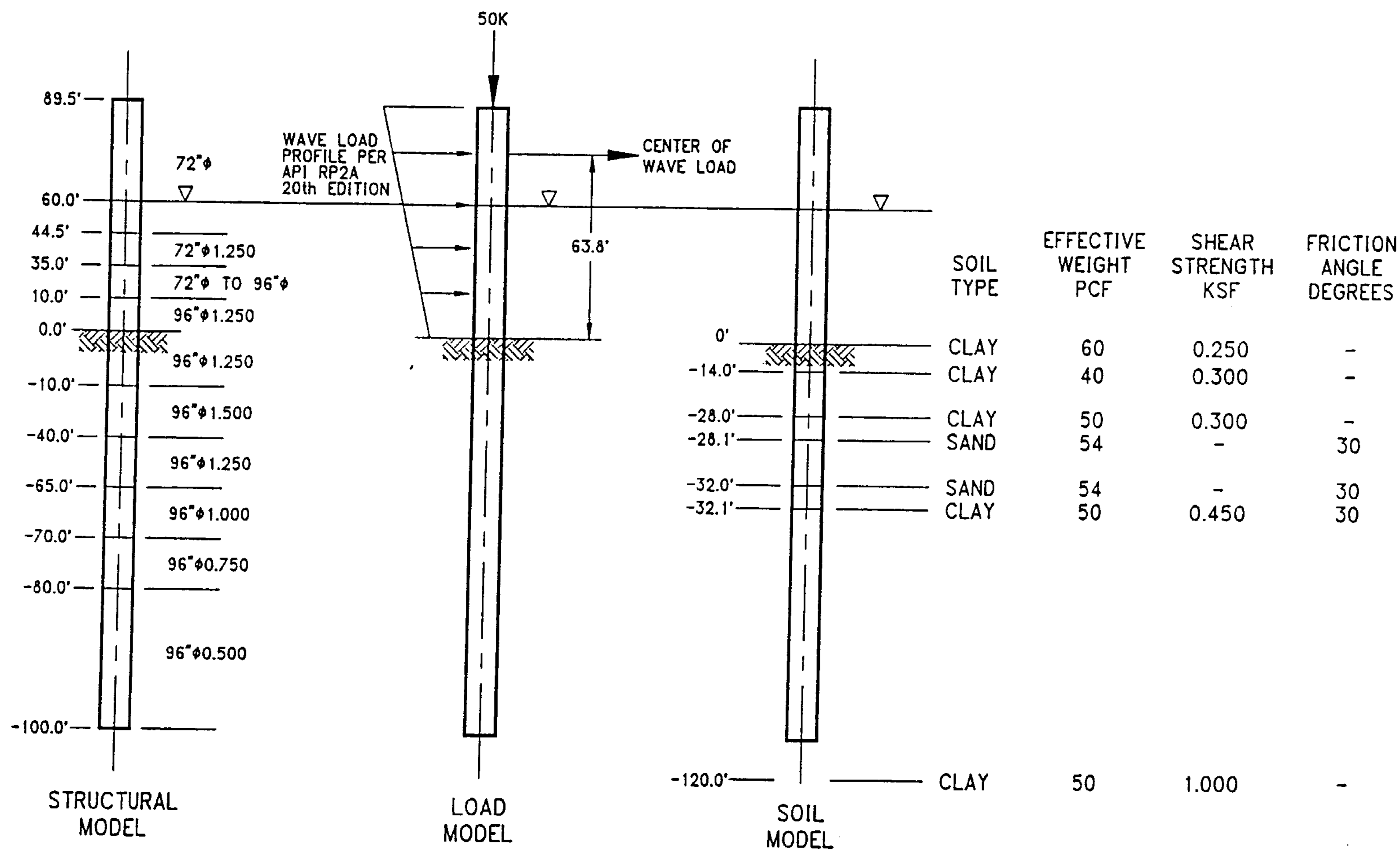
\MMS\2-2D 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.E
GENERAL DESCRIPTION OF CAISSON N2

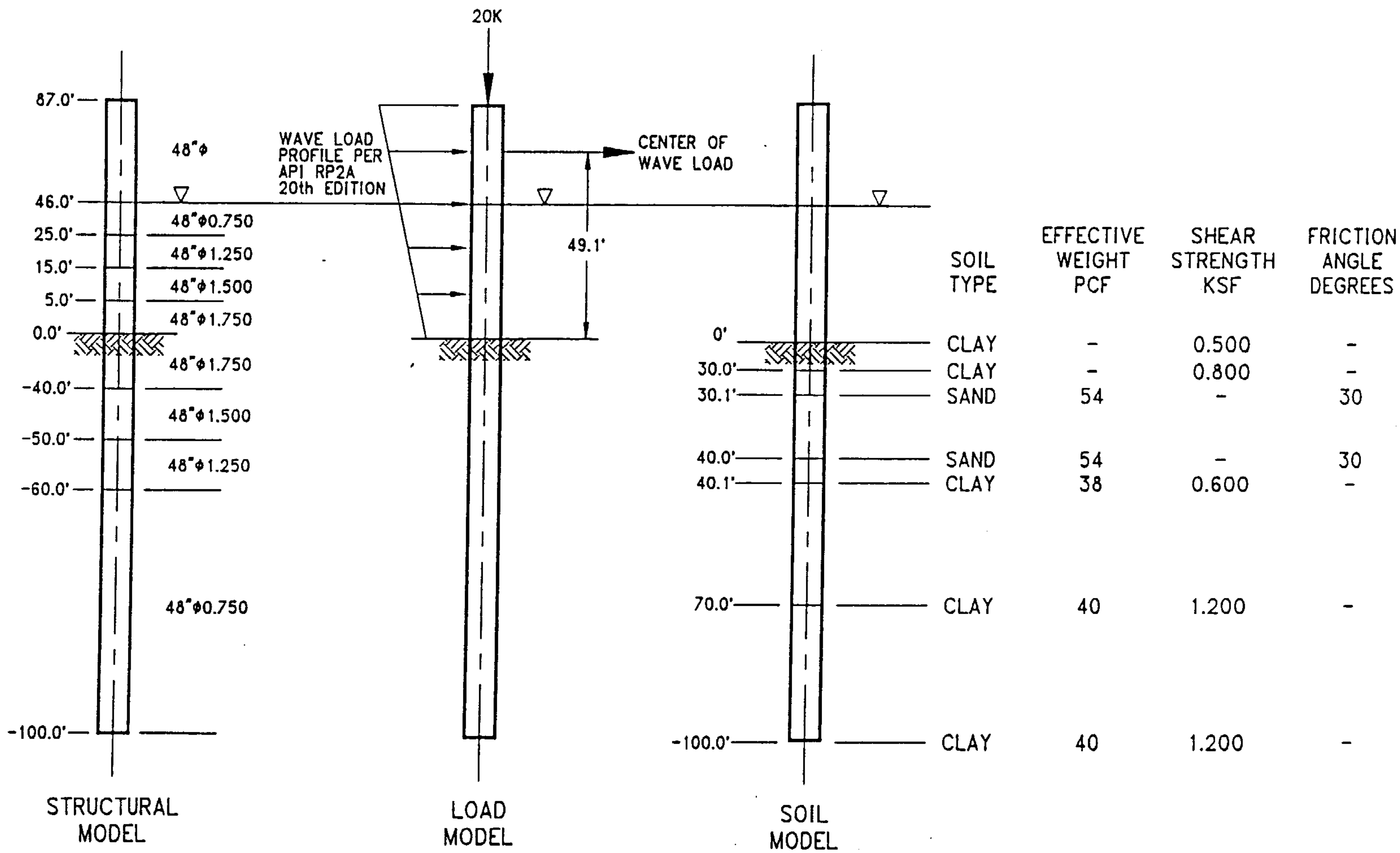
\MMS\2-2E 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.F
GENERAL DESCRIPTION OF CAISSON N3

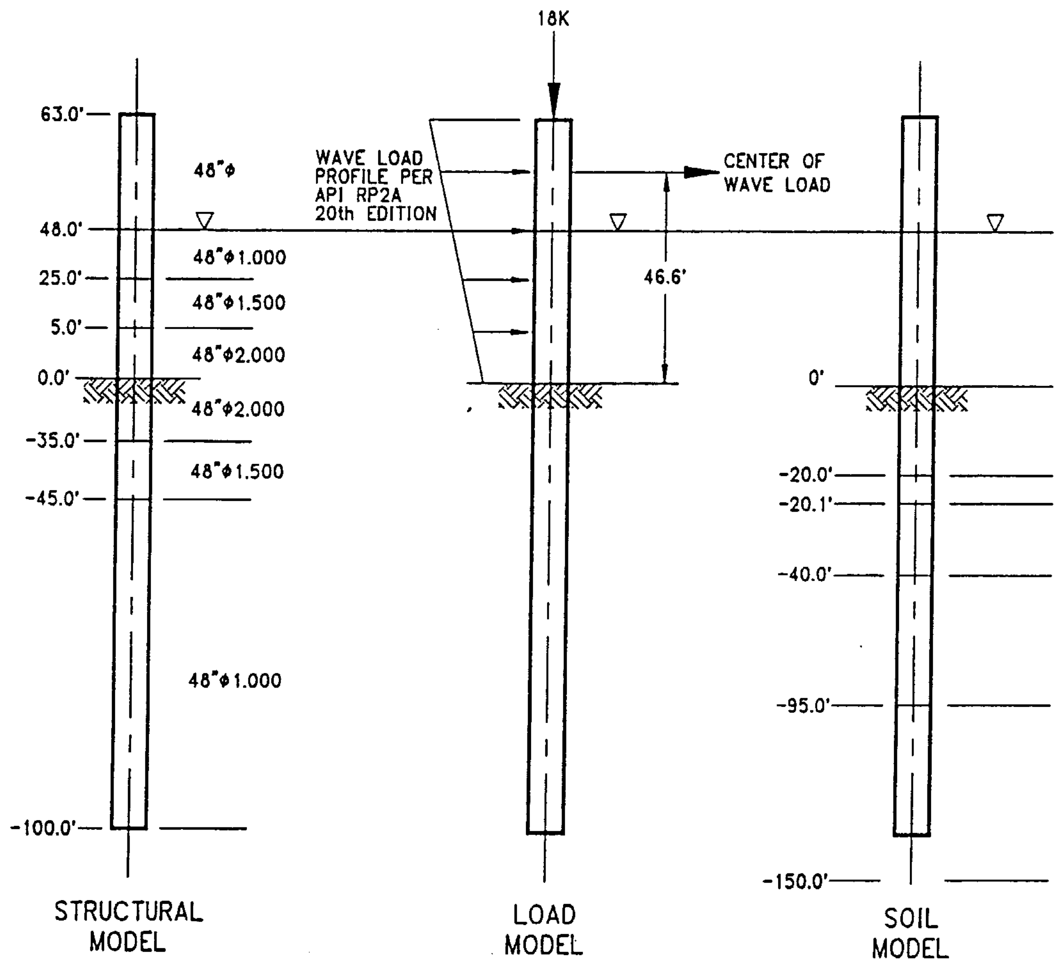
\MMS\2-2F 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.G
GENERAL DESCRIPTION OF CAISSON Y1

\MMS\2-2G 1=1 MW 7/18/94

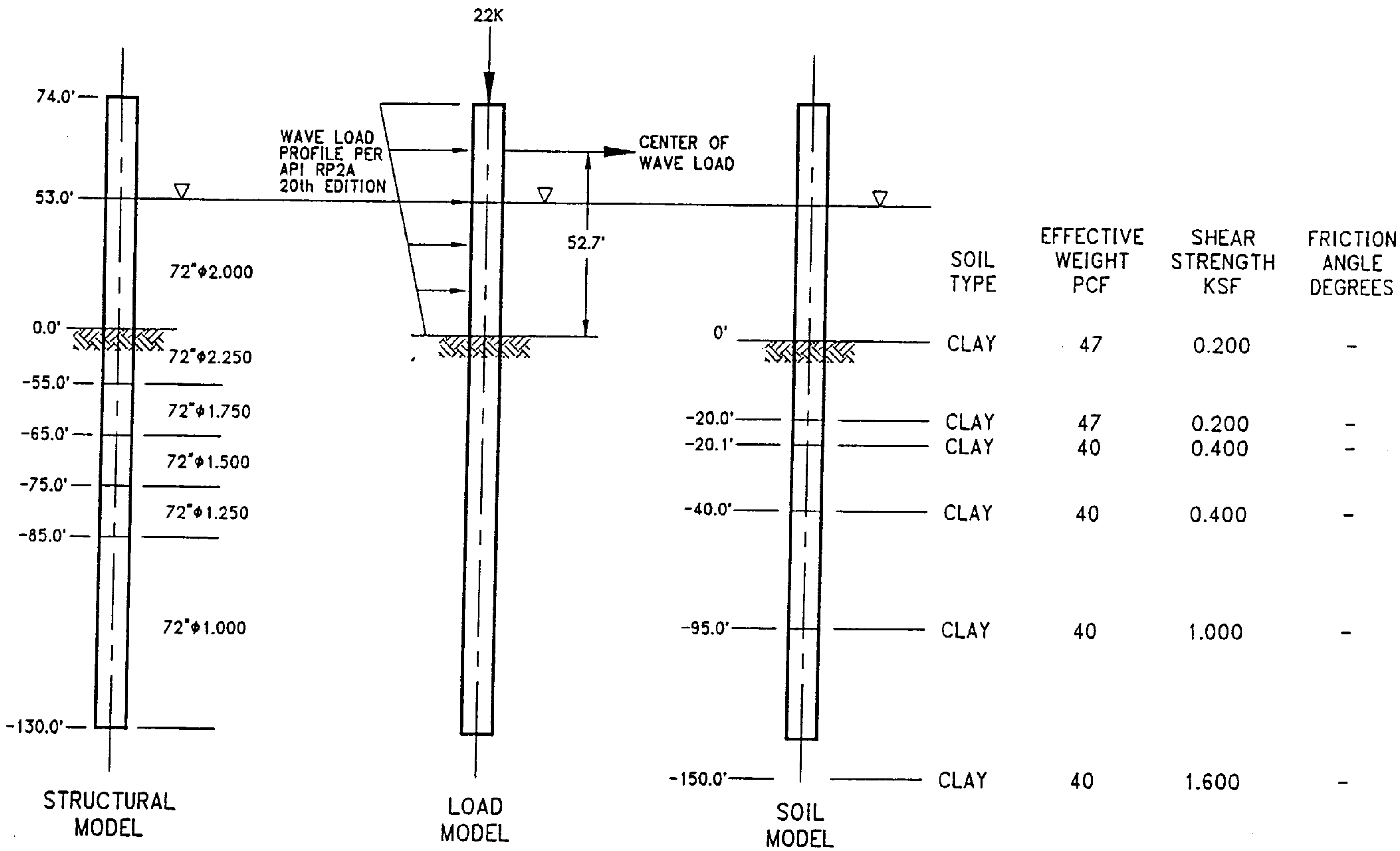


SOIL TYPE	EFFECTIVE WEIGHT PCF	SHEAR STRENGTH KSF	FRICTION ANGLE DEGREES
CLAY	47	0.200	-
CLAY	47	0.200	-
CLAY	40	0.400	-
CLAY	40	0.400	-
CLAY	40	1.000	-
CLAY	40	1.600	-

NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.H
GENERAL DESCRIPTION OF CAISSON Y2

\MMS\2-2H 1=1 MW 7/18/94



NOTE: ELEVATION NOT TO SCALE

FIGURE 2.2.1
GENERAL DESCRIPTION OF CAISSON Y3

\MMS\2-21 1=1 MW 7/18/94

3.0 Extreme Wave Response of Caissons

In this section is reported the development of the analysis models and the results of using those models to estimate the residual lean after an extreme wave loading event.

3.1 Analysis Models

In Figure 3.1.A are shown the generic models for the actual caissons and for the equivalent caissons.

For the actual caissons, the lateral load was based on API-RP2A, 20th Edition, (Reference 3), using the design level wave height, current, hydrodynamic coefficients, etc. The vertical load includes the deck load, the weight of the caisson and, in some cases, a portion of the weight of the casings.

The soil is modelled using the guidelines in Reference 3, along with the assumption that the static soil response is appropriate for the expected large deflections. As none of the caissons are grouted, the stiffness of the structure is assumed to be only that of the outer caisson.

For the equivalent caissons, all of the defining parameters are simplified so that the response can be presented in terms of the fewest variables. These simplifications include:

1. Representation of the lateral load as a concentrated load at the mean water line. This simplification is focused on the assumption that the wave load profile yields a center of pressure approximately at the mean water line.

2. Only uniform diameter and wall thickness are considered.

3. The soil is assumed to be adequately represented as a clay with linearly increasing shear strength.

4. All axial loads are ignored.

Model Features

In the following paragraphs are discussed the features of the analysis models for the yielding steel caisson and for the non-yielding caisson.

The behavior of a incremental length of caisson is shown in Figure 3.1.B. This figure shows the relationship among the diameter, the curvature, the radius of curvature, the outer fiber strain, and the bending moment; all based on the fundamental assumption of plane sections remaining plane.

For a simple tubular, Figure 3.1.C (reproduced from data in Figure C 3.3.2-1 of Ref. 3) presents an estimate of the ultimate bending moment versus the variable, Fy*D/t. Also in Figure 3.1.C is the normalized curvature value versus Fy*D/t. For a given value of Fy*D/t, the value for the ultimate moment and the ultimate strain are considered to be allowable since they are estimates of the maximum values that may occur without any local buckling. The reduction in the moment curve from it's maximum normalized value of 1.27 is primarily due to the ovalling of the section.

For this study the stress-strain for the steel is assumed to be elastic-plastic as shown in Figure 3.1.D(a). Several References (e.g. 4, 5 and 6) report the "simplified" normalized moment versus the normalized curvature shown in Figure 3.1.D(b) for no axial load. These analyses do not recognize the ovalling of the section or the potential for local buckling of the section.

Because we wish to account for the axial load, to limit the strain to less than the local buckling value, and to account for the section ovalling during bending, the "Behavior" curve shown in Figure 3.1.E(b) was developed as follows:

1. The "Simplified" curve, A, in Figure 3.1.E(b) was developed using the LPILE+ (Ref. 7) program for values of curvature up to the allowable value shown in Figure 3.1.C.

2. LPILE+ does not recognize the reduced value of the ultimate moment shown in Figure 3.1.C. Thus, a linear bias factor, B, was developed as shown in Figure 3.1.E(a).

3. The "Behavior" curve in Figure 3.1.E(b) was developed by multiplying the Curve A time the bias factor, B.

Approximate Method for Caisson Response:

The LPILE+ program solves the yielding steel caisson problem with restrictions on loading conditions, soil representation, ultimate bending moment capacity and non-uniformity of caisson diameter and wall thickness. Thus, an "approximate" method was developed for computing the non-linear behavior of the caisson based on the assumption that the bending moment, even along the yielding length, for a yielding caisson is very nearly equal to that computed for a non-yielding caisson. The accuracy of this assumption is indicated in Figure 3.1.F which presents plots of the bending moments from the LPILE+ program for the following two cases:

1. With Caisson Yielding - The maximum moment is the ultimate moment.

2. Without Caisson Yielding - The maximum moment is the same value as the ultimate moment (case 1) but the yield stress has been artificially increased so that no yielding occurs.

Given that the moment profiles of the yielding and the non-yielding caissons are comparable, the StruCAD program (Ref. 8) could have been used to develop the moment profile (curve A, Figure 3.1.F) for the condition (case 2) of the maximum moment equal to the ultimate moment. The StruCad program does not allow yielding of the steel caisson. However, StruCAD does have good capability for handling the multiple sized sections of the caisson and for developing the appropriate wave loading. A decision was made to proceed from this point with StruCAD in place of LPILE+ for the bulk of the computations. A comparison to be presented later, shows this "approximate" response compared with the "exact" response from LPILE+.

Computation of Residual Lean Angle:

StruCAD was used in combination with a spreadsheet, to compute the residual lean of the caisson when the maximum strain was equal to the maximum allowable strain without local buckling. Shown in Figure 3.1.G is the response of a caisson when the maximum moment (location B) has a value equal to the ultimate moment. The locations at which only the outer fibers are yielded are indicated as A and C (see Figure 3.1.G). The computation of the residual lean angle is also indicated in Figure 3.1.G. Note that the assumption implicit in those calculations is that the soil offers no restraint to the elastic recovery of the caisson and that the permanent lean at location C is zero for the loaded condition. This estimate of the residual lean is judged to be low as some permanent soil deformation should occur.

The residual lean angles are shown in Figure 3.1.F for the two moment curves shown. Comparison of these angles indicate that the "approximate" method underestimates the residual lean angle by about 12 percent as compared to an "exact" method.

The lean angle at the mudline versus the applied lateral load is shown in Figure 3.1.H for the caisson whose moment diagrams are presented in Figure 3.1.F. The lean angle is 2.12 degrees when the caisson first yields. The StruCAD program computes only 2.83

degrees lean for the condition when the bending moment is equal to the ultimate allowable moment. Of course, no yielding occurs in the StruCAD model. The maximum mudline lean angle (6.65 degrees) from LPILE+(the "exact" method) for 42 ksi compares favorably with that (5.86 degrees) obtained from the approximate method. The estimate (5.86 degrees) of the maximum lean angle is obtained from the addition of the residual lean angle (3.74 degrees) and the yield angle (2.12 degrees).

The "approximate" analysis model discussed above is judged to yield acceptable estimates based on the comparison with the "exact" model. The assumption of the lack of restraint or restoring force of the soil is an uncertainty for either the "approximate" or "exact" analysis model that has not been resolved. An upper bound estimate of the residual lean angle would be the maximum lean angle.

3.2. Actual Caisson Structures

The residual lean angle at the mudline is shown in Table 3.2.A for each of the nine actual caissons analyzed. The values for the residual lean are computed per the equation shown in Figure 3.1.G. The "linear part" of the maximum lean is computed by the StruCAD program with the lateral load factor scaled to result in the maximum moment at location B equal to the ultimate moment of the most strained section. The maximum lean angle is the sum of the linear (non-yielded portion below the mudline) part and the non-linear (residual lean angle) part. Also, shown in Table 3.2.A are the values for the 48" X 1.600" equivalent caisson used to validate the approximate method.

Note that none of the actual caissons are expected to exhibit large values of lean due to soil failure without having yielding in the steel caisson.

3.3 Equivalent Caisson Structures

Parametric analyses were performed to study the effects of water depth, caisson diameter, caisson thickness, caisson depth below the mudline and the soil conditions on the residual lean. Table 3.3.A lists the parameters that were considered for this study.

In Figures 3.3.A-D are shown the residual lean versus water depth for various values of diameter, diameter to thickness ratio, soil shear strength, and caisson penetration below the mudline. The two sets of soil parameters are expected to bound the values of the nine actual caissons. Because of the apparent lack of sensitivity to water depth, the values in Figures 3.3.A-D for 50 ft of water depth are plotted in Figures 3.3.E and F as lean angle versus caisson diameter for very soft soil and soft soil, respectfully.

Table 3.2.A

LEAN ANGLE AT MUDLINE FOR ACTUAL CAISSONS

ANGLE at MUDLINE, degrees

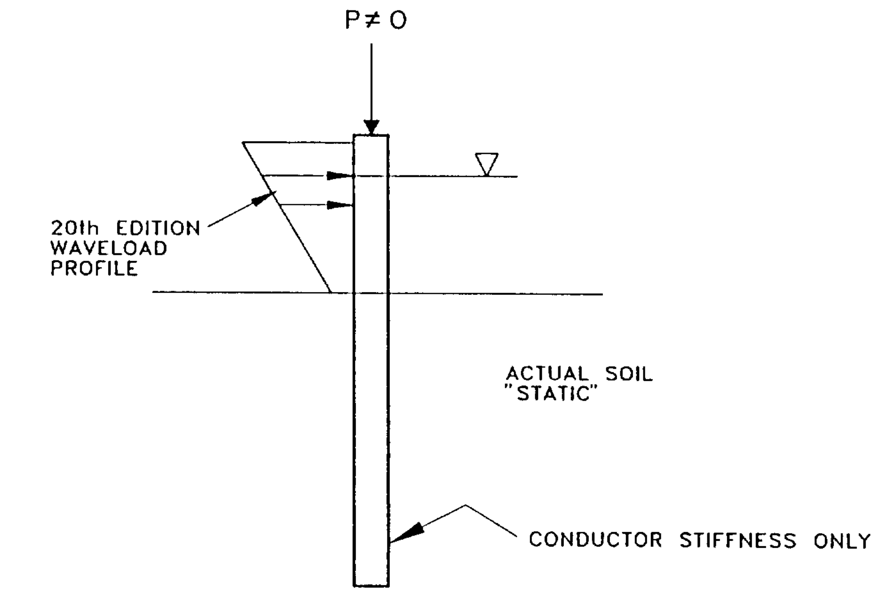
No.	I.D. No.	Yield Y	Residual R	Linear S	Maximum M1 R+Y
1	L1	2.24	1.49	2.93	3.73
2	L2	2.98	1.54	3.64	4.52
3	L3	2.64	2.48	3.58	5.12
4	N1	1.15	0.61	1.64	1.76
5	N2	0.94	0.94	1.01	1.88
6	N3	2.49	0.21	2.76	2.70
7	Y1	1.72	3.88	2.26	5.60
8	Y2	1.85	0.44	2.21	2.29
9	Y3	2.03	0.97	2.55	3.00
10	L1*	1.85	1.29	2.42	3.14
11	L2*	2.41	1.21	2.87	3.62
12	L3*	2.27	2.32	3.09	4.59
13	48 x 1.600 "Approximate"	2.12	3.74	-	5.86
14	48 x 1.600 "Exact"	2.12	4.20	-	6.65

* - Includes some loading from inner casings
See Figure 3.1.1.H for definitions of angles

Table 3.3.A

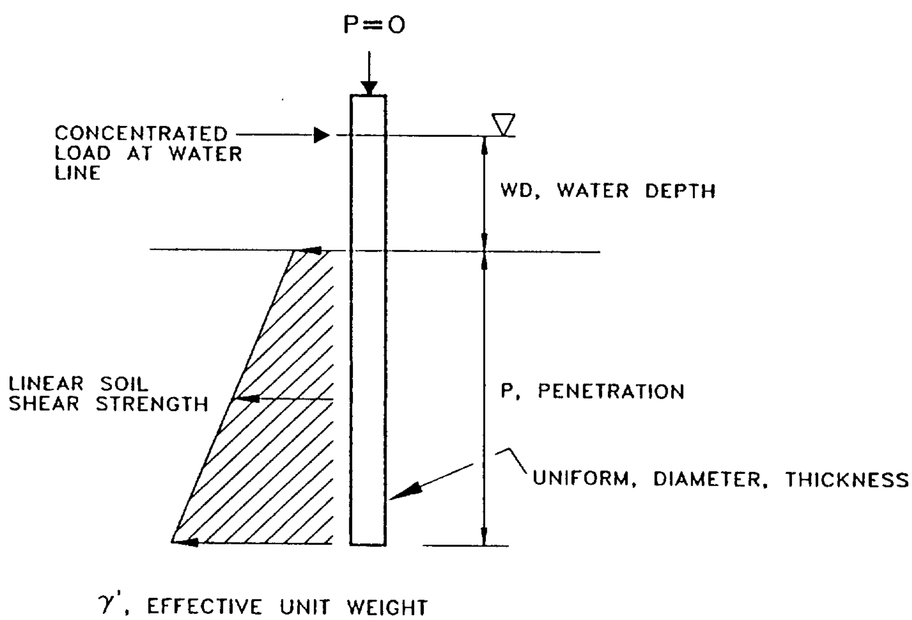
Characteristics of Equivalent Caisson Structures for Parametric Study

Water Depth, ft	20	80	
Diameter, in	30	48	72
D/T Diameter to Thickness Ratio	20	60	90
Penetration, ft.	100	200	
Soil Shear Strength, (linear)	Very Soft Clay		Soft Clay
@Mudline, ksf	0.1		0.4
@ -100 ft, ksf	0.5		1.2



ACTUAL CAISSONS

(a)



EQUIVALENT CAISSONS

(b)

Figure 3.1.A
Analysis Models

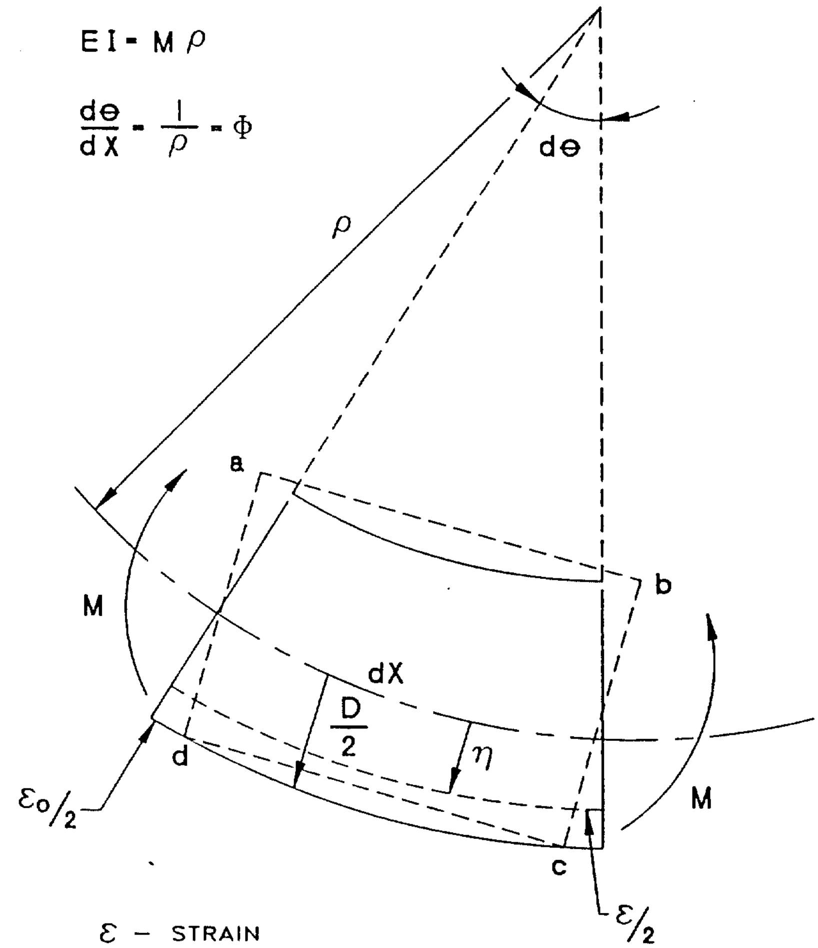
\MMS\3-1A 1=1 MW 7/18/94

$$\mathcal{E} = \frac{d\theta}{dX}\eta = \Phi\eta$$

$$\mathcal{E}_o = \frac{d\theta}{dX}\frac{D}{2} = \Phi\frac{D}{2}$$

$$EI = M\rho$$

$$\frac{d\theta}{dX} = \frac{1}{\rho} = \Phi$$



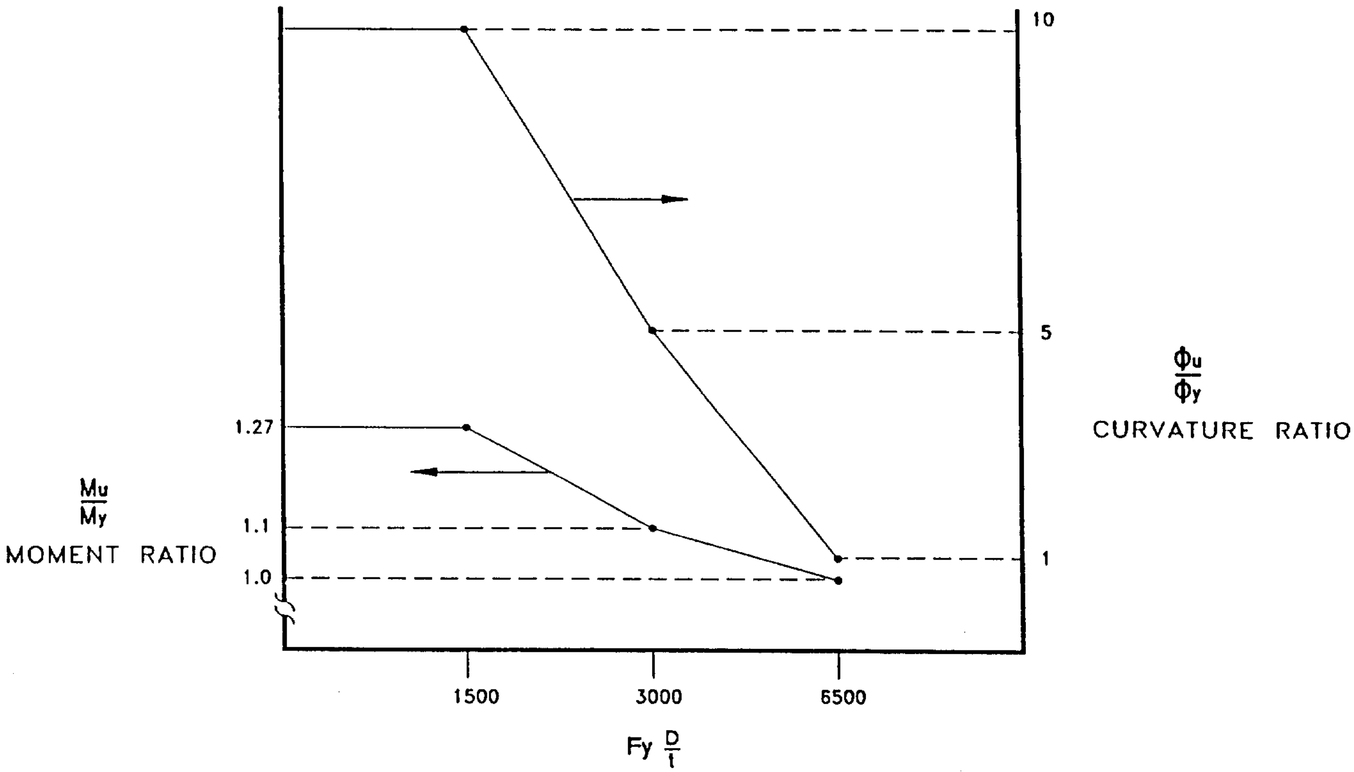
$\mathcal{E}$ – STRAIN

Φ – CURVATURE

ρ – RADIUS OF CURVATURE

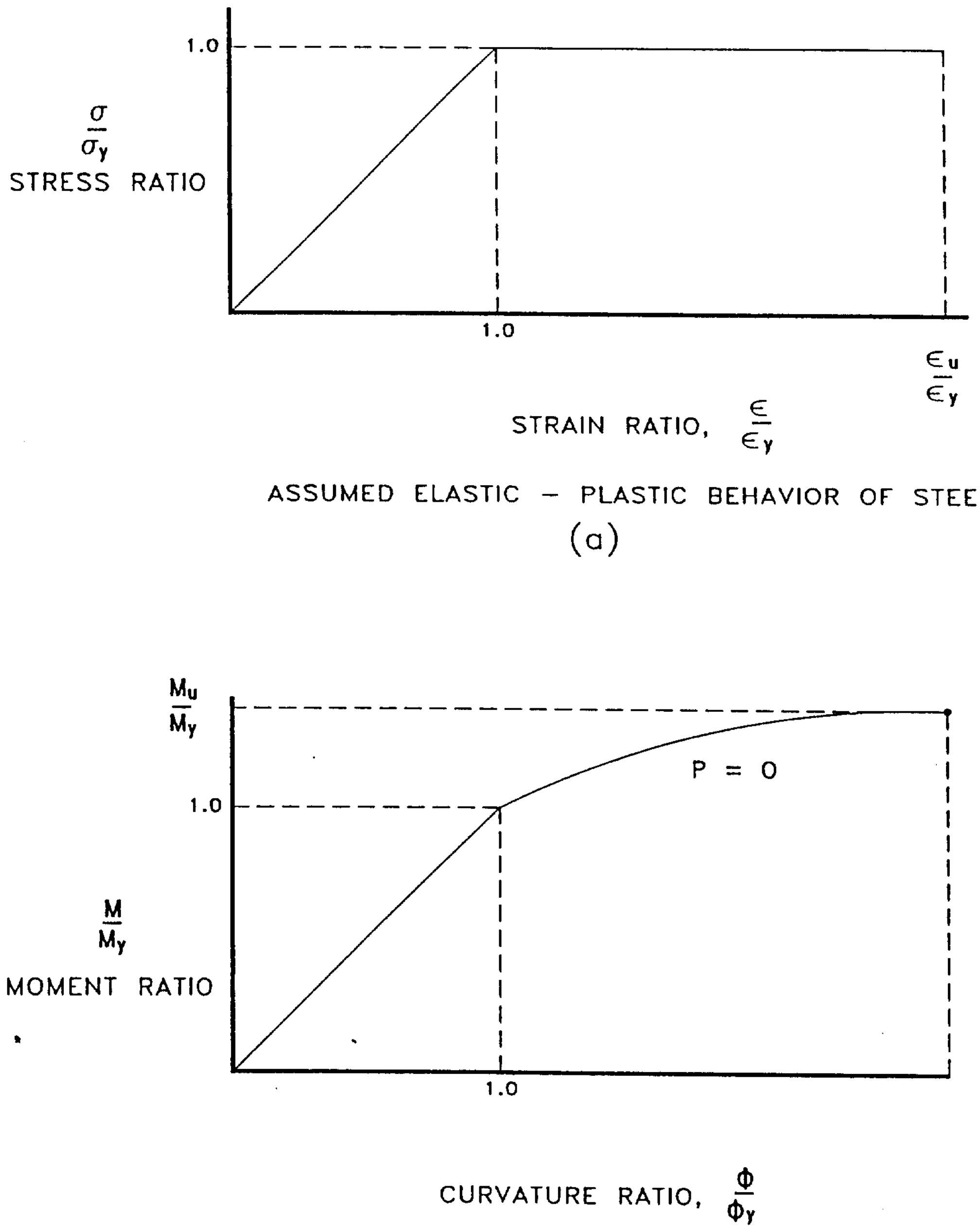
D – DIAMETER

Figure 3.1.B
Element From A Beam Subjected
To Pure Bending



M = BENDING MOMENT
Fy = YIELD STRESS, k.s.i.
D = DIAMETER
t = THICKNESS
Φ = CURVATURE
u = ULTIMATE
y = YIELD

Figure 3.1.C
Interpretation Of Ultimate Strength For Fabricated Steel Cylinder Under Bending



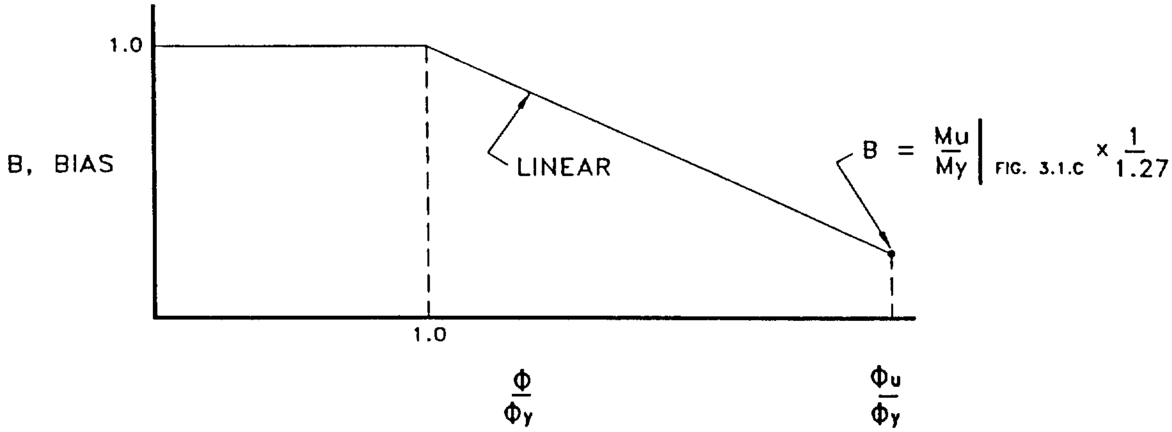
ASSUMED ELASTIC – PLASTIC BEHAVIOR OF STEEL

(a)

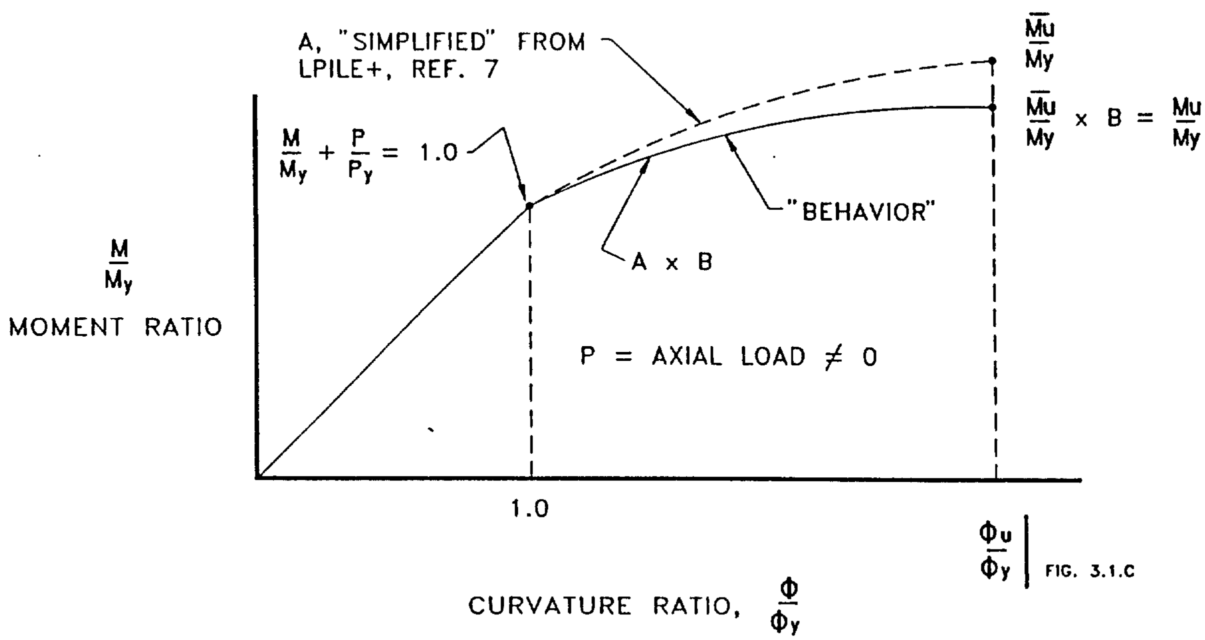
BEHAVIOR OF A CYLINDRICAL SECTION IN BENDING

(b)

Figure 3.1.D



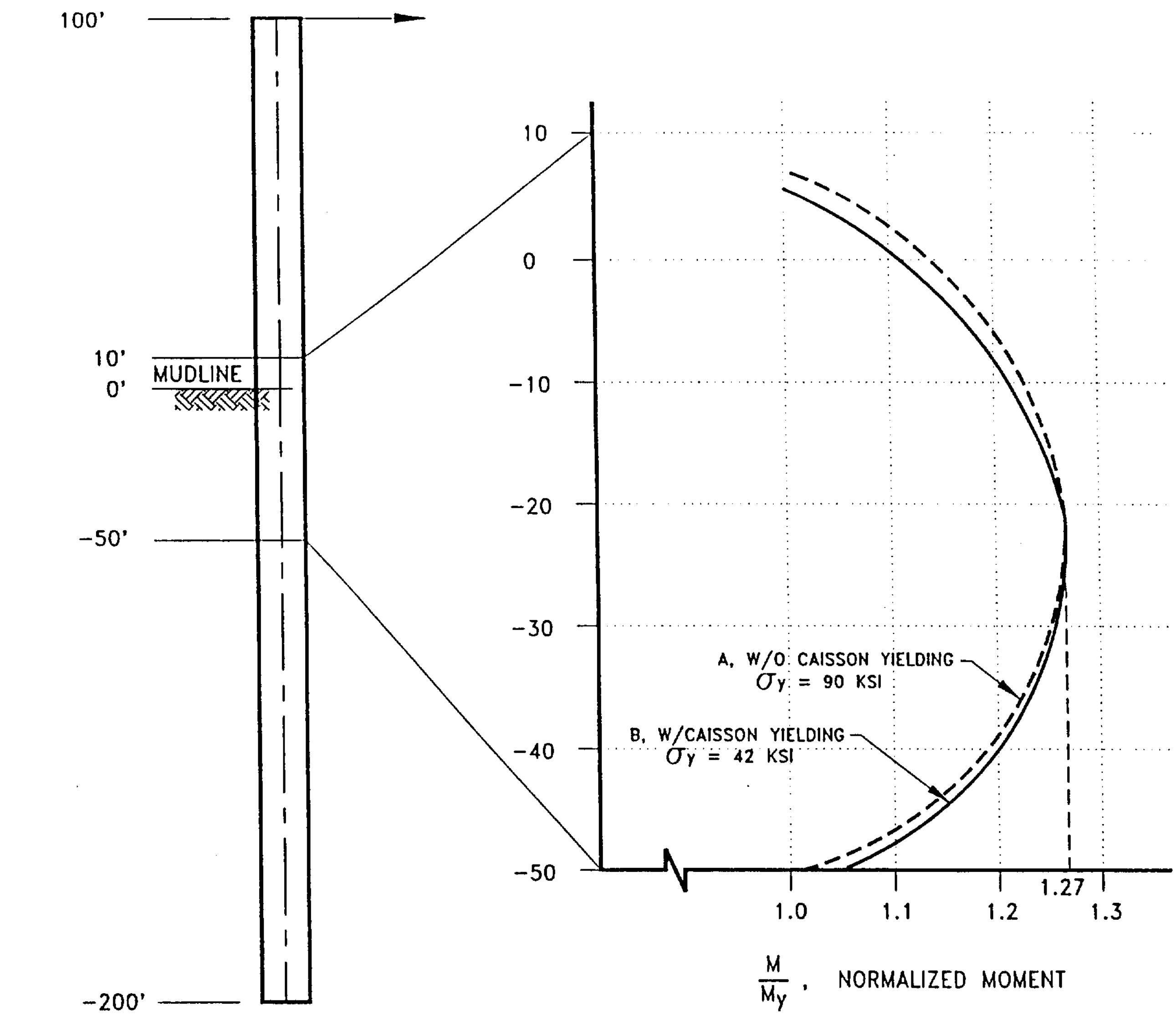
(a)



(b)

Figure 3.1.E
Behavior Of A Cylindrical Section In Bending With Axial Load

\MMS\3-1E 1=1 MW 7/18/94



$\frac{M_u}{M_y} = 1.27$

β_R = 3.74 DEGREES, CURVE A ("APPROXIMATE")

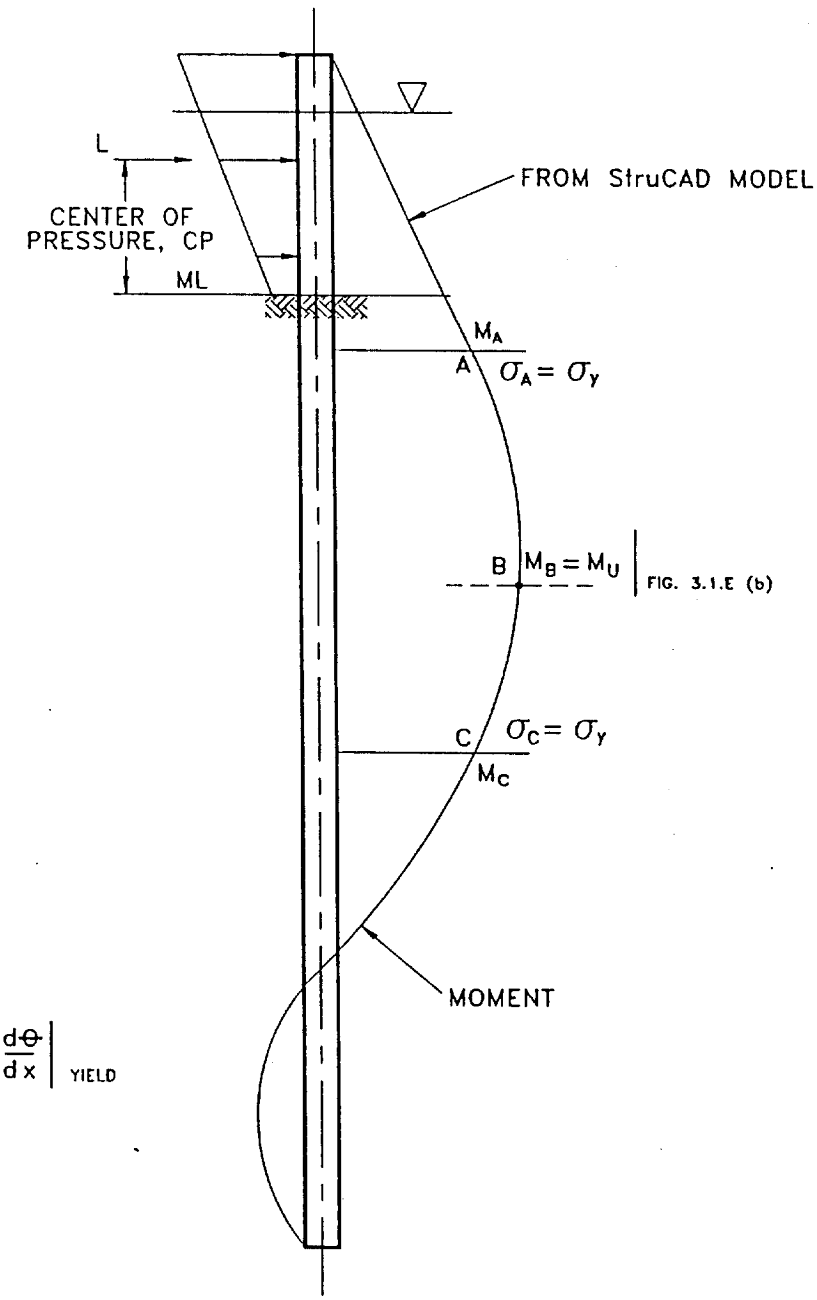
β_R = 4.20 DEGREES, CURVE B ("EXACT")

D = 48"

t = 1.600 in.

SOIL = SOFT CLAY; 0.25 KSF @ MUDLINE
1.92 KSF @ PILE TIP

Figure 3.1.F
Comparison Of Moment Profiles



NOTE: $\dfrac{\Phi}{\Phi_y} = \dfrac{d\theta}{dx} \Big/ \dfrac{d\theta}{dx}\Big|_{\text{YIELD}}$

$$\beta_R = \beta_{\text{RESIDUAL}} = \int_A^C \frac{d\theta}{dx}\,dx - \int_A^C \frac{d\theta}{dx}\Big|_{\text{YIELD}} dx$$

Figure 3.1.G
Computation Of Residual Lean Angle

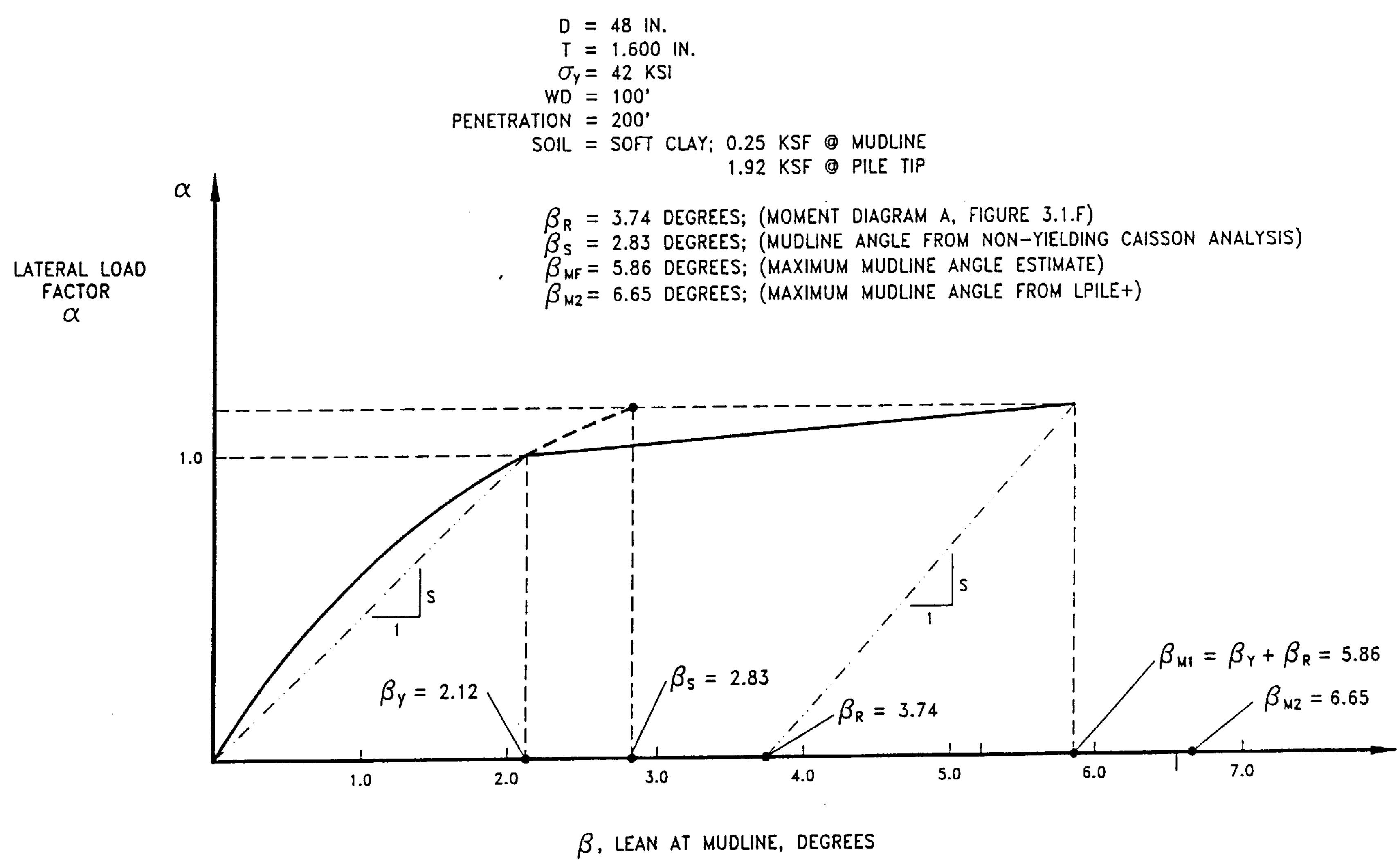


Figure 3.1.H
Lean At Mudline vs Load Factor

\MMS\3-1H 1=1 MW 7/18/94

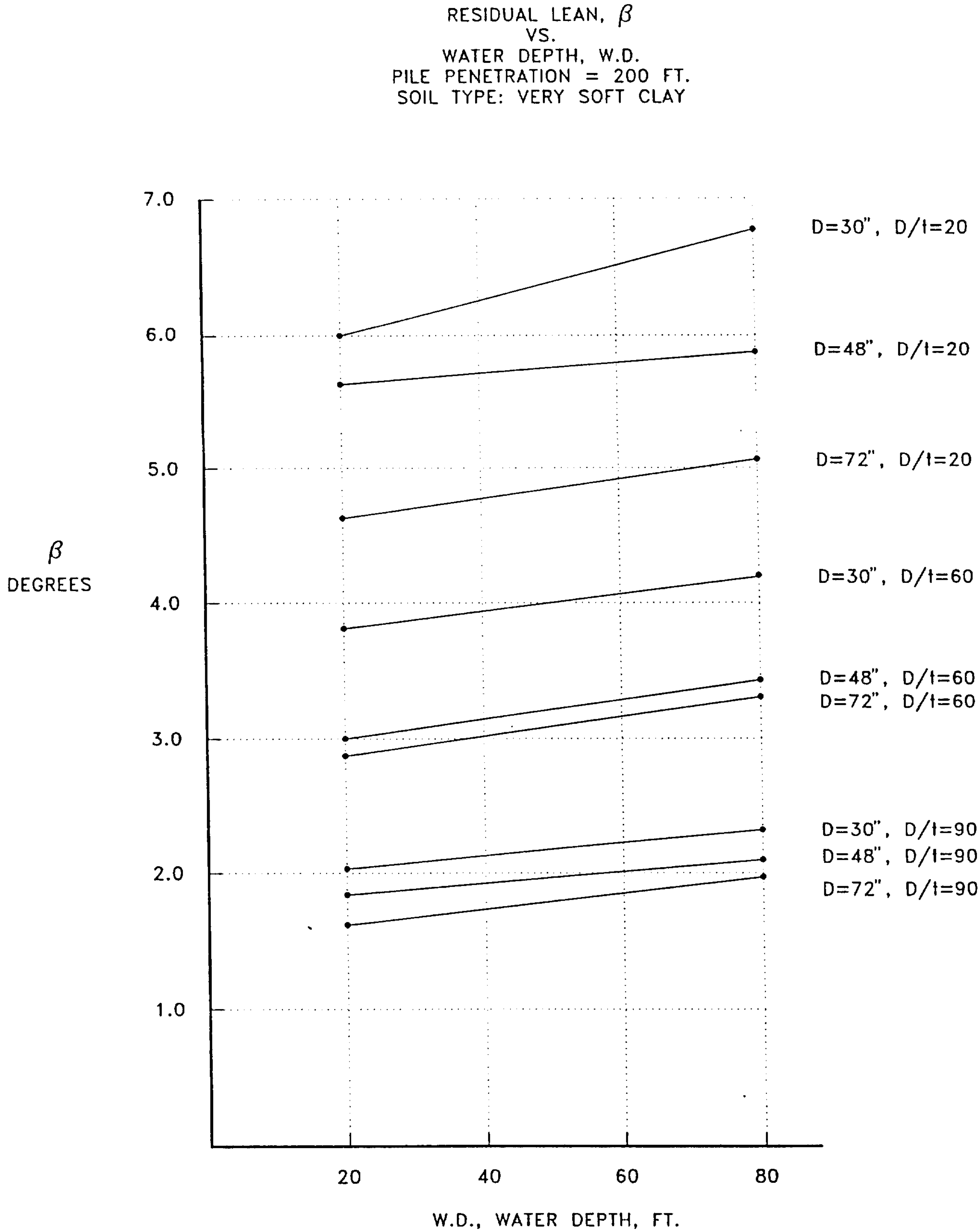


Figure 3.3.A

\MMS\3-3A 1=1 MW 7/18/94

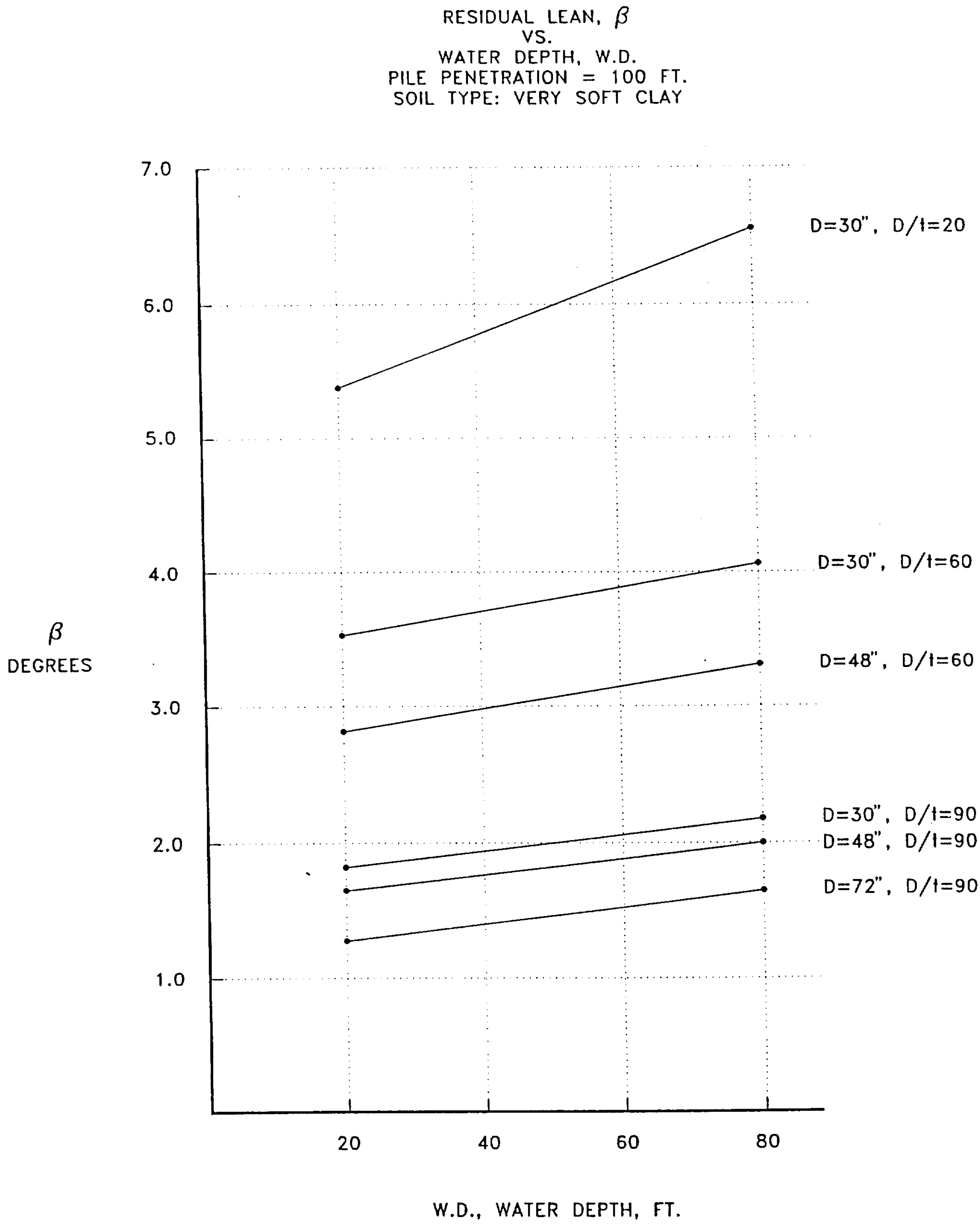


Figure 3.3.B

\MMS\3-3B 1=1 MW 7/18/94

RESIDUAL LEAN, β
VS.
WATER DEPTH, W.D.
PILE PENETRATION = 200 FT.
SOIL TYPE: SOFT CLAY

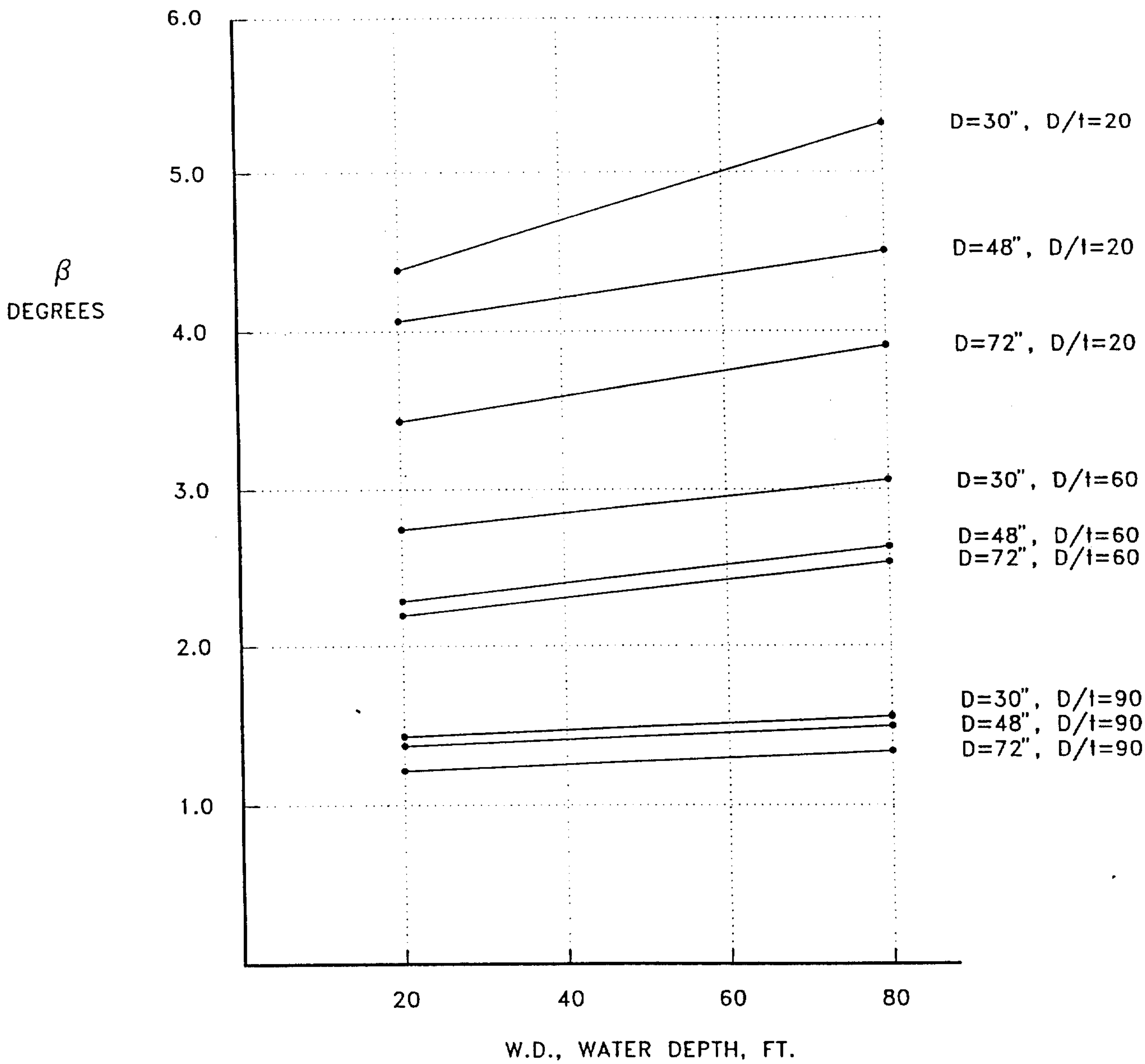


Figure 3.3.C

\MMS\3-3C 1=1 MW 7/18/94

RESIDUAL LEAN, β
VS.
WATER DEPTH, W.D.
PILE PENETRATION = 100 FT.
SOIL TYPE: SOFT CLAY

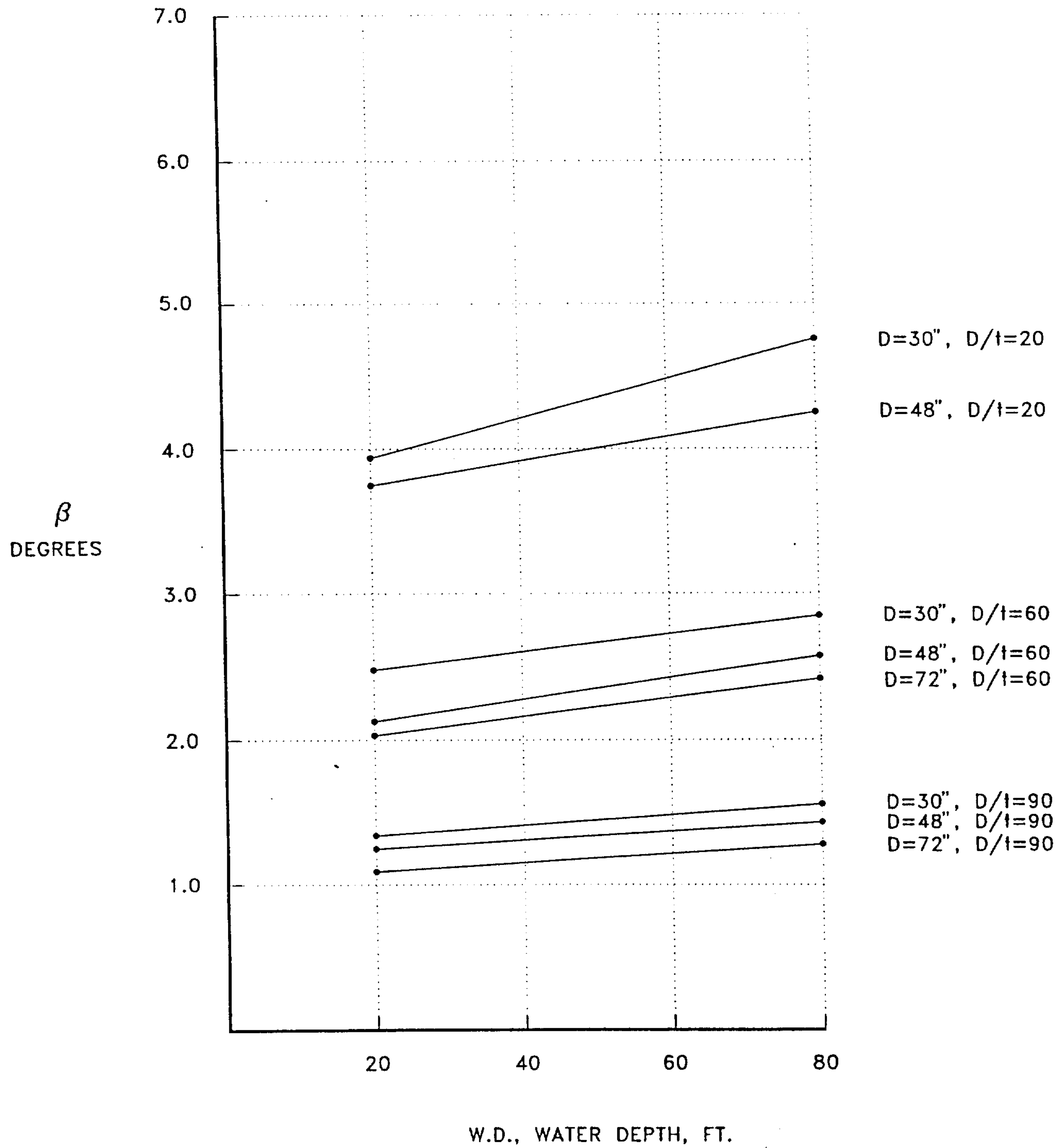


Figure 3.3.D

\MMS\3-3D 1=1 MW 7/18/94

FIGURE 3.3.E
RESIDUAL LEAN ANGLE vs. PILE DIAMETER
50' WATER DEPTH
VERY SOFT CLAY

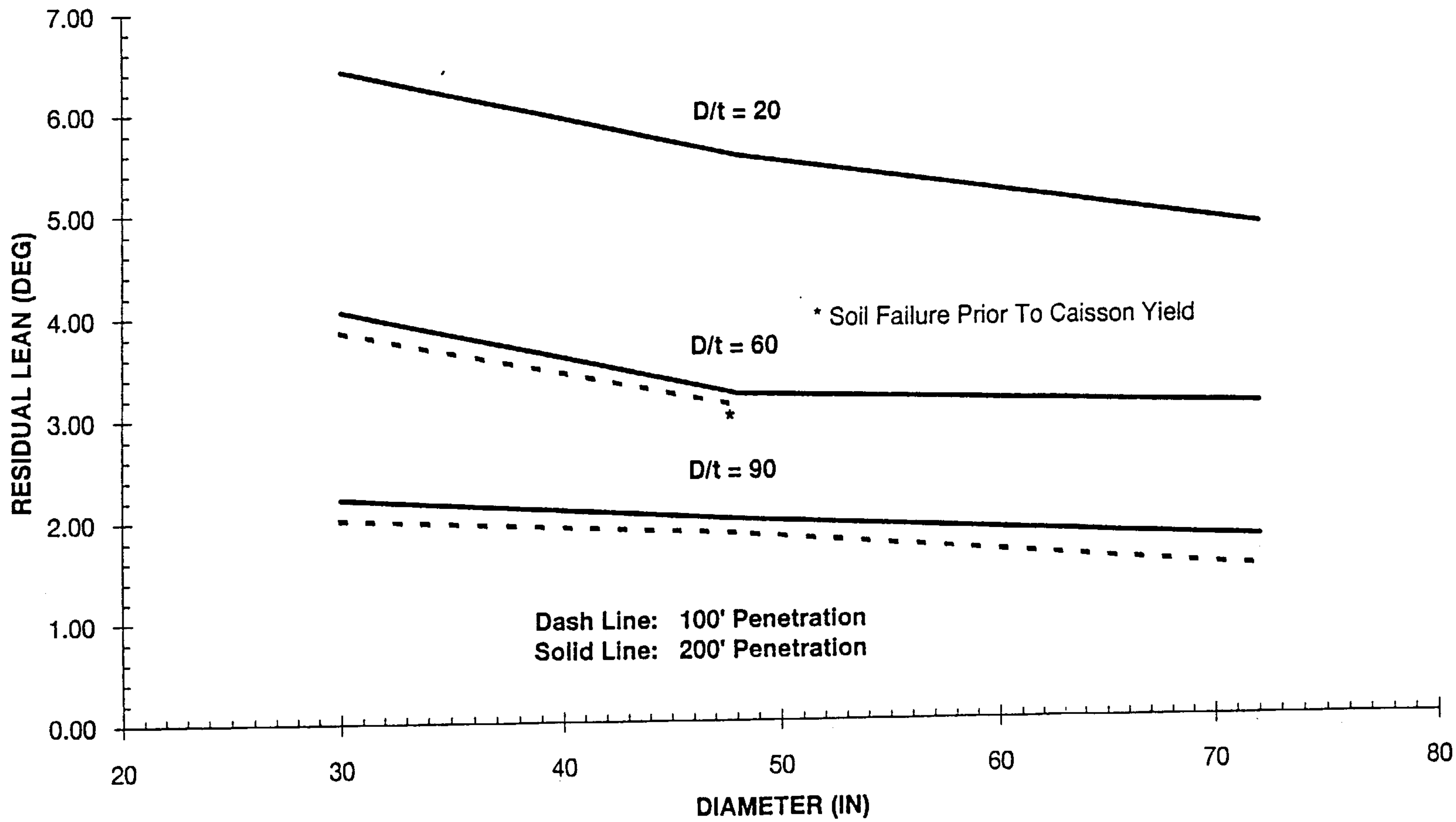
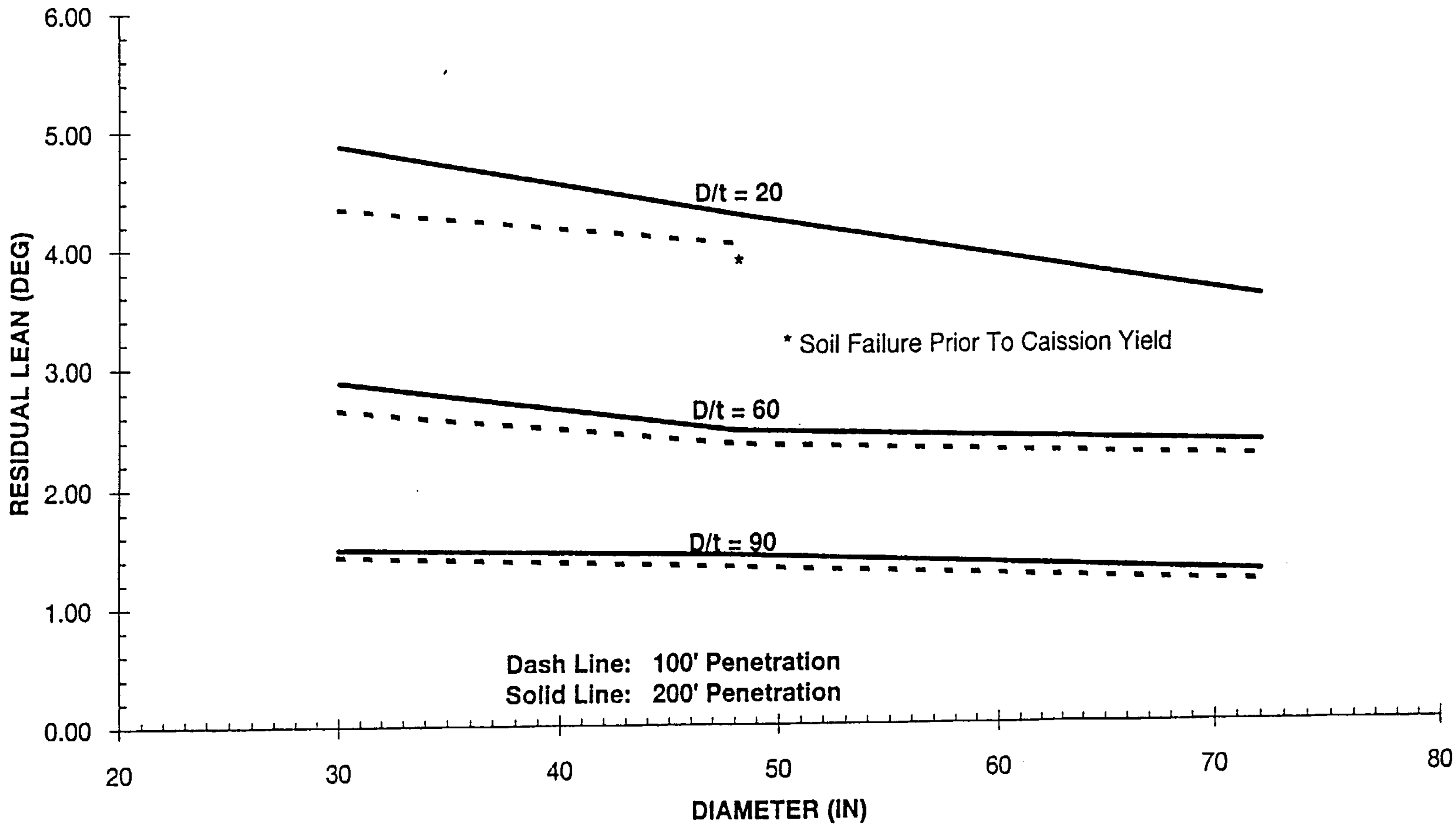


FIGURE 3.3.F
RESIDUAL LEAN ANGLE vs. PILE DIAMETER
50' WATER DEPTH
SOFT CLAY



4.0 Development of Acceptance Criteria

4.1 General Observations of Response

The computed angle of lean of the all of caissons appear to be very low compared to the observed values. Post Hurricane Andrew lean was observed to be greater than 15 degrees on many caissons; whereas, the analysis model developed in this report would have predicted total failure of the caisson because the local yielding would have been well beyond the local buckling value.

The equivalent caisson study is believed to show proper trends. The allowable lean angle will increases with the softer soil. The allowable lean angle increase with decreasing values of diameter to thickness(D/t) ratios. For the same D/t ratio, the allowable lean angle decreases with increasing caisson diameter. For small D/t values, lower than those for the actual caissons, massive soil failure was predicted prior to caisson yielding.

4.2 Acceptance Criteria Guidelines

The analysis results of the actual caissons which are reported in Table 3.2.A show that the residual lean angle for these caissons is quite small. The assumption that the residual lean angle is due to only the permanent deformation of the yielded steel caisson is likely to underestimate the actual residual lean angle. Inelastic soil deformation could cause a residual lean angle, even without caisson yielding. Thus, the actual, allowable residual angle may be closer to the maximum lean. From Table 3.2.A, the maximum lean estimates vary between 1.88 degrees and 5.60 degrees.

The residual lean angles for the actual caissons appears to be slightly correlated such that lower diameter caissons have larger allowable lean angles. This observation is also made from the equivalent caisson study. However, no trends in the data for the actual caissons were outstanding. Thus, acceptance of the residual lean for a particular damaged caisson needs to be based on all of the available data related to the design. If no known damage beyond the buckling strain is known to exist, and if the design details are relatively close to those used in this analysis, then a residual lean angle of about 3 degrees is judged to be acceptable. Otherwise, a detailed inspection and evaluation analysis program should be the basis of acceptance.

5.0 Damage Assessment and Repair Guidelines

Because of the limited information on the damage of the caissons only very general guidelines for damage assessment and repair can be given. The fundamental assumption for assessing the allowable lean angles is that the caisson yield strain should be less than that corresponding to local buckling. This very localized condition, high stress condition could result in local fracture of the caisson. If the lean angle of a caisson exceeds about 3 degrees or if the design details are substantially different from those caissons used in this study then a detailed damage assessment should be undertaken.

An appropriate damage assessment could be an analysis similar to that outlined in this report. If the analysis indicates that local buckling did occur then an inspection verification would be in order.

The repair of a tilted or overstressed caisson should be based on an engineering analysis which reflects the proposed repairs. Simulation of a straightening load could be performed using procedures similar to those outlined herein. If local buckling was not present then the straightening process could proceed if desired. If local damage, such as local buckling, did occur, then repairs should be made either prior to or after straightening.

The placement of a larger caisson over a damaged caisson has been implemented in some cases. This process should be acceptable if the final configuration meets the required design criteria.

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