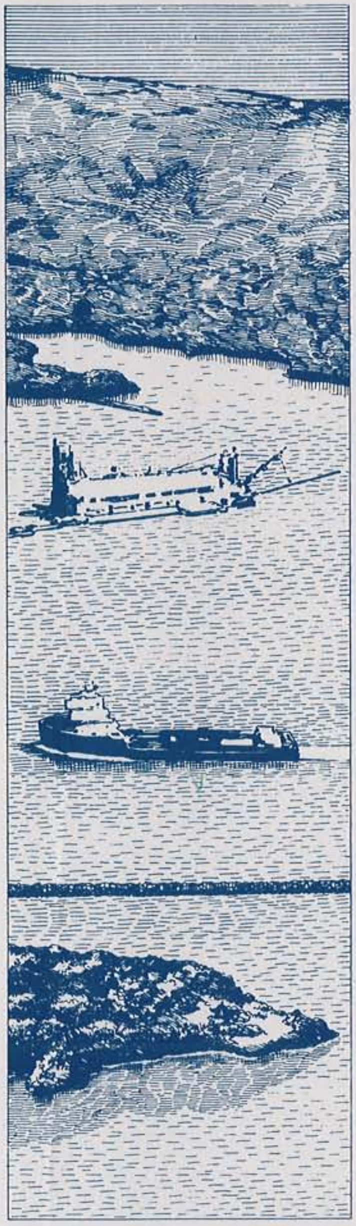
US Army Corps of Engineers



DREDGING RESEARCH PROGRAM

CONTRACT REPORT DRP-92-1

DREDGE MOORING STUDY CONCEPTUAL DESIGN PHASE I REPORT

by

SOFEC, Inc.
6300 Rothway, Suite 100
Houston, Texas 77040

May 1992

Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit 32477
Contract No. DACW39-90-C-0075

Monitored by Coastal Engineering Research Center
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

The Dredging Research Program (DRP) is a seven-year program of the US Army Corps of Engineers. DRP research is managed in these five technical areas

- Area 1 - Analysis of Dredged Material Placed in Open Water
- Area 2 - Material Properties Related to Navigation and Dredging
- Area 3 - Dredge Plant Equipment and Systems Processes
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
- Area 5 - Management of Dredging Projects

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13. ABSTRACT *(Maximum 200 words)*

This report describes the conceptual design of a direct pump-out facility for Corps of Engineers hopper dredges. Operational conditions were a significant wave height of 6.0 ft, wind velocity of 30 knots, and a current velocity of 2 knots. The mooring system was designed for operation in a minimum depth of 30 ft and a maximum depth of 45 ft. The following operational criteria were also required for the mooring design: (a) transportation by truck or rail, (b) rapid assembly with little or no diver support, and (c) installation with a minimum of lift support. The report examines five alternatives: (a) a guyed tower, tension leg platform (TLP), (b) a single anchor mooring (SALM), (c) a three-leg catenary anchor leg mooring (CALM), and (d) a four-leg CALM. The four-leg CALM was selected for further study because it best met the operational criteria. To accommodate truck transport, a 28-ft-long, 11-ft 6-in.-high, 7-ft 6-in.-deep capsule buoy was designed. The entire system (buoy, fluid swivel, mooring table, and buoy piping) is capable of being transported on six flatbed trucks or a single 40- by 120-ft deck barge.

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PREFACE

The study described herein was authorized as part of the Dredging Research Program (DRP) by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Work was performed under the Dredging Equipment for Nearshore/Onshore Placement (DENOP) Work Unit 32477 of DRP Technical Area 3 (TA3), Dredge Plant Equipment and System Processes, at the Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station (WES). Messrs. Robert H. Campbell and Gerald E. Greener were the HQUSACE Chief and TA3 Technical Monitor, respectively, for the DRP. Mr. E. Clark McNair, CERC, was DRP Program Manager (PM), and Dr. Lyndell Z. Hales, CERC, was Assistant PM. Mr. William D. Martin, Chief, Estuarine Engineering Branch, Estuaries Division, Hydraulics Laboratory (HL), was Technical Manager of DRP TA3, which includes Work Unit 32477. The study was conducted under contract. At the start of the contract, the Principal Investigator on the DENOP Work Unit and Contract Monitor was Thomas A. Chisholm, Hydraulic Engineer, Engineering Applications Unit (EAU), Coastal Structures and Evaluation Branch (CSE), Engineering Development Division (EDD), CERC. Mr. James E. Clausner, Research Hydraulic Engineer, EAU, CSE, EDD, CERC, replaced Mr. Chisholm as the Principal Investigator on the DENOP work unit and also became Contract Monitor.

This report, "Dredge Mooring Study - Conceptual Design - Phase I" was written by SOFEC, Inc., of Houston, TX, under contract No. DACW39-90-C-0075, during the period 15 September 1990 through 1 March 1991. The principal author at SOFEC, Inc. was Mr. Wayne A. Herbrich. Messrs. Chisholm and Clausner were under the direct supervision of Dr. Yen-hsi Chu, Chief, EAU, Ms. Joan Pope, Chief, CSE, Mr. Thomas W. Richardson, Chief, EDD, and under the general supervision of Dr. James R. Houston, Director, and Mr. Charles C. Calhoun, Jr., Assistant Director, CERC.

Ms. Sandra Staggs, Contracts Division, WES, provided oversight of the contracting process.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

Additional information can be obtained from Mr. E. Clark McNair, Jr., DRP Program Manager, at (601)634-2070 or Mr. James E. Clausner, Principal Investigator, at (601)634-2009.

DREDGE MOORING STUDY
Conceptual Design
Phase I Report

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CONVERSION FACTORS
Non-SI to SI Units of Measure

Non-SI units of measure used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
dead weight tons (dwt)	1016.0	kilograms (kg)
degrees (angle)	0.01745329	radians
feet (ft)	0.3048	meters (m)
feet squared (ft^2)	0.0929	square meters (m^2)
inches (in)	0.0254	meters (m)
kilo dead weight ton (kdwt)	1,016,000.0	kilograms (kg)
kilopounds weight (kips)	453.6	kilograms (kg)
kilopounds feet (kip-ft)	1,355.8	joules (j)
knot (kt)s	0.5144	meter per second (m/s)
miles (mi) (US statute)	1,609.3	meters (m)
short tons (ston)	907.2	kilograms (kg)

SUMMARY

This report is phase I of a two-phase study whose purpose was to design a direct pump-out (DPO) facility for Corps of Engineers (CE) hopper dredges. At the beginning of the study (Aug 90), the CE did not have the capability for DPO of their hopper dredges in open water. The CE desired this capability to be able to respond to national emergencies (such as hurricanes) where the ability to quickly place sand on the beach is needed. The existence of a DPO facility would also allow an increased amount of suitable dredged material to be used beneficially; for example, to place sand on eroding beaches or to place fine-grained materials to supplement wetlands.

This study was contracted to SOFEC, Inc., of Houston, TX. The mooring system was designed to hold the CE Hopper Dredge Wheeler, the largest of the three CE hopper dredges. Operational conditions were a significant wave height of 6.0 ft, wind velocity of 30 knots, and a current velocity of 2 knots. The mooring system was designed for operation in a minimum depth of 30 ft and a maximum depth of 45 ft. The following operational criteria were also required for the mooring design: (a) transportable by truck or rail, (b) assembled rapidly with little or no diver support, and (c) installed with a minimum of lift support.

The phase I report examined five alternatives: (a) a guyed tower, (b) a tension leg platform (TLP), (c) a single-anchor mooring (SALM), (d) a three-leg catenary anchor leg mooring (CALM), and (d) a four-leg CALM. The guyed tower and SALM were not chosen for further study primarily due to the size of the base required in each case to resist sliding caused by the maximum mooring load and the logistics of transporting, assembling, and installing the base. The TLP was eliminated from further study due to the difficulty of designing a system in which the tendons could withstand the effect of snap loads during storm conditions. The three-leg CALM was eliminated from further study due to the offset of the buoy with respect to the stationary under-buoy hose during maximum mooring loads, which could over-tension the under-buoy hose. The four-leg CALM was selected for more detailed study for the following reasons: (a) the CALM system provides a very compliant mooring, which is the most adaptable to water depth changes of any of the concepts proposed; (b) the system can be designed to disassemble for truck transport and be reassembled at the side of a pier; (c) the installation can be accomplished with the assistance of chain-handling boats and requires a minimal amount of diver or surface swimmer support; (d) the CALM system should require very little preparation for most storms other than the possible need to disconnect the floating and under-buoy hoses; and (e) the CALM is the least costly system to construct.

To meet truck transportation requirements, a capsule buoy, 28 ft long by 11 ft 6 in. wide, by 7 ft 6 in. deep was designed. The anchor chains would be connected to a separate mooring table that is attached to the underside of the buoy. Each mooring leg would be 600 ft long and consist of a 2-in.-diam chain, and a 10,000-lb Navy Navmoor or a 6,000-lb Bruce anchor. The approximate weights (in short tons) of the

major components are: mooring buoy - 23.0; mooring table - 8.5; buoy piping - 3.0; and fluid swivel. The mooring system could be transported on as few as six "lowboy" flatbed tractor trailer trucks, or a single 40-ft by 120-ft deck barge.

The phase II report, "Recommended Design," describes in more detail the design details and installation procedures.

DREDGE MOORING STUDY
Conceptual Design
Phase I Report
U. S. Army Corps Of Engineers
Waterways Experiment Station

SOFEC, Inc., Houston, TX
Contract No. DACW39-90-C-0075

March 1, 1991

1.0 INTRODUCTION

1. Direct Pump-Out (DPO) of hopper dredges has been used in Europe and the United States for the past 25 years for beach replenishment and nearshore placement of dredge material. More recently, direct pump out of dredges has been used in the development of seaport projects in the Middle and Far East and in the construction of artificial Islands in the Arctic region of Canada.

2. The direct pump out method of off-loading hopper dredges has been a method which has gained in popularity to accomplish both the placement of dredge material into dredge fill locations and onto beach zones which require replenishment. The U.S. Army Corps of Engineers has found that there is a growing need to replenish beach zones both for protection of property, to maintain recreation areas and to place dredged material contained in hopper dredges. The Corps also sees a need to develop the direct pump out method for rapid action for recovery from natural disasters and to maintain preparedness for national defense emergencies.

3. The direct pump out of a hopper dredge is accomplished by pumping through a pipeline which has been laid along the sea floor from the location that the dredge material is required to a location offshore in which the water depth is adequate for the dredge to operate. The dredge will fill its hoppers some distance away from the replenishment location. The dredging site is usually chosen to clear or create a channel or an area which contains quality beach material. The loaded dredge will then moor itself in some manner. The mooring may be a buoy or an anchor clump weight resting on the sea floor. The dredge will then connect to the subsea pipeline through a hose which is floating on the surface of the water. The dredge then discharges the dredge material through the pipeline and returns to the dredging site for more material.

2.0 PURPOSE OF THIS STUDY

4. SOFEC, Inc. was contracted by the U.S. Army Engineers Waterways Experiment Station, as part of the Dredging Research Program, to study methods for mooring hopper dredges for the purpose direct pump out for beach replenishment and dredge material disposal. The study focuses on mooring systems which are currently used in commercial industry. The mooring shall be designed to be easily transported, assembled and installed. The mooring system should be transported by truck, rail or barge. The system should be able to be assembled either alongside a pier or on land within 48 hours of arrival at the location. The system should be able to be towed to the mooring location and connected with a minimum of diver support. The study will consist of two phases. This report presents the Phase I results.

5. Phase I establishes a series of mooring concepts to satisfy the performance criteria. This report presents analysis of the Phase I mooring systems. The mooring concepts were developed to the point that preliminary "order of magnitude" costs can be made. A preferred concept was chosen and that concept developed further. The following items are presented in the Phase I Report.

1. Analysis of Vessel Motion and Operating Water Depth Recommendations
2. Variation of Current Forces vs. Wave Loading on the Dredge.
3. Presentation of Preliminary Concepts.
4. Further Development of Preferred Concept.
5. Transportation Analysis.
6. Preliminary Installation Scenario.
7. Preliminary Operational Scenario.
8. Cost Estimates of the Preliminary and the Preferred Concept.
9. Recommendations for Phase II of the Study.

6. Phase II will further develop the preferred concept and produce preliminary engineering sketches of the mooring system complete with dimensions and overall system scantlings. Preliminary specifications for major components of the system will also be developed.

3.0 DESIGN PARAMETERS

Design Vessels

7. The mooring study considered the following three of the U.S. Army Corps of Engineers Hopper Dredges.

USACE "Wheeler"	Length	408.0 ft
	Beam	78.0 ft
	Loaded Draft	29.5 ft
USACE "Essayons"	Length	350.0 ft
	Beam	68.0 ft
	Loaded Draft	28.5 ft
USACE "McFarland"	Length	300.0 ft
	Beam	72.0 ft
	Loaded Draft	26.0 ft

Figure 3.1 shows a plan and elevation of the hopper dredge Wheeler. Tables 3.1 through 3.3 show a detailed list of vessel particulars for the Wheeler, Essayons and McFarland respectively.

Environmental Conditions

8. The following design conditions were used for the basis of the design.

a. **Water Depth.** The water depth specified for the design of the mooring is 30 feet. However, in the maximum wave and swell environments on which the mooring loads have been developed, the dredge will contact the sea floor. As a result, the design water depth was kept as close to 30 feet as possible. A further discussion of the impact of the water depth and wave conditions is discussed in Section 4.0.

b. **Operating Wave Environment.** The following wave environment is based on the practical operating limits of a hopper dredge.

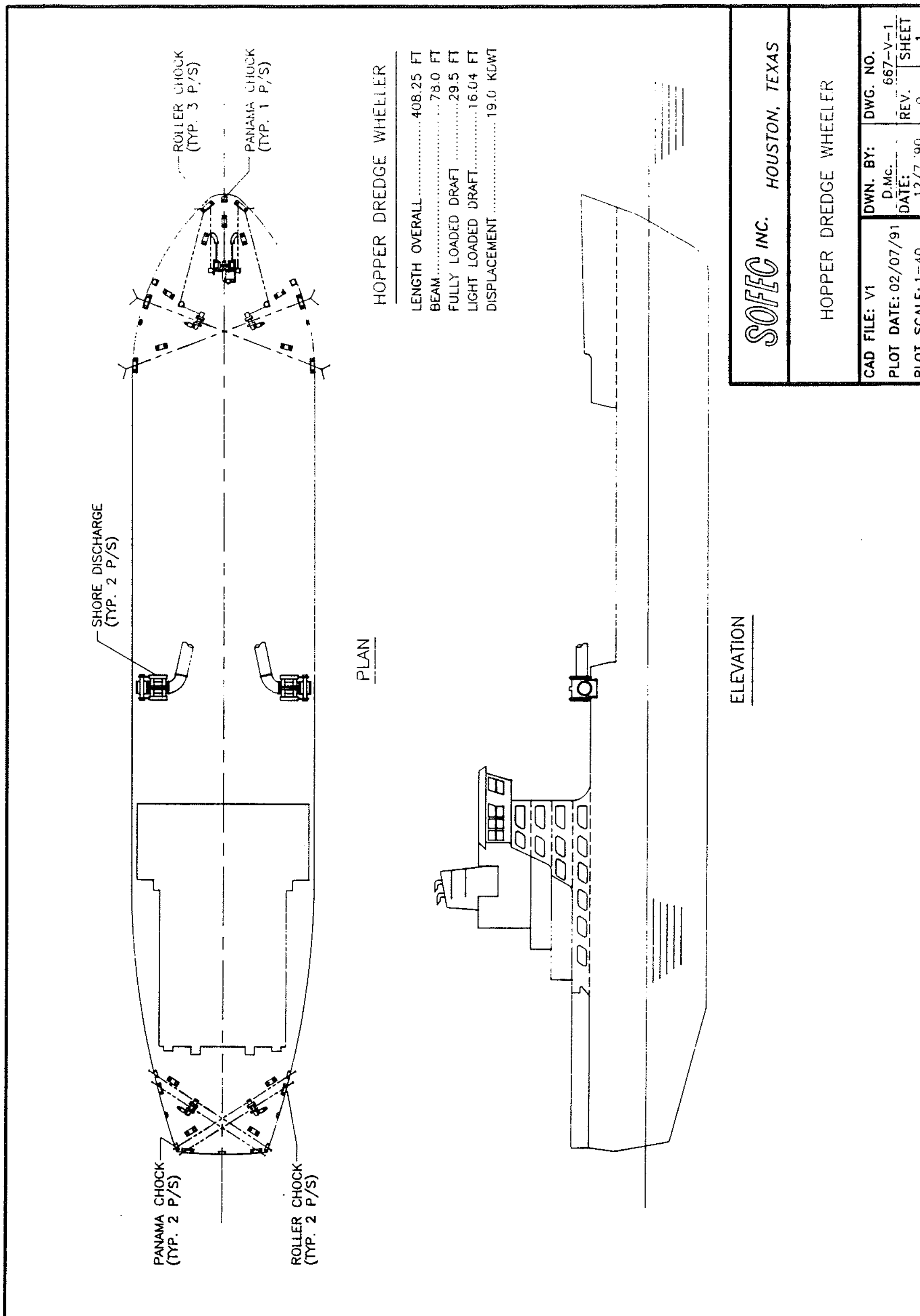


FIGURE 3.1

HOPPER DREDGE WHEELER-PLAN AND ELEVATION

TYPICAL VESSEL CHARACTERISTICS

USACE "WHEELER"

Table 3.1

OVERALL SHIP LENGTH	408.25	FEET	124.44	METERS
LENGTH BETWEEN PERPENDICULARS	384.00	FEET	117.04	METERS
BEAM OF SHIP	78.00	FEET	23.77	METERS
BILGE RADIUS	6.00	FEET	1.83	METERS
MOULDED DEPTH	39.10	FEET	11.92	METERS
FULLY LOADED DRAFT	29.50	FEET	8.99	METERS
LIGHT LOADED DRAFT	16.04	FEET	4.89	METERS
FULLY LOADED FREEBOARD	9.60	FEET	2.93	METERS
LIGHT LOADED FREEBOARD	23.06	FEET	7.03	METERS
HAWSER ATTACHMENT ABOVE DECK LEVEL .	0.00	FEET	0.00	METERS

BEAM-ON HULL AREA - LOADED	8,554	FT**2	795	M**2
BEAM-ON HULL AREA - LIGHT	13,834	FT**2	1,285	M**2
BEAM-ON SUPERSTRUCTURE AREA	2,181	FT**2	203	M**2
HEAD-ON HULL AREA - LOADED	1,248	FT**2	116	M**2
HEAD-ON HULL AREA - LIGHT	2,298	FT**2	213	M**2
HEAD-ON SUPERSTRUCTURE AREA	4,264	FT**2	396	M**2

LOAD CONDITION - DRAFT	100.00	50.00	0.00	PERCENT
COEFFICIENT - DISPLACEMENT	0.7550	0.6905	0.6320	
COEFFICIENT - WATERPLANE	0.8580	0.8238	0.7928	
DISPLACEMENT - KIPS	42,695	29,714	19,432	KIPS
DISPLACEMENT - METRIC TONS	19,366	13,478	8,814	M-TONS
DISPLACEMENT - LONG TONS	19,060	13,265	8,675	L-TONS

KMT - METACENTRIC / TRANSVERSE	33.13	34.75	40.71	FEET
KML - METACENTRIC / LONGITUDINAL ...	432.48	559.58	775.18	FEET
KB - VERTICAL CENTER OF BUOYANCY ..	15.94	12.16	9.10	FEET
KG - VERTICAL CENTER OF GRAVITY ...	27.63	25.98	30.68	FEET
VESSEL WATER PLANE AREA	25,700	24,676	23,745	FT**2
HAWSER ATTACHMENT FROM CENTERLINE ..	192.00	192.00	192.00	FEET
HAWSER ATTACHMENT ABOVE THE KEEL ...	39.10	39.10	39.10	FEET
HAWSER ATTACHMENT ABOVE MEAN WATER .	9.60	16.33	23.06	FEET
LENGTH OF VESSEL AT WATERLINE	384.00	384.00	384.00	FEET
BEAM OF VESSEL AT WATERLINE	78.00	78.00	78.00	FEET
VESSEL DRAFT	29.50	22.45	16.04	FEET
PITCH GYRADIUS	107.77	110.96	113.85	FEET
ROLL GYRADIUS	21.05	21.15	21.25	FEET
YAW GYRADUS (APPROXIMATED)	109.81	112.96	115.82	FEET
YAW GYRADUS (CALCULATED)	97.14	112.24	102.53	FEET

HEAD-ON EFFECTIVE AREA - WIND	5,512	6,062	6,562	FT**2
BEAM-ON EFFECTIVE AREA - WIND	10,735	13,501	16,015	FT**2
HEAD-ON EFFECTIVE AREA - CURRENT ...	2,301	1,751	1,251	FT**2
BEAM-ON EFFECTIVE AREA - CURRENT ...	10,948	8,182	5,668	FT**2

TYPICAL VESSEL CHARACTERISTICS

USACE "ESSAYONS"

Table 3.2

OVERALL SHIP LENGTH	350.00	FEET	106.68	METERS
LENGTH BETWEEN PERPENDICULARS	333.00	FEET	101.50	METERS
BEAM OF SHIP	68.00	FEET	20.73	METERS
BILGE RADIUS	7.50	FEET	2.29	METERS
MOULDED DEPTH	35.00	FEET	10.67	METERS
FULLY LOADED DRAFT	28.53	FEET	8.70	METERS
LIGHT LOADED DRAFT	17.86	FEET	5.44	METERS
FULLY LOADED FREEBOARD	6.47	FEET	1.97	METERS
LIGHT LOADED FREEBOARD	17.14	FEET	5.22	METERS
HAWSER ATTACHMENT ABOVE DECK LEVEL .	0.00	FEET	0.00	METERS

BEAM-ON HULL AREA - LOADED	5,274	FT**2	490	M**2
BEAM-ON HULL AREA - LIGHT	8,866	FT**2	824	M**2
BEAM-ON SUPERSTRUCTURE AREA	4,753	FT**2	442	M**2
HEAD-ON HULL AREA - LOADED	1,052	FT**2	98	M**2
HEAD-ON HULL AREA - LIGHT	1,777	FT**2	165	M**2
HEAD-ON SUPERSTRUCTURE AREA	2,430	FT**2	226	M**2

LOAD CONDITION - DRAFT	<u>100.00</u>	<u>50.00</u>	<u>0.00</u>	PERCENT
COEFFICIENT - DISPLACEMENT	0.7900	0.7600	0.6400	
COEFFICIENT - WATERPLANE	0.9300	0.9000	0.8400	
DISPLACEMENT - KIPS	33,376	24,965	16,554	KIPS
DISPLACEMENT - METRIC TONS	15,139	11,324	7,509	M-TONS
DISPLACEMENT - LONG TONS	14,900	11,145	7,390	L-TONS
KMT - METACENTRIC / TRANSVERSE	20.30	31.60	34.40	FEET
KML - METACENTRIC / LONGITUDINAL ...	425.63	541.99	763.32	FEET
KB - VERTICAL CENTER OF BUOYANCY ..	11.91	9.25	6.92	FEET
KG - VERTICAL CENTER OF GRAVITY ...	29.08	28.91	26.88	FEET
VESSEL WATER PLANE AREA	21,439	20,720	18,998	FT**2
HAWSER ATTACHMENT FROM CENTERLINE ..	166.50	166.50	166.50	FEET
HAWSER ATTACHMENT ABOVE THE KEEL ...	35.00	35.00	35.00	FEET
HAWSER ATTACHMENT ABOVE MEAN WATER .	6.47	11.81	17.14	FEET
LENGTH OF VESSEL AT WATERLINE	333.00	333.00	333.00	FEET
BEAM OF VESSEL AT WATERLINE	68.00	68.00	68.00	FEET
VESSEL DRAFT	28.53	22.29	17.86	FEET
PITCH GYRADIUS	100.32	100.15	101.48	FEET
ROLL GYRADIUS	18.78	18.67	19.09	FEET
YAW GYRADUS (APPROXIMATED)	102.06	102.66	103.26	FEET
YAW GYRADUS (CALCULATED)	87.05	83.34	80.70	FEET
HEAD-ON EFFECTIVE AREA - WIND	3,482	3,906	4,207	FT**2
BEAM-ON EFFECTIVE AREA - WIND	10,027	12,134	13,619	FT**2
HEAD-ON EFFECTIVE AREA - CURRENT ...	1,916	1,492	1,190	FT**2
BEAM-ON EFFECTIVE AREA - CURRENT ...	9,069	6,962	5,477	FT**2

TYPICAL VESSEL CHARACTERISTICS

USACE "McFARLAND"

Table 3.3

OVERALL SHIP LENGTH	300.00	FEET	91.44	METERS
LENGTH BETWEEN PERPENDICULARS	288.00	FEET	87.78	METERS
BEAM OF SHIP	72.00	FEET	21.95	METERS
BILGE RADIUS	8.00	FEET	2.44	METERS
MOULDED DEPTH	33.00	FEET	10.06	METERS
FULLY LOADED DRAFT	26.00	FEET	7.92	METERS
LIGHT LOADED DRAFT	14.26	FEET	4.35	METERS
FULLY LOADED FREEBOARD	7.00	FEET	2.13	METERS
LIGHT LOADED FREEBOARD	18.74	FEET	5.71	METERS
HAWSER ATTACHMENT ABOVE DECK LEVEL .	0.00	FEET	0.00	METERS

BEAM-ON HULL AREA - LOADED	6,221	FT**2	578	M**2
BEAM-ON HULL AREA - LIGHT	9,550	FT**2	887	M**2
BEAM-ON SUPERSTRUCTURE AREA	3,685	FT**2	342	M**2
HEAD-ON HULL AREA - LOADED	1,540	FT**2	143	M**2
HEAD-ON HULL AREA - LIGHT	2,386	FT**2	222	M**2
HEAD-ON SUPERSTRUCTURE AREA	2,348	FT**2	218	M**2

LOAD CONDITION - DRAFT	100.00	50.00	0.00	PERCENT
COEFFICIENT - DISPLACEMENT	0.7700	0.7500	0.7100	
COEFFICIENT - WATERPLANE	0.8300	0.8100	0.8000	
DISPLACEMENT - KIPS	26,380	19,804	13,178	KIPS
DISPLACEMENT - METRIC TONS	11,966	8,983	5,977	M-TONS
DISPLACEMENT - LONG TONS	11,777	8,841	5,883	L-TONS
KMT - METACENTRIC / TRANSVERSE	20.20	32.00	37.20	FEET
KML - METACENTRIC / LONGITUDINAL ...	257.13	301.50	383.75	FEET
KB - VERTICAL CENTER OF BUOYANCY ..	6.90	5.30	3.60	FEET
KG - VERTICAL CENTER OF GRAVITY ...	23.23	24.48	27.31	FEET
VESSEL WATER PLANE AREA	17,061	16,612	16,168	FT**2
HAWSER ATTACHMENT FROM CENTERLINE ..	144.00	144.00	144.00	FEET
HAWSER ATTACHMENT ABOVE THE KEEL ...	33.00	33.00	33.00	FEET
HAWSER ATTACHMENT ABOVE MEAN WATER .	7.00	12.87	18.74	FEET
LENGTH OF VESSEL AT WATERLINE	288.00	288.00	288.00	FEET
BEAM OF VESSEL AT WATERLINE	72.00	72.00	72.00	FEET
VESSEL DRAFT	26.00	20.10	14.26	FEET
PITCH GYRADIUS	78.31	76.16	72.64	FEET
ROLL GYRADIUS	17.21	17.29	17.38	FEET
YAW GYRADUS (APPROXIMATED)	80.18	77.43	74.69	FEET
YAW GYRADUS (CALCULATED)	81.40	81.21	81.01	FEET
HEAD-ON EFFECTIVE AREA - WIND	3,888	4,313	4,734	FT**2
BEAM-ON EFFECTIVE AREA - WIND	9,906	11,583	13,235	FT**2
HEAD-ON EFFECTIVE AREA - CURRENT ...	1,845	1,420	999	FT**2
BEAM-ON EFFECTIVE AREA - CURRENT ...	**7,331**	**5,654**	**4,002**	**FT**2**

Significant Wave Height	6.0 ft
Wave Direction	60^{o} from the Shoreline
Wind Velocity	30.0 knots
Wind Direction	90^{o} from the Shoreline
Current Velocity	2.0 knots
Current Direction	Parallel to the Shoreline

c. **Operating Swell Environment.** The swell environment is based on the maximum swell in which the hopper dredge can operate.

Swell Height	6.0 ft
Wave Direction	60^{o} from the Shoreline
Wind Velocity	30.0 knots
Wind Direction	90^{o} from the Shoreline
Current Velocity	2.0 knots
Current Direction	Parallel to the Shoreline

d. **Survival Environment.** The survival environment is listed as a swell height and wave height only. No period was provided in the contract. Periods will be chosen which are practical for the survival conditions.

Significant Wave Height	10.0 ft
Swell Height	20.0 ft

Design Codes

9. The dredge mooring analysis will comply with the latest edition of the following standards and codes where applicable:

1. American Bureau of Shipping (ABS) "Rules for Building and Classing Single Point Moorings"

2. American Bureau of Shipping (ABS) "Non-Destructive Inspection of Hull Welds"

3. American Bureau of Shipping (ABS) "Rules for Building and Classing Steel Vessels"

4. American Bureau of Shipping (ABS) "Guide for the Certification of Offshore Mooring Chain", latest issue.

5. Oil Companies International Marine Forum (OCIMF) "Standards for Equipment Employed in Mooring of Ships at Single Point Moorings"

6. American Petroleum Institute (API) RP2A "Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms"

7. API RP2B "Specification for Fabricated Structural Steel Pipe"

8. API Spec 2F "Specification for Mooring Chain", latest issue.

9. API RP-01 "National Association of Corrosion Engineers"

10. American Institute for Steel Construction (AISC) "Steel Construction Manual"

11. American National Standards Institute (ANSI) B31.3 "Petroleum Refinery Piping"

12. American Welding Society (AWS) D1.1-84 "Structural Welding Code"

13. American Petroleum Institute (API) Std. 1104 "Standard for Welding Pipelines and Related Facilities"

14. American Society for Testing and Materials (ASTM), appropriate sections, latest issue.

15. Steel Structures Painting Council (SSPC), as appropriate, latest issue.

16. American Society of Mechanical Engineers (ASME), Section VIII, Pressure Vessels, latest issue.

17. American Society of Mechanical Engineers (ASME), ANSI/ASME B31.3 -- Chemical Plant and Petroleum Refinery Piping, latest issue.

18. American Society of Mechanical Engineers (ASME), ANSI/ASME B31.8 -- Gas Transmission and Distribution Piping Systems, latest issue.

19. "Guidelines for Deepwater Port Single Point Mooring Design" U.S. Department of Transportation, United States Coast Guard, September, 1977

4.0 DESIGN LOADS AND OPERATIONAL PARAMETERS

Vessel Used in Study

10. Of the three vessels listed in Section 3.1, the USACE Wheeler was chosen as the vessel to be used to develop the loads for preliminary mooring system design. The Wheeler is the largest vessel of the three. The Wheeler's displacement, beam and draft would feel the greatest effect of the wind, waves and current. The draft of the Wheeler was considered in the determination of the minimum operational water depth during the maximum sea states which is discussed in Section 4.3.

System Design Load and Method of Calculation

11. SOFEC Inc. has an extensive empirical base of model test data that is applicable in deriving the mooring loads. The water depths range from 25 feet to 1,200 feet, significant wave heights range from 0 to 45 feet, current velocities range from 0 to 8 knots; wind velocities range from 0 to 100 knots. This data allows SOFEC to design systems to meet various environmental conditions and system criteria other than those specifically tested.

12. A series of model tests have been selected from the data bank that best fits the design basis. For the Dredge Mooring Study two such model test series have been selected. They are briefly summarized as follows:

SALM SHALLOW WATER MODEL TESTS
Report No. (In House Reports)
Date: May 1980

Model Basin:	Offshore Technology Corporation
System:	SALM - Hawser
Tanker:	60,000 dwt
Water Depths:	57 feet
Scale Factor:	1:45

MODEL STUDIES OF A CALM

Report No. OTC-81-74
Date: October 1981

Model Basin:	Offshore Technology Corporation
System:	CALM - Hawser
Tanker:	85,000 dwt
Water Depth:	60 feet
Scale Factor:	1:42

13. The statistical procedure used in this analysis to determine maximum design forces from model test data is similar to that described by Haring et al. "Design Of Single Point Mooring Systems For The Open Ocean", OTC 1022 (1969). It takes into account the stationary nature of the average force, F(avg) and the standard deviation of the force F(stdv) and the random nature of the maximums F(max) observed during the test duration of the model tests.

14. The force multipliers, $F^* = [\ F(max) - F(avg)\ ] / F(stdv)$, that are developed from the model test data are ranked and plotted on probability paper. Then, storm durations greater than the modeled duration may be determined from the following relationship:

$$Pd = 1 - (1 - Pm)^{Td/Tm}$$

Where:
- Pd = Probability for design duration
- Pm = Probability for modeled duration
- Td = Design duration time
- Tm = Modeled duration time

15. Based on the specified model tests and the general procedures described above, an analysis was performed to determine the design loads for the hopper dredge. Using the model tests conducted with a 60,000 dwt vessel produced a hawser design load of 83 kips and the tests with a 85,000 dwt vessel produced a design hawser load of 72 kips (Reference Table 4.1 and Table 4.2).

SCALED MODEL TEST DATA
60,000 DWT VESSEL

Table 4.1

	Model Test Data	Scale Factor	Scaled Data	Desired Data	
Vessel Size	60.00	0.33	20.00	20.00	KDWT
Net Buoyancy	400.00	0.33	133.33	#N/A	Kips
Water Depth	57.00	0.69	39.52	40.00	Feet
Sign. Wave Height	8.65	0.69	6.00	6.00	Feet
Wind Velocity	36.03	0.83	30.00	30.00	Knots
Current Velocity	1.60	0.83	1.33	2.00	Knots
Ave. Hawser Force	46.65	0.33	15.55	#N/A	Kips
Standard Deviation	37.55	0.33	12.52	#N/A	Kips
Hawser Strength	940.00	0.33	313.33	#N/A	Kips
Max. Hawser Force	247.90	0.33	82.63	#N/A	Kips

Notes:

1. Scaled data is based on "SOFEC" Model Tests conducted at the Offshore Technology Corporation in June of 1980 on a 60 KDWT Vessel.

2. The Maximum Hawers Force is based on a storm duration of six hours and a 50 percent probability.

SCALED MODEL TEST DATA
85,000 DWT VESSEL

Table 4.2

	Model Test Data	Scale Factor	Scaled Data	Desired Data	
Vessel Size	85.00	0.24	20.00	20.00	KDWT
Net Buoyancy	NA	0.24	#N/A	#N/A	Kips
Water Depth	65.00	0.62	40.13	40.00	Feet
Sign. Wave Height	9.72	0.62	6.00	6.00	Feet
Wind Velocity	38.18	0.79	30.00	30.00	Knots
Current Velocity	3.05	0.79	2.40	2.00	Knots
Ave. Hawser Force	63.17	0.24	14.86	#N/A	Kips
Standard Deviation	57.15	0.24	13.45	#N/A	Kips
Hawser Strength	586.00	0.24	137.88	#N/A	Kips
Max. Hawser Force	305.49	0.24	71.88	#N/A	Kips

Notes:

1. Scaled data is based on "SOFEC" Model Tests conducted at the Offshore Technology Corporation in October of 1981 on a 85 KDWT Vessel.
2. The Maximum Hawers Force is based on a storm duration of six hours and a 50 percent probability.

16. Based upon the model test data we would predict a design hawser load of 83 kips. However, in predicting a design load all design parameters must be taken into effect. The 83 kips is predicated on a wave spectrum not on a swell. The depth of the vessel relative to the depth of the water may cause an effect known a vessel damming. In this occurrence, the vessel effectively dams the path of the current causing an increase of current load greater than would be generally predicted by the model tests chosen for the design load development. To account for any swell and for the very shallow water depth, the predicted hawser force has been increased by approximately 20 percent to 100 kips.

Minimum Recommended Operational Water Depth

17. In order to fix the minimum water depth at which the dredge would impact the sea floor, an analysis was conducted to determine the vertical motion (z-displacement) at four locations on the bottom of the dredge as a function of wave/swell heading with respect to the barge. The z-displacement at each location is due to the combined motions of roll, pitch and heave. The four locations are described as follows. The x, y and z coordinates are referenced to the center of the dredge at keel level (0,0,0). The locations were chosen as representative of the lowest locations on the barge.

X	Y	Z		
176'	0'	0'	16.0	Feet Behind The Forward Perpendicular
-142'	0'	0'	50.0	Feet Forward Of The Aft Perpendicular
124'	33'	0'	68.0	Feet Behind The Forward Perpendicular
			6.0	Feet Inboard Of The Port Beam
124'	-33'	0'	16.0	Feet Behind The Forward Perpendicular
			6.0	Feet Inboard Of The Starboard Beam

18. It should be noted that in some locations along the Outer Continental Shelf of the United States, the dredge may be required to operate in less than the water depth chosen for this part of the analysis. This would most likely occur in areas where the bottom slope is very shallow. The dredge would be required to operate in water depths very near to its maximum loaded draft in order to be near enough to shore to reduce the length of pipeline needed to reach the shore. This limitation is set by the pumping capacity of the dredge and the flow rate needed to keep the dredge material in suspension during the pumping process. When this problem occurs, the operator will be required to reduce the operating seastate criteria, reduce the loading of the dredge or a combination to safely operate the mooring.

19. The computer program Shipsim was utilized to perform the dredge motion analysis. The program is a general-purpose six degree-of-freedom, wave-frequency, vessel motions package specifically enhanced for displacement-hull vessels with relatively large block coefficients. Vessels in this category include drillships, barges and tankers.

20. Shipsim utilizes an efficient algorithm for calculating wave-frequency forces and moments which permits accurate simulation using as input only gross hydrostatic and mass properties (metacentric heights, displacements, overall dimensions, centers of gravity, gyradii, etc.), eliminating the need for tedious and error-prone input of vessel lines details. Non-linear effects, particularly in the roll degree of freedom, are fully simulated, leading to realistic roll response predictions which depend on details of bilge geometry. A wide range of environmental conditions is accommodated, including extensive built-in wave spectral types, azimuthal spreading of wave directions and an optional independent background swell. Accelerations, velocities and displacements at any point on the vessel can be computed. Effects of finite water depth on the waves are fully simulated.

21. Shipsim output is in the form of amplitude and phase of vessel Response Amplitude Operators (RAOs) and/or statistical characterizations of vessel response to irregular wave conditions. Simulation is carried out in the frequency domain, resulting in short execution times and unambiguous predictions of statistical response values.

22. The vessel motion due to various wave heights was analyzed. A water depth of 35.0 feet was assumed. Four significant sea states were investigated:

	Significant Wave Height	Peak Wave Period
Wave #1	2.00	3.90
Wave #2	4.00	5.52
Wave #3	6.00	6.76
Wave #4	8.00	7.81

23. The results of the analysis indicate that the vessel will remain clear of the bottom in a 6.00 foot significant sea with a peak wave period of 6.76 seconds. The vessel will touch the sea floor in a 8.00 foot significant sea (Reference graphs in Appendix A).

24. The vessel motion due to various swell heights was analyzed. A water depth of 35.0 feet was assumed. Four significant sea states were investigated:

	Swell Height	Swell Period
Wave #1	2.00	11.00
Wave #2	4.00	11.00
Wave #3	6.00	11.00
Wave #4	8.00	11.00

25. The results of the analysis indicate that the vessel will impact the bottom in a 6.00 foot, 11.00 second period, swell if the vessel angle with respect to the swell is equal to or greater than 60 degrees (Reference graphs in Appendix A). The vessel will impact the bottom for all conditions greater than a 6.00 foot swell.

Wave Reduction vs. Current Increase

26. In some instances, the current force may be greater than the design current force of 2.0 knots. The vessel response due to an increase in current was analyzed using a combination of model test data and the computer program Forcesim. The model test data were used to derive the standard deviations for the maximum forces for seastates from 6.0 ft significant to 2.0 ft significant for vessel load cases of 100% loaded, 50% loaded and light (0% loaded). The system was modeled in the computer program Forcesim for currents from 2.0 knots to 5.0 knots. The mean force output was then statistically increased based on the standard deviations derived from the model tests. Table 4.3 presents the results of the analysis. The maximum mooring load is 100 kips or 50 short tons. The table shows the significant wave height/current combinations which maintain a mooring force at or less than the design mooring force of 100 kips. The areas in bold and in the boxes contain the combinations in which the load exceeds the maximum design load. Note that the 50% load condition produces more excluded load cases due to the attitude of the vessel with respect to the waves and current due to the 30 knot wind. Other factors such as damping and its effect on behavior also change as the vessel draft changes

DESIGN HAWSER FORCES Versus WAVE HEIGHT & CURRENT

Table 4.3

	SIGNIFICANT WAVE HEIGHT (FEET)	CURRENT VELOCITY (KNOTS) 2.00	3.00	4.00	5.00
		DESIGN HAWSER FORCE (KIPS)			
	6.00	100.00	**105.58**	**113.31**	**123.02**
	5.50	91.71	97.12	**104.70**	**114.30**
100%	5.00	83.42	88.65	96.10	**105.57**
VESSEL	4.50	75.87	80.90	88.13	97.41
LOAD	4.00	68.32	73.16	80.17	89.26
CASE	3.50	61.45	66.08	72.90	81.82
	3.00	54.58	59.00	65.63	74.37
	2.50	48.15	52.41	58.91	67.54
	2.00	41.72	45.81	52.18	60.71
	6.00	99.35	**108.65**	**121.79**	**137.72**
	5.50	91.40	**100.58**	**113.53**	**129.35**
50%	5.00	83.44	92.51	**105.27**	**120.97**
VESSEL	4.50	76.11	84.95	97.44	**112.97**
LOAD	4.00	68.78	77.40	89.62	**104.96**
CASE	3.50	62.06	70.42	82.39	97.53
	3.00	55.34	63.44	75.16	90.09
	2.50	49.05	56.95	68.49	83.27
	2.00	42.76	50.45	61.82	76.45
	6.00	99.26	96.64	**104.82**	**117.67**
	5.50	91.29	89.03	97.31	**110.08**
0%	5.00	83.33	81.41	89.79	**102.50**
VESSEL	4.50	75.75	74.30	82.58	95.11
LOAD	4.00	68.17	67.18	75.38	87.72
CASE	3.50	61.15	60.67	68.60	80.70
	3.00	54.14	54.15	61.82	73.67
	2.50	47.64	48.07	55.45	67.11
	2.00	41.14	41.98	49.08	60.54

Note: The values in bold indicate that if the hopper dredge is moored in the specified environment the bow hawser force will exceed the predicted design hawser force.

5.0 PRELIMINARY MOORING CONCEPTS

27. Preliminary concepts were developed which could act as possible moorings for the hopper dredge. The concepts were adaptations of commercially operating mooring and offshore systems. The following five concepts were presented for consideration.

1. Guyed Tower
2. Tension Leg Platform (TLP)
3. Single Anchor Leg Mooring (SALM)
4. Catenary Leg Mooring (CALM) - 3 Leg
5. Catenary Leg Mooring (CALM) - 4 Leg

28. The concepts were judged on the following criteria:

1. Is the system a practical mooring for the water depth in which the system will need to operate?

2. Can the system operate in water depths from 30 ft to 45 ft?

3. Can the system be assembled at a pier in 24 hours or less?

4. Can the system be assembled with a 25 ton crane?

5. Can the system be prepared to withstand a storm with 10' significant seas in 4 hours or less?

6. Can the system be installed with a minimum of diver support?

7. Can the system be transported by truck?

8. Can the system be transported by rail?

9. Will the system be able to be safely towed 100 miles or less?

10. Is the system cost effective?

29. The following pages describe each of the preliminary systems along with their advantages and disadvantages. Based on the information presented here and discussions with the Corps of Engineers representatives, the Catenary Anchor Leg Mooring (CALM) - 4 Leg concept was chosen as the basis of continuing the study. CALM systems are the most widely used moorings throughout the world. They are more tolerant to water depth changes, seafloor slopes and conditions than any of the other concepts presented. The CALM buoy is a wave rider and for that reason is much less susceptible to wave action damage than the other systems. No equipment other than the mooring chains, anchors

and submerged pipeline are in contact with the seafloor reducing the damage of equipment by the deposition of bottom sediments.

Guyed Tower

30. Figure 5.1 shows the Guyed Tower concept. The tower is supported by an 80 ft X 80 ft base. A vertical column is connected to the base through a u-joint and rises to the surface. A rotating turntable is mounted atop the vertical column. The mooring hawser and floating hose connect to the mooring system at the turntable. Four guy wires provide the upright stability for the mooring system.

a. **Guyed Tower System Advantages.** The system weight is minimized due to the structural arrangement. In comparison to a SALM or TLP, the overall structure will require less steel.

The base, tower and turntable could be disassembled and loaded onto trucks for transport by land.

The system could be assembled at dockside and floated out to the mooring site. The base could then be flooded to rest on the seafloor and the guy wires attached.

To prepare for a storm, the turntable would be small enough that it could be disconnected and lifted onto a barge for transport to storage on shore. The tower could be disconnected from the guy wires, flooded and pivoted to lay on the base. The tower could be secured by divers to inhibit movement.

b. **Guyed Tower System Disadvantages.** The Guyed Tower is based on the concept of a gravity base. As a result the base must be heavy enough to resist sliding along the seafloor. This weight will cause the base to be broken into many sections for truck transport.

The system installation, preparation for storms and retrieval will require extensive diver support.

The tower presents a very stiff mooring which will cause very high dynamic loads in the hawser and turntable. This may increase the

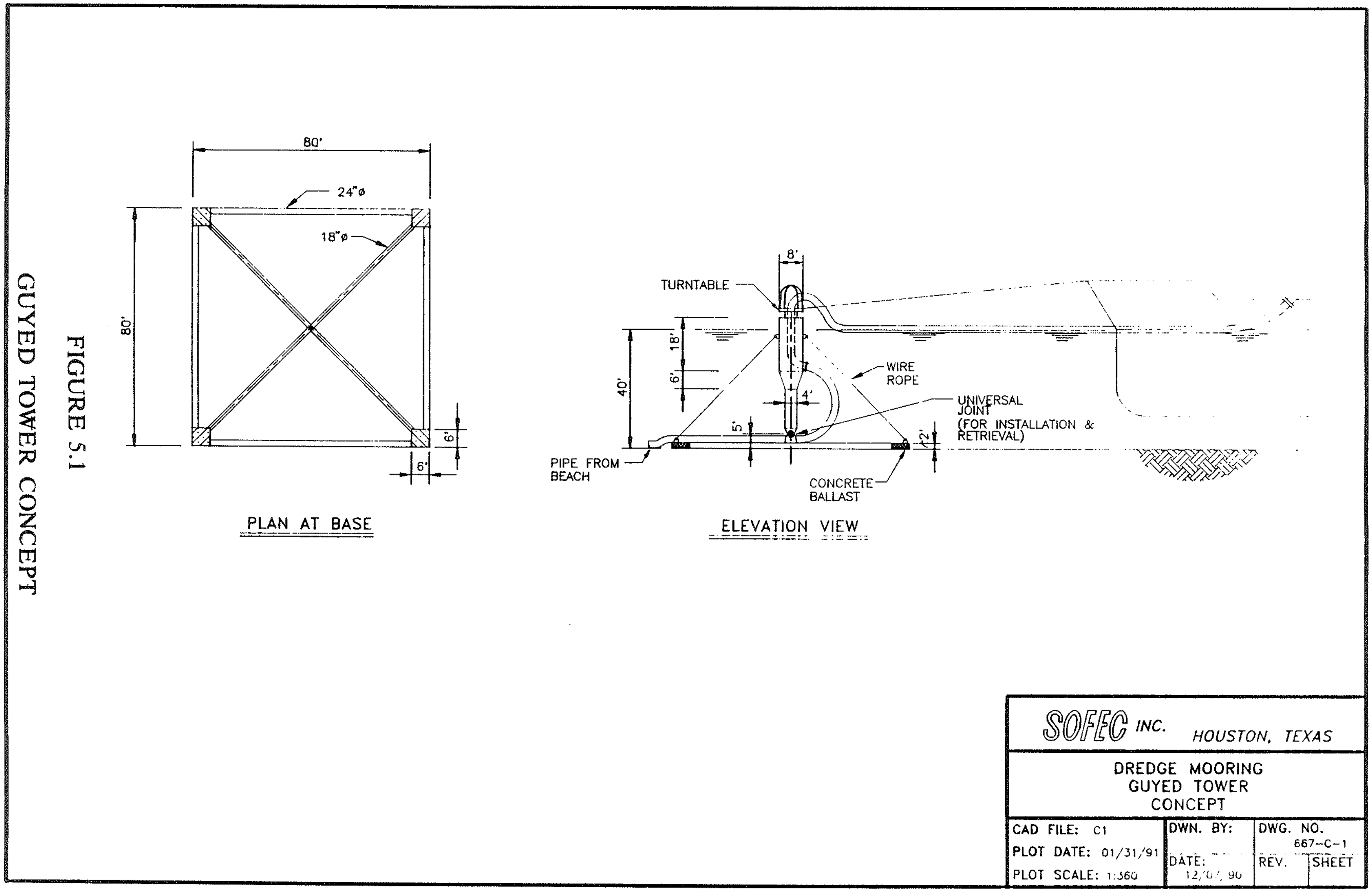


FIGURE 5.1
GUYED TOWER CONCEPT

size of the turntable and turntable bearing which will add additional costs.

31. The Guyed Tower was not chosen for further study primarily due to the size of the base required to resist sliding caused by the maximum mooring load and the logistics of transporting, assembling and installing the base.

Tension Leg Platform (TLP)

32. The Tension Leg Platform concept is shown in Figure 5.2. The TLP is anchored by a base which is approximately 25 ft by 25 ft. Tendons extend from the base upward to the buoyancy columns which make the platform. A turntable sits on top of the platform. The mooring hawser and floating hose attach to the turntable.

a. Tension Leg Platform Advantages. The TLP provides a very compliant mooring system. The tension of the system due to the excess buoyancy provides a relatively stiff spring which helps to damp the dynamic forces on the mooring while at the same time allowing the system to displace very little. The minimal system displacement reduces the operating circle needed to moor the vessel and assist in the design of the submerged hose system.

The system could be designed to be a bolted assembly which would facilitate disassembly for truck transport.

Since the TLP is very buoyant, the TLP can serve as the device to transport the base to the mooring location. The base can be deballasted and transported to the mooring location while it is suspended below the TLP. Portions of the base can then be flooded and the TLP tendons released to lower the base to the seafloor. The remainder of the TLP base can then be flooded to increase the on bottom weight of the base.

b. Tension Leg Platform Disadvantages. The overall system is one of the most complex of the concepts presented. The TLP requires more fabricated steel than some of the other concepts to accomplish the same function. The base of the TLP controls the size of the platform at the surface. If in order to resist sliding, the base needs to increase in size, the platform at the surface will be required to increase in size, which causes the turntable to increase in size to support the overboard piping.

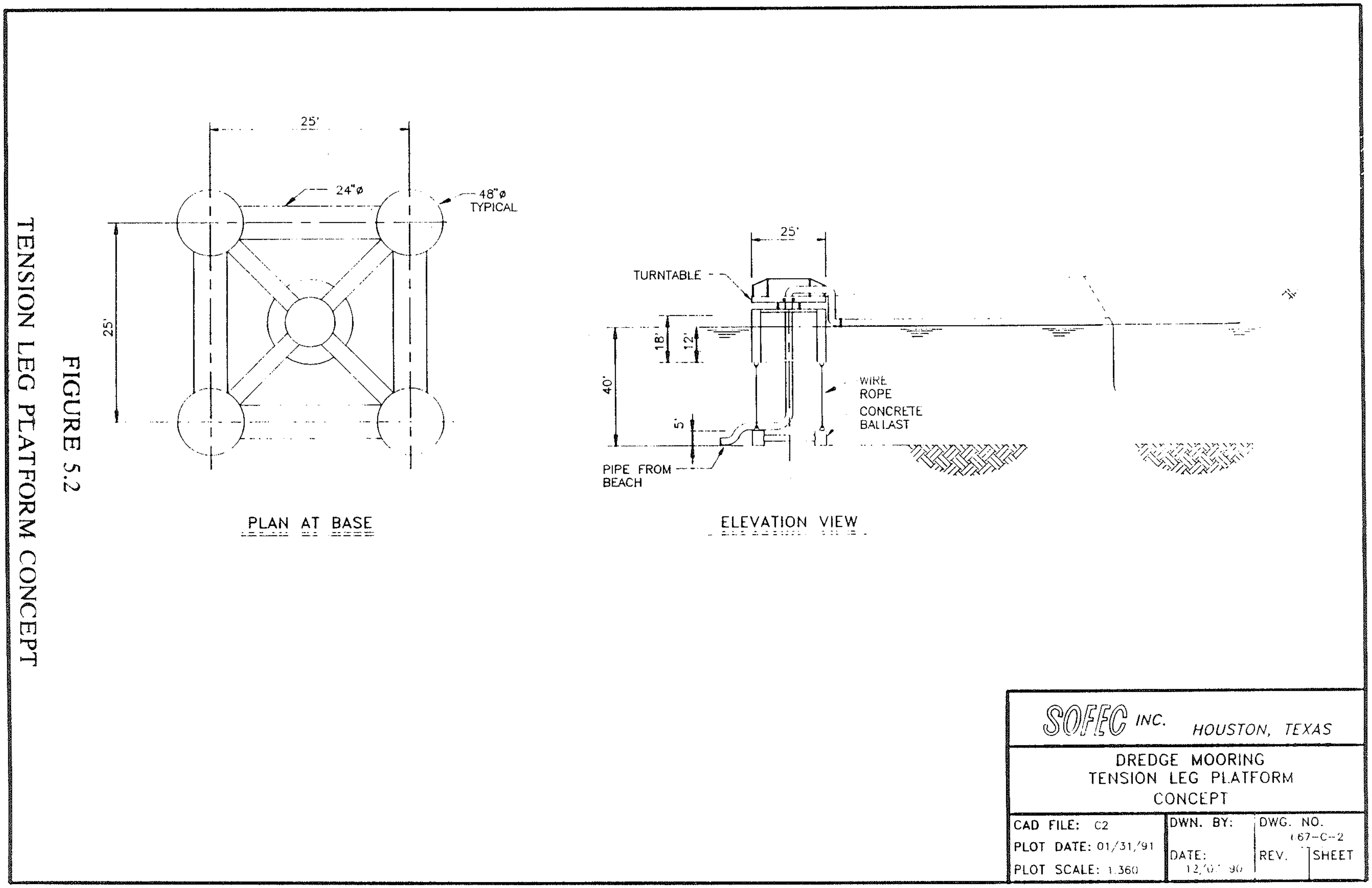


FIGURE 5.2
TENSION LEG PLATFORM CONCEPT

The TLP is difficult to protect in a storm. If waves or swell become large enough, the tendons become slack. This causes snap loads in the tendons which is a very difficult design problem.

The system requires extensive diver support to install the base and connect the hose to the pipeline.

33. The Tension Leg Platform was not chosen for further study primarily due to the difficulty of designing a system in which the tendons could with stand the effect of snap loads during storm conditions.

Single Anchor Leg Mooring Tower (SALM)

34. The Single Anchor Leg Mooring Tower (SALM) concept is shown in Figure 5.3. In the figure, the SALM is moored by an 80 ft by 80 ft base. The SALM tower is connected to the base through a u-joint. On top of the SALM tower is a rotating turntable. The floating discharge hose and mooring hawser connect to the turntable. Other than the 4-Leg Catenary Leg Mooring (CALM), the SALM Tower appeared to be the second most suitable mooring system.

35. More analysis was undertaken to approximate the size and weight of SALM base which would be needed to resist sliding during the peak mooring loads. Figure 5.4 shows a configuration for modular base concept. The base is composed of 13 modules and covers an area approximately 56 ft on each side. Each module weighs 25 short tons for a total in air weight of 325 short tons.

a. **Single Anchor Leg Mooring Tower - Advantages.** The SALM Tower provides a compliant mooring system which will help to reduce the dynamic mooring forces by damping the motion of the vessel.

The system can be disassembled for transport and the pieces can be loaded onto trucks.

The SALM Tower and base can be towed to the mooring location as one piece. The base can be flooded and lowered to the bottom.

In preparation for storms, the SALM turntable can be disconnected and lifted off of the SALM. The tower can be flooded and lowered to the seafloor. Divers can secure the tower to the SALM base.

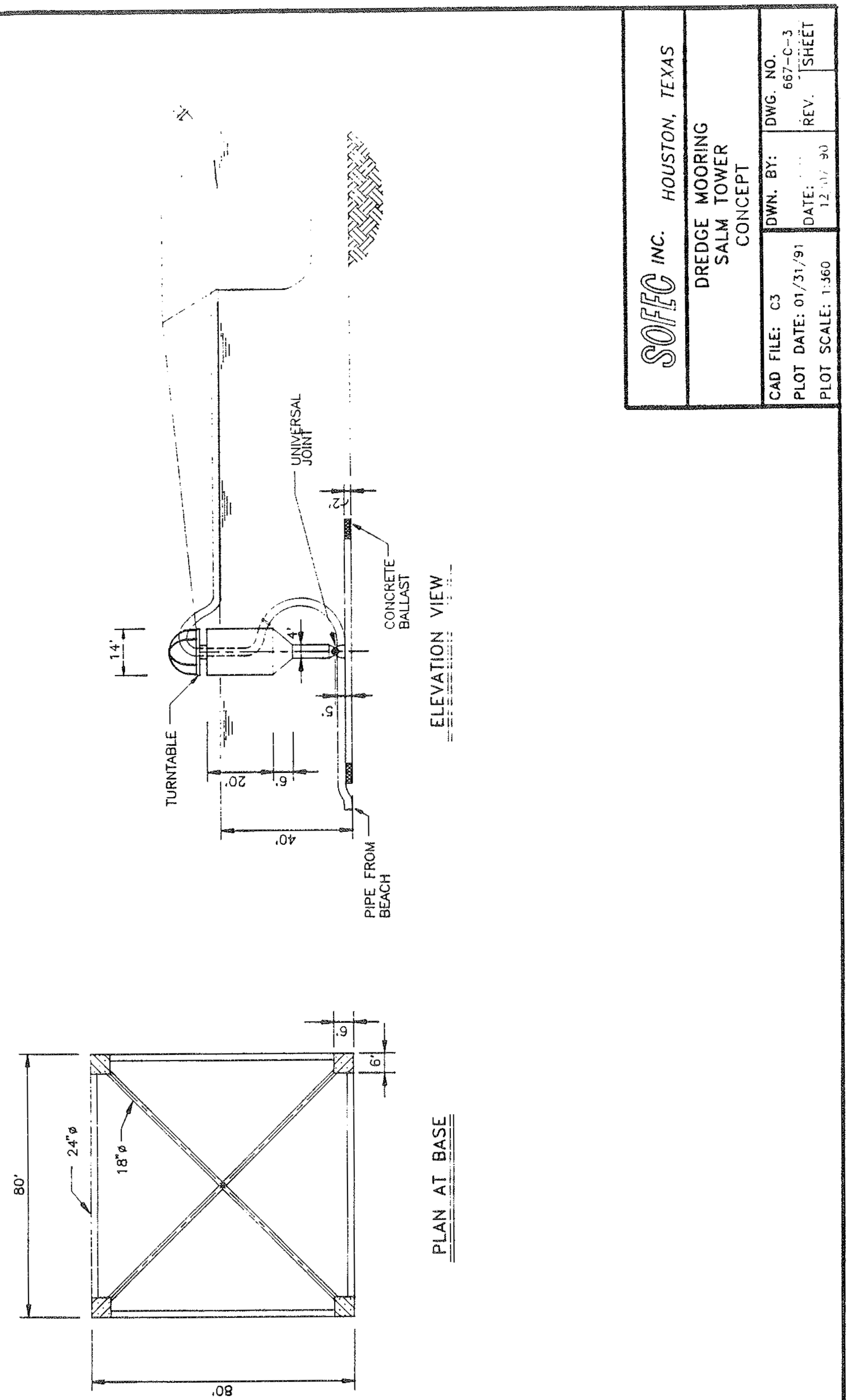


FIGURE 5.3

SINGLE ANCHOR LEG MOORING TOWER CONCEPT

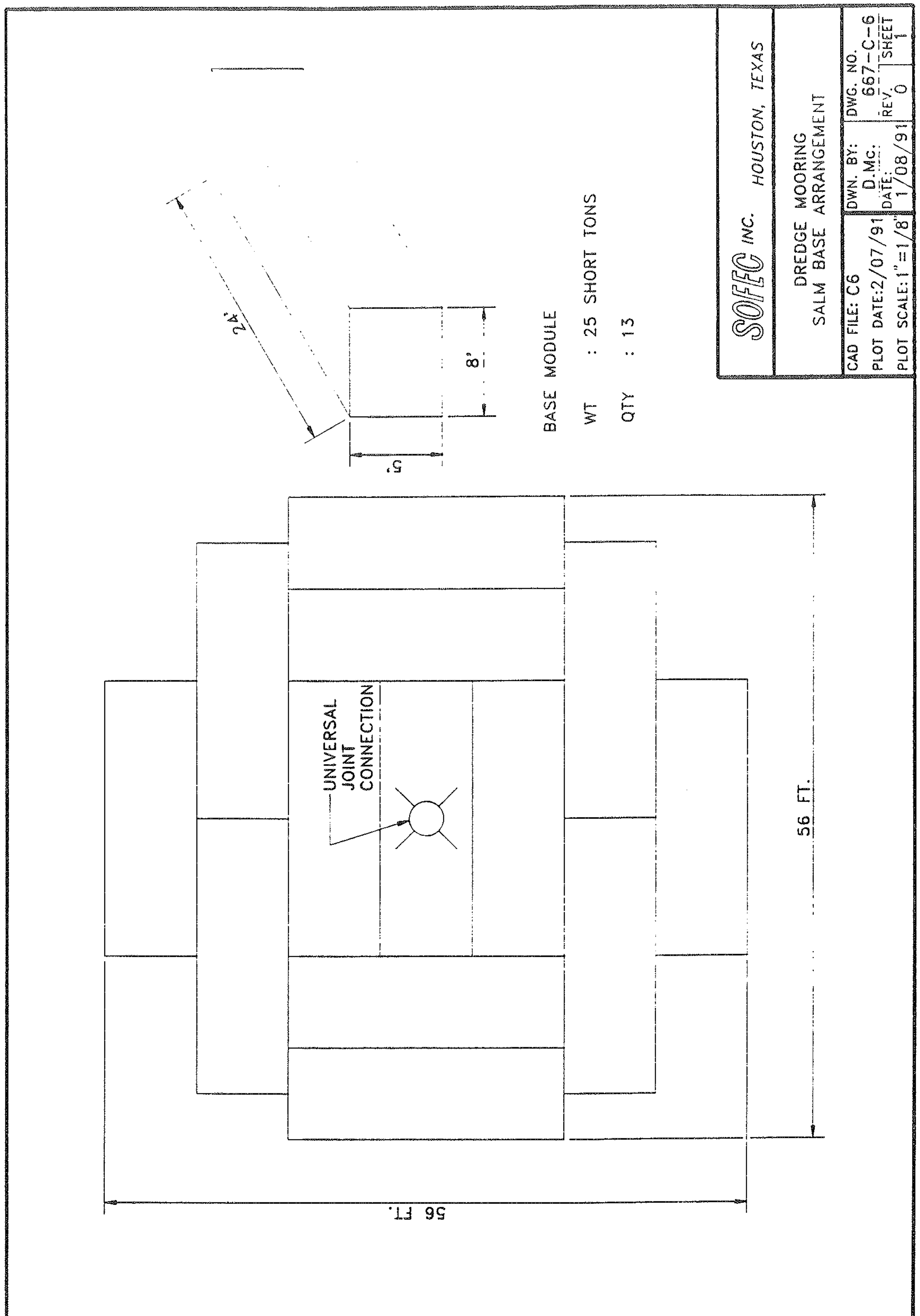


FIGURE 5.4

SALM BASE ARRANGEMENT

b. **Single Anchor Leg Mooring Tower - Disadvantages.** As shown in Figure 5.4, the SALM base will require a large amount of fabricated steel to supply the on bottom weight which is required to resist sliding under the maximum mooring loads. The base alone would require 13 truck loads to be transported.

At the maximum mooring loads, the SALM turntable and swivel will be submerged. This will require that the turntable be designed to withstand the water pressure and will increase its weight.

The system will require diver support to install the SALM base and to connect the hose to the pipeline.

36. The Single Anchor Leg Mooring Tower was not chosen for further study primarily due to the size of the base required to resist sliding caused by the maximum mooring load and the logistics of transporting, assembling and installing the base.

Catenary Anchor Leg Mooring (CALM) 3-Leg Concept

37. The Catenary Anchor Leg Mooring (CALM) 3-Leg concept is shown in Figure 5.5. The system is anchored by 3 anchor legs which are arranged 120^{o} apart. Each anchor leg is approximately 600 ft long with an anchor suitable for sand and clay connected to the end. The CALM buoy in the figure is 24 ft diameter and has a 28 ft diameter skirt which extends beyond the buoy. A turntable mounts on top of the buoy. The mooring hawser and floating discharge hose connect to the turntable.

a. **Catenary Anchor Leg Mooring - Advantages.** The major advantages of the CALM system will be covered in Section 5.5, the CALM 4-Leg concept.

The one major advantage that the 3-Leg CALM has over the 4-Leg CALM is that one less anchor leg needs to be purchased and installed. This is a saving of both time and money.

b. **Catenary Anchor Leg Mooring - Disadvantages.** The disadvantage of reducing the number of CALM legs is that the buoy will move a greater horizontal distance under the maximum mooring load. This could damage the underbuoy hose.

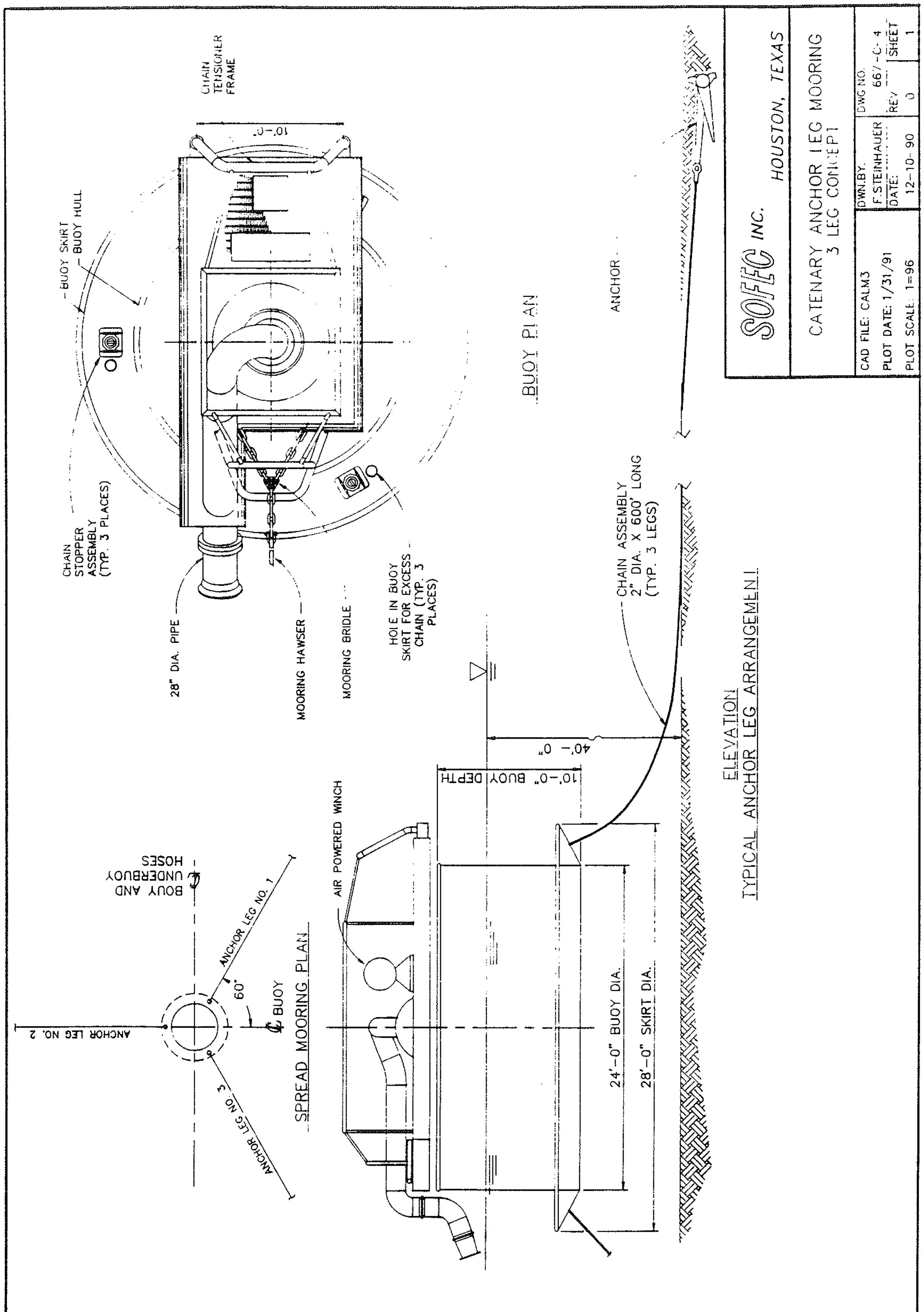


FIGURE 5.5

CATENARY ANCHOR LEG MOORING 3-LEG CONCEPT

38. The Catenary Anchor Leg Mooring 3-Leg was not chosen for further study primarily due to the offset of the buoy under the effects of the maximum mooring loads with respect to the stationary submerged pipeline. The large offset could over tension the underbuoy hose by pulling against the submerged pipeline.

Catenary Anchor Leg Mooring (CALM) 4-Leg Concept

39. The Catenary Anchor Leg Mooring (CALM) 4-Leg concept is shown in Figure 5.6. The system is anchored by 4 anchor legs which are arranged 90^{o} apart. Each anchor leg is approximately 600 ft long with an anchor suitable for sand and clay connected to the end. The CALM buoy in the figure is 24 ft diameter and has a 28 ft diameter skirt which extends beyond the buoy. A turntable mounts on top of the buoy. The mooring hawser and floating discharge hose connect to the turntable.

a. **Catenary Anchor Leg Mooring - Advantages.** The CALM system provides a very compliant mooring which is the most adaptable to water depth changes of any of the concepts proposed.

   The system can be designed to disassemble for truck transport and reassembled at the side of a pier.

   The installation and retrieval of the system can be accomplished with the assistance of chain handling boats. A minimal amount of diver or surface swimmer work would be required.

   A CALM system is inherently a wave rider and should require very little preparation for most storms other than the possible need to disconnect the floating and underbuoy hoses.

b. **Catenary Anchor Leg Mooring - Disadvantages.** The 4-Leg CALM would require the purchase and installation of one more anchor leg than the 3-Leg CALM.

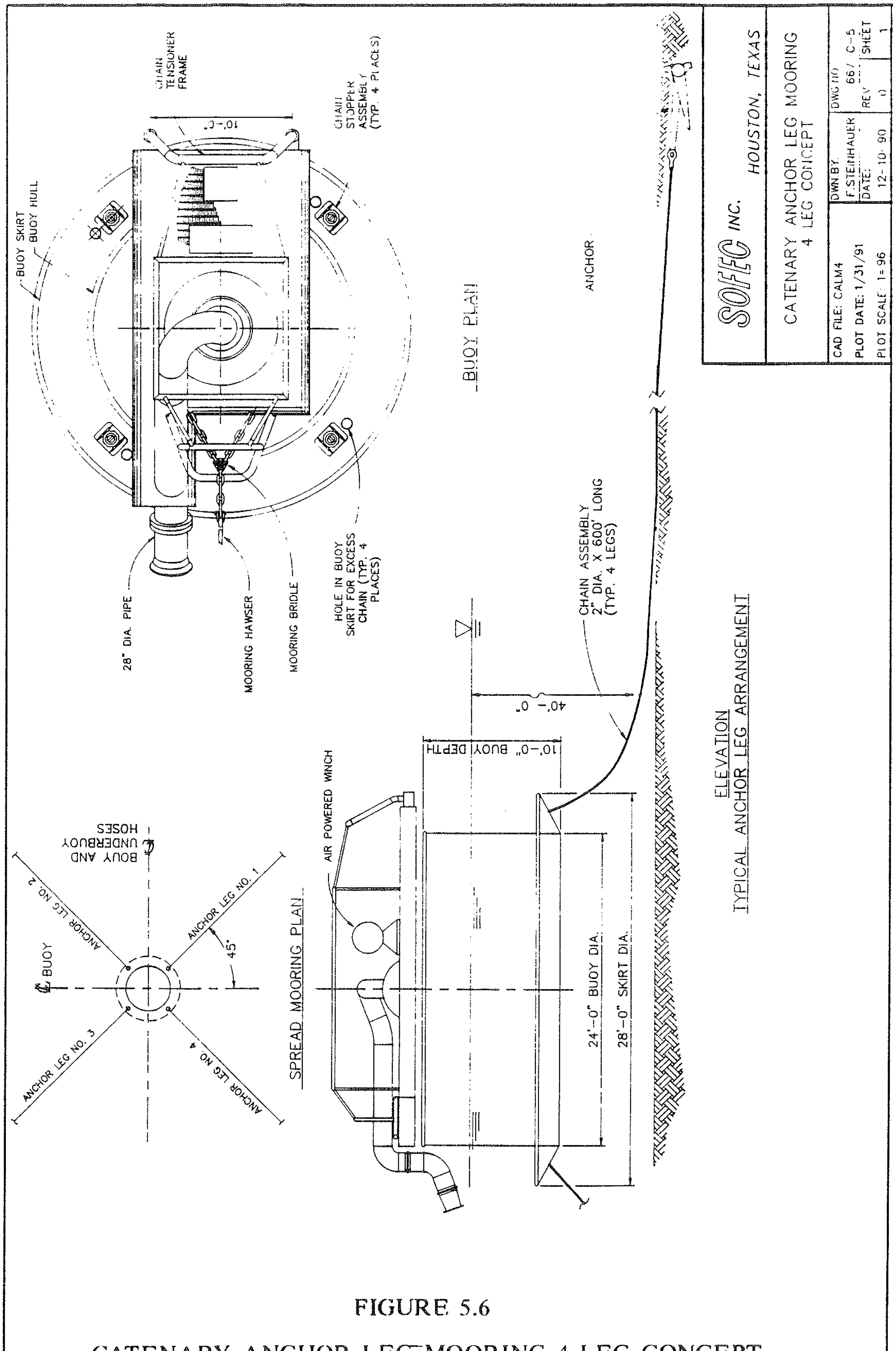


FIGURE 5.6

CATENARY ANCHOR LEG MOORING 4-LEG CONCEPT

6.0 CALM MOORING SYSTEM DESIGN

40. The 4-Leg CALM mooring concept was chosen as the concept on which to focus the detailed analysis for Phase I of the mooring study. The CALM preliminary design focused on a light weight buoy which could be transported either as a single piece or disassembled into multiple pieces. Two concepts were considered.

41. The first buoy concept is a system very similar to the design shown in Figure 5.6 with a fixed cylindrical buoy and a rotating turntable mounted on top of the buoy. The buoy size required to support the turntable and piping became so large that the buoy would need to be divided into at least 3 segments to have segments small and light enough for truck transport. Assembly of the buoy would be difficult along side a pier and the hardware to connect the buoy segments would increase the weight and complexity of the system. As a result of these concerns, this concept was not developed further.

42. The second buoy concept is a capsule shaped buoy (in plan view) which rotates about a fixed mooring table. The buoy is one complete component and does not require disassembly for transport. The buoy supplies the mounting location for the transfer piping and acts as platform for the tensioning of the anchor legs and connection of the under buoy hose during the system installation. The mooring table is a light weight structure attached to the buoy by permanently lubricated bearings. The mooring table acts to transfer the mooring loads from the buoy to the mooring chains. Figure 6.1 depicts the complete mooring system in operation.

Buoy Assembly

43. The buoy assembly (Figure 6.2 and Figure 6.3) is a capsule shaped buoy which is approximately 28'-0" long by 11'-6" wide by 7'-6" deep. The reason for choosing a capsule shape is to provide a buoy which is long enough and possesses adequate flotation to support the piping while keeping the buoy narrow enough to allow road transport with out major disassembly. The lift weight of the buoy will be approximately 23 short tons. The lift weight of the piping will be approximately 3 short tons.

44. The buoy acts as a foundation for the fluid piping. The slurry from the dredge enters the buoy through a floating hose connected to the fluid piping just above the water at the outer edge of the buoy. The piping has been designed to contain the least number of bends to reduce the areas of high abrasion. The slurry travels through the piping and through a fluid swivel mounted just below the 90° elbow. The piping connects to a flexible rubber underbuoy hose string just below the fluid swivel. The

buoy centerwell acts as a fairlead for the connection of the underbuoy hose.

45. The buoy is supplied with a water ballastable compartment opposite the fluid piping. The compartment is flooded after the system has been installed. The ballast is necessary to offset the weight of the fluid in the piping. The ballast box can be deballasted using air pressure. When the ballast box is without ballast the buoy will be trimmed toward the piping which will assist towing.

46. The buoy piping support also acts as a mooring bracket for the connection of the mooring hawser.

47. At the bottom of the centerwell of the buoy a 48" flange is provided. This flange supplies a bolted connection to the buoy mooring table.

48. The buoy will be supplied with lifting lugs for system assembly, sockets for portable handrails and mounting pads for a removable winch will be used for the chain and hose installation.

Mooring Table Assembly

49. The mooring table assembly (Figure 6.4) mounts to a 48" flange located at the bottom of the buoy centerwell. The mooring table assembly extends the buoy centerwell below the chain connection location and provides a bell fairing at the bottom of the centerwell to assist to installation of the under buoy hose and to reduce chafing wear on the underbuoy hose. A locking mechanism will be incorporated to prevent relative motion between the buoy and the mooring table during towing and chain installation.

50. The mooring table also provides four chain support assemblies which connect the CALM buoy to the mooring chains. The mooring table can be lifted by the chain support assemblies during system assembly. The lift weight of the mooring table is approximately 8.5 short tons.

Mooring Table Support Assembly

51. The mooring table support assembly (Figure 6.5) consists of two permanently lubricated bronze bushings located at the top and bottom of the centerwell of the buoy. The bushings are less expensive and require less maintenance than a roller bearing assembly.

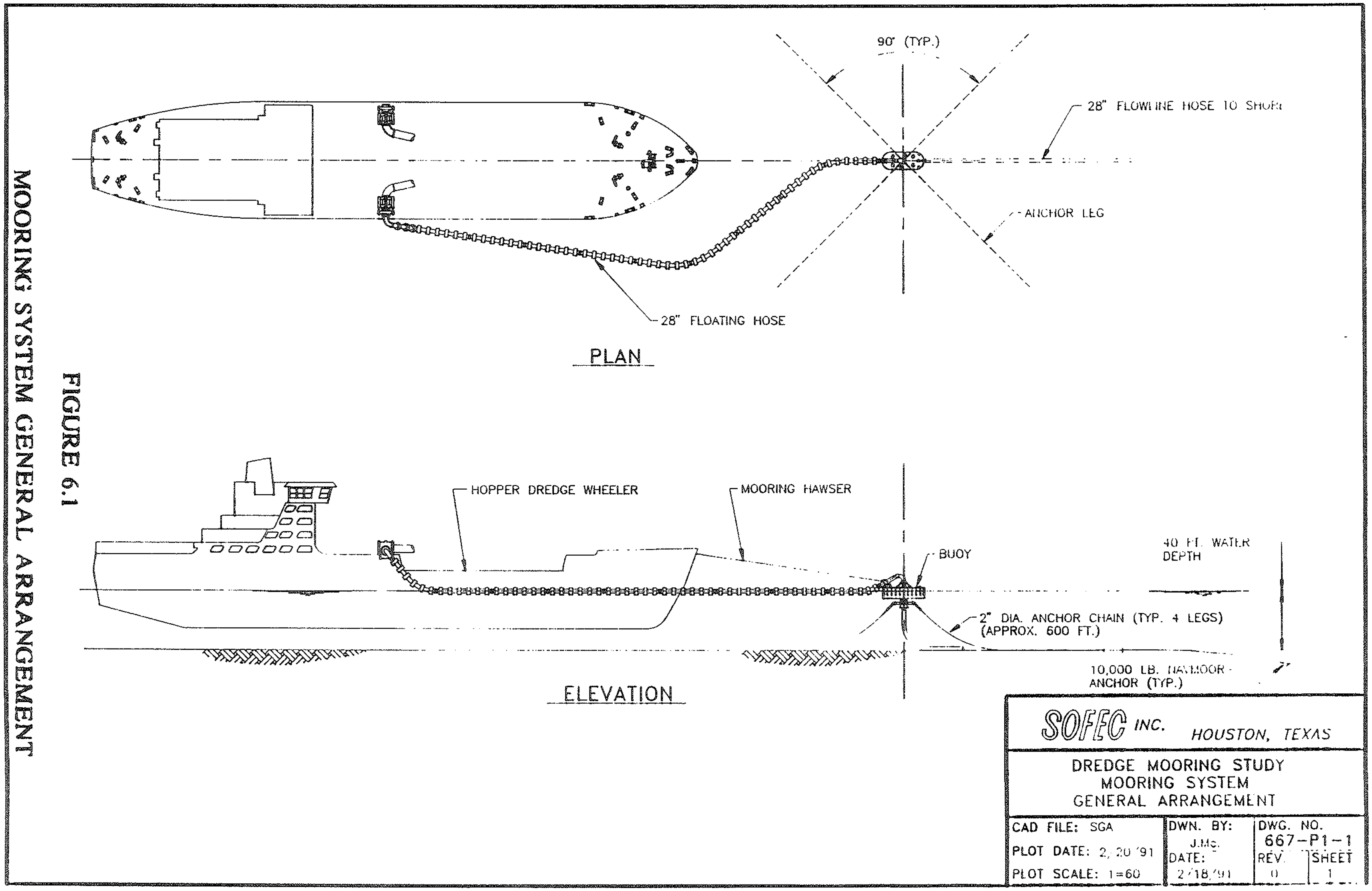


FIGURE 6.1
MOORING SYSTEM GENERAL ARRANGEMENT

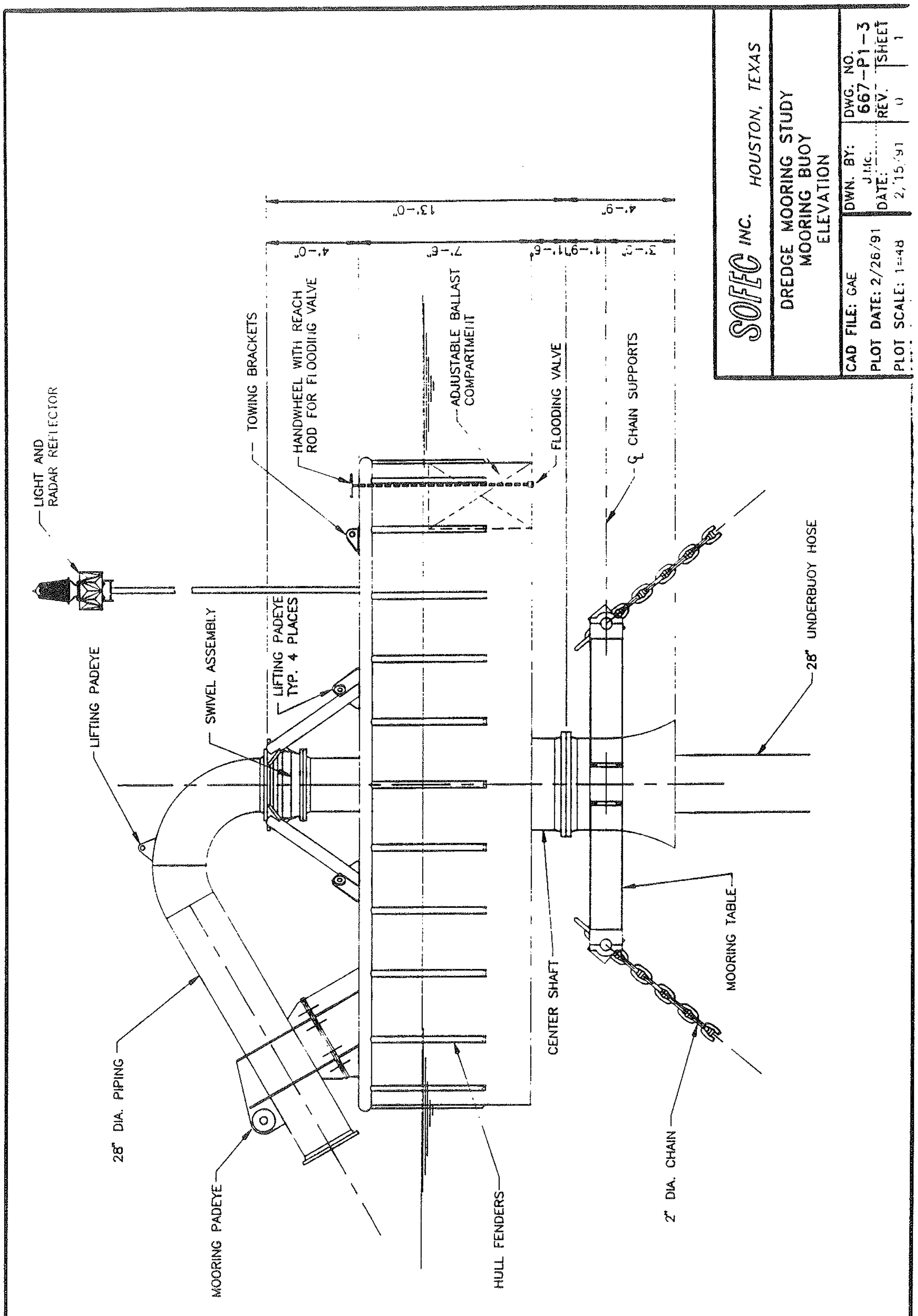
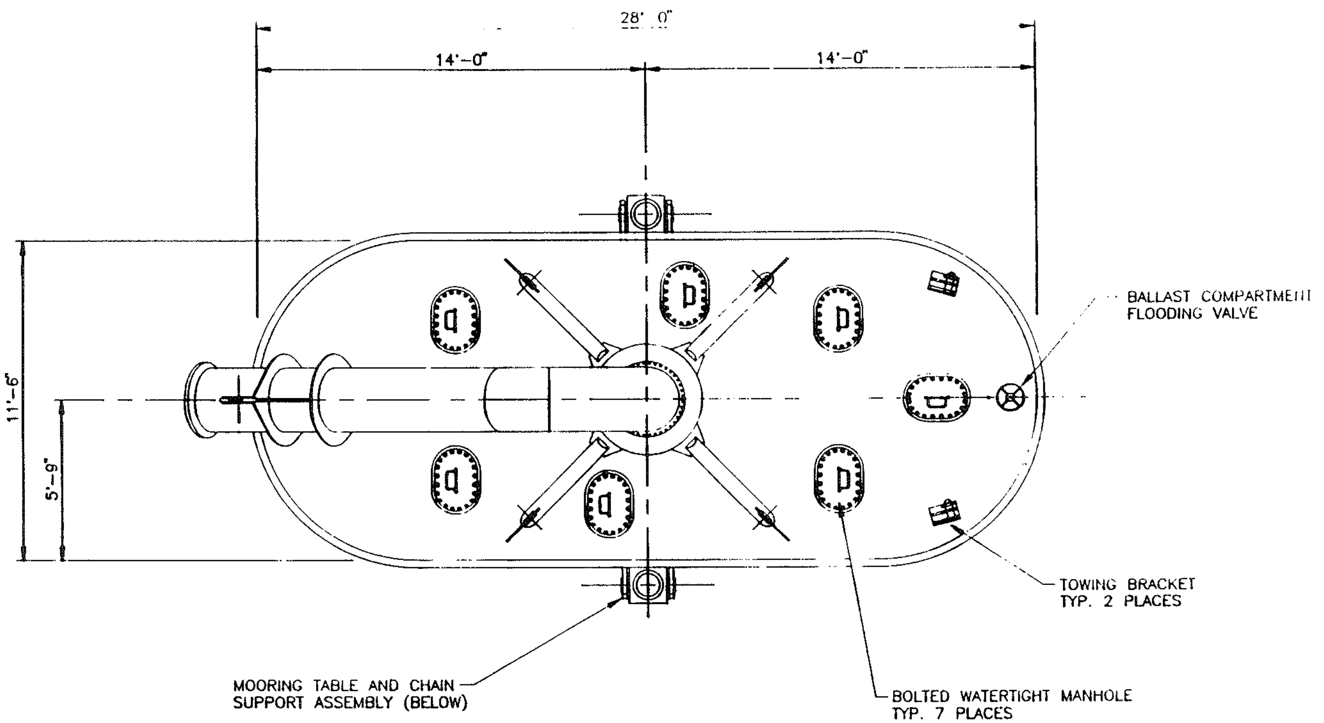


FIGURE 6.2

MOORING BUOY - ELEVATION

FIGURE 6.3
MOORING BUOY - PLAN



SOFEC INC. HOUSTON, TEXAS

DREDGE MOORING STUDY
MOORING BUOY
PLAN VIEW

CAD FILE: GAP	DWN. BY: J.Mc.	DWG. NO. 667-P1-4
PLOT DATE: 2/26/91	DATE: 2/15/91	REV. 0 / SHEET 1
PLOT SCALE: 1=48		

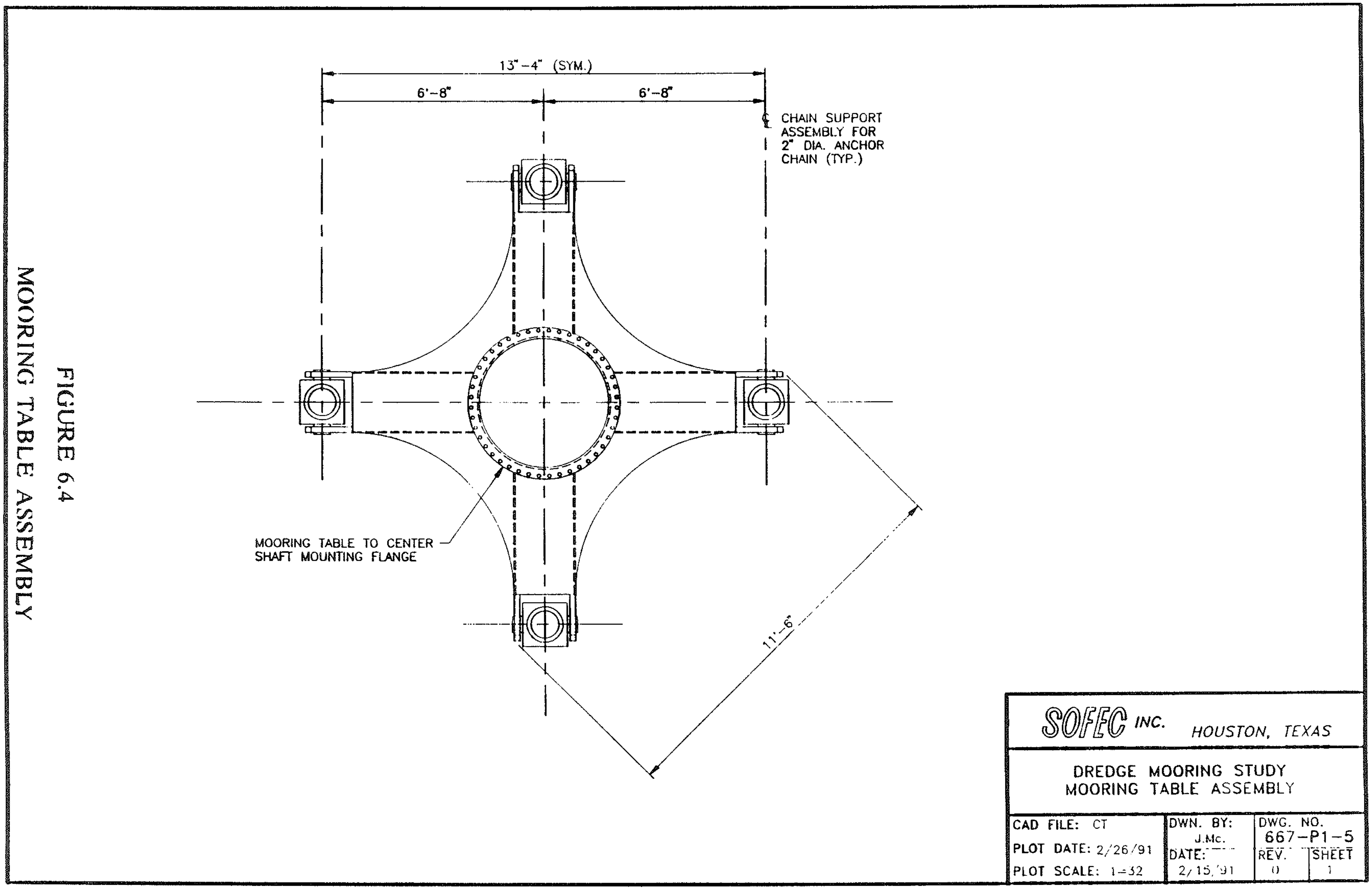


FIGURE 6.4
MOORING TABLE ASSEMBLY

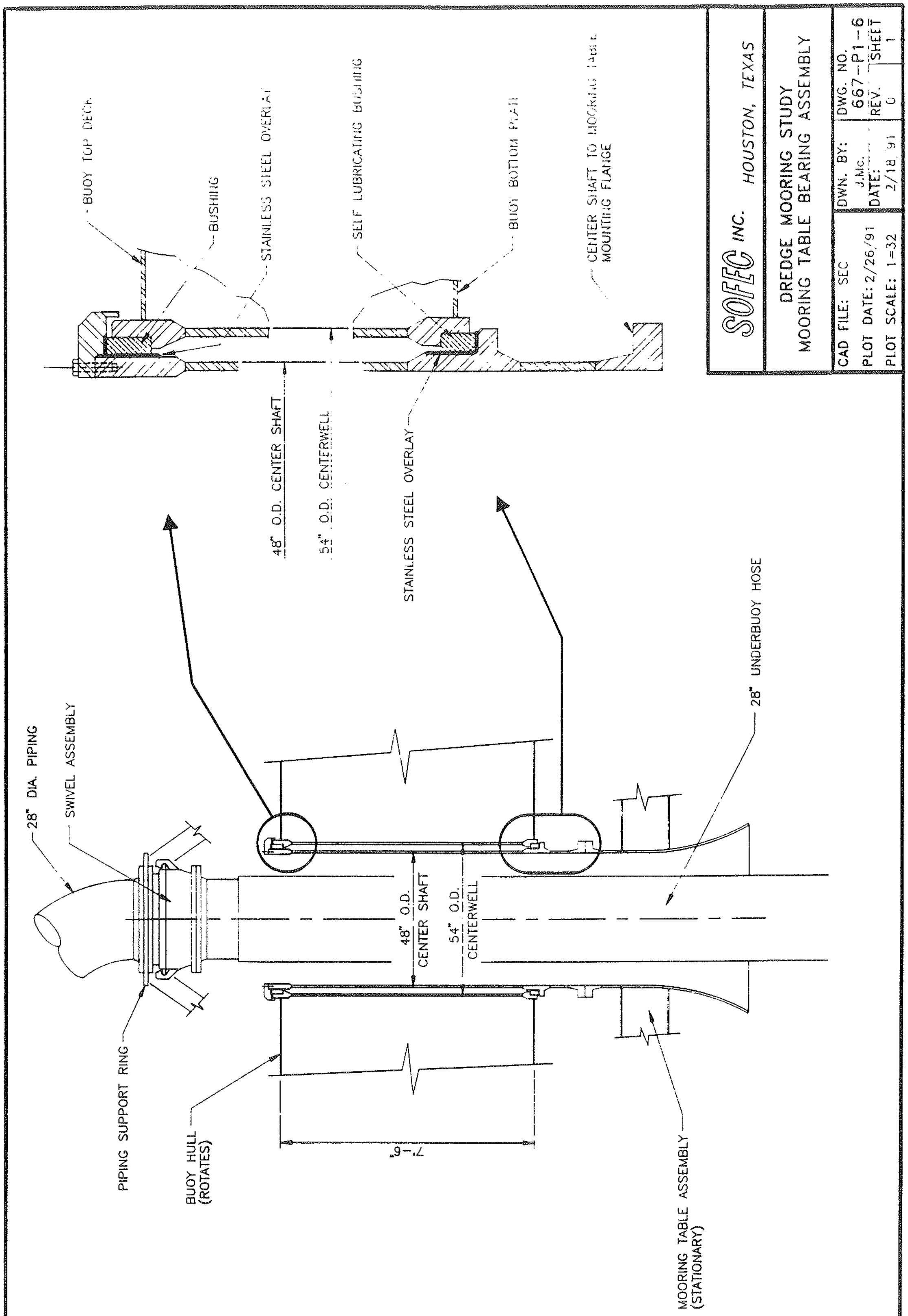


FIGURE 6.5

MOORING TABLE BEARING ASSEMBLY

Monthly grease injection with a standard hand held grease gun will be desirable but is not mandatory for these bushings.

Fluid Swivel

52. The fluid swivel which is currently being considered for the system is currently in use in the commercial dredge buoys. The swivel contains bronze bushings which are lubricated through grease ports located around the perimeter of the swivel. A quick release coupling will be mounted to the bottom of the swivel to assist the installation of the under buoy hose.

Mooring Hawser

53. The mooring hawser is a 3.2 in. diameter, 10 in. circumference "2 in 1 Viking Braidline". At one end of the hawser a 1 5/8 in. diameter by 5 ft long chafe chain will connect the hawser to the buoy. The hopper dredge can moor to the other end of the hawser via either a soft loop or small chafing chain. Details of the hopper dredge connection will be coordinated with the operators in Phase II of the study.

Anchor Legs

54. The CALM is moored by 4 chain anchor legs. Each leg will be 600 ft in length and will consist of 2 in. diameter ORQ (Oil Rig Quality) stud link chain. One end of the chain will fit directly into the chain support assembly at the buoy. The other end of the chain will be fitted with a open link to allow for the connection to the mooring anchor.

Mooring Anchor

55. Either of two types of mooring anchors may be used to moor the CALM system (Figure 6.6). The Navy Navmoor and Bruce FFTS anchors were sized based on a safety factor of 2.0 to the anchor's ultimate holding capacity. Both anchors would require that the fluke angle be set for the type of soil in the mooring location prior to installation. Both anchors will upright themselves as they are set.

56. Based on holding power curves published by NCEL, an 10,000 lb Navy Navmoor anchor will be required to develop the required mooring force. Based upon recent experience, the Naval Civil Engineering

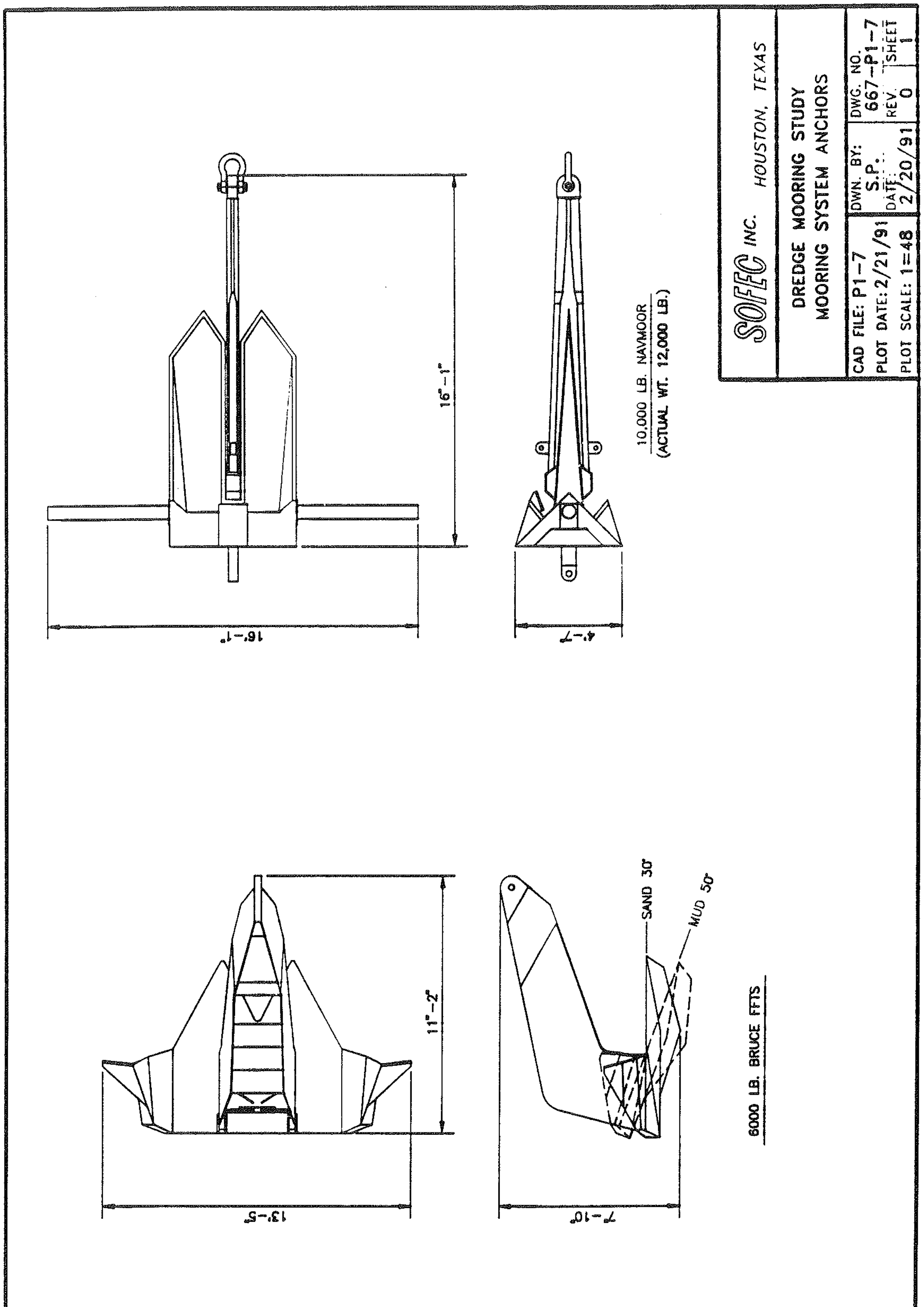


FIGURE 6.6

MOORING SYSTEM ANCHORS

Laboratory (NCEL) indicates that a Bruce FFTS anchor is a good alternative to the Navmoor anchor. The Bruce anchor is manufactured by Bruce International Limited in the United Kingdom. The size of the Bruce FFTS anchor is 6,000 lb. The use of this anchor would reduce the weight for transport and handling.

Floating and Underbuoy Hoses

57. The floating and underbuoy hoses will be commercially available dredge hoses in use world wide. Phase II of the study will define the type, exact number and specifications for those hoses.

7.0 TRANSPORTATION, INSTALLATION AND OPERATION ANALYSIS

58. The mooring buoy assembly is comprised of modular components which can be disassembled for transport via truck or rail, assembled at pierside, towed to the installation location, and installed. Figure 7.1 shows the major components of the CALM buoy. It consists of the following four major components:

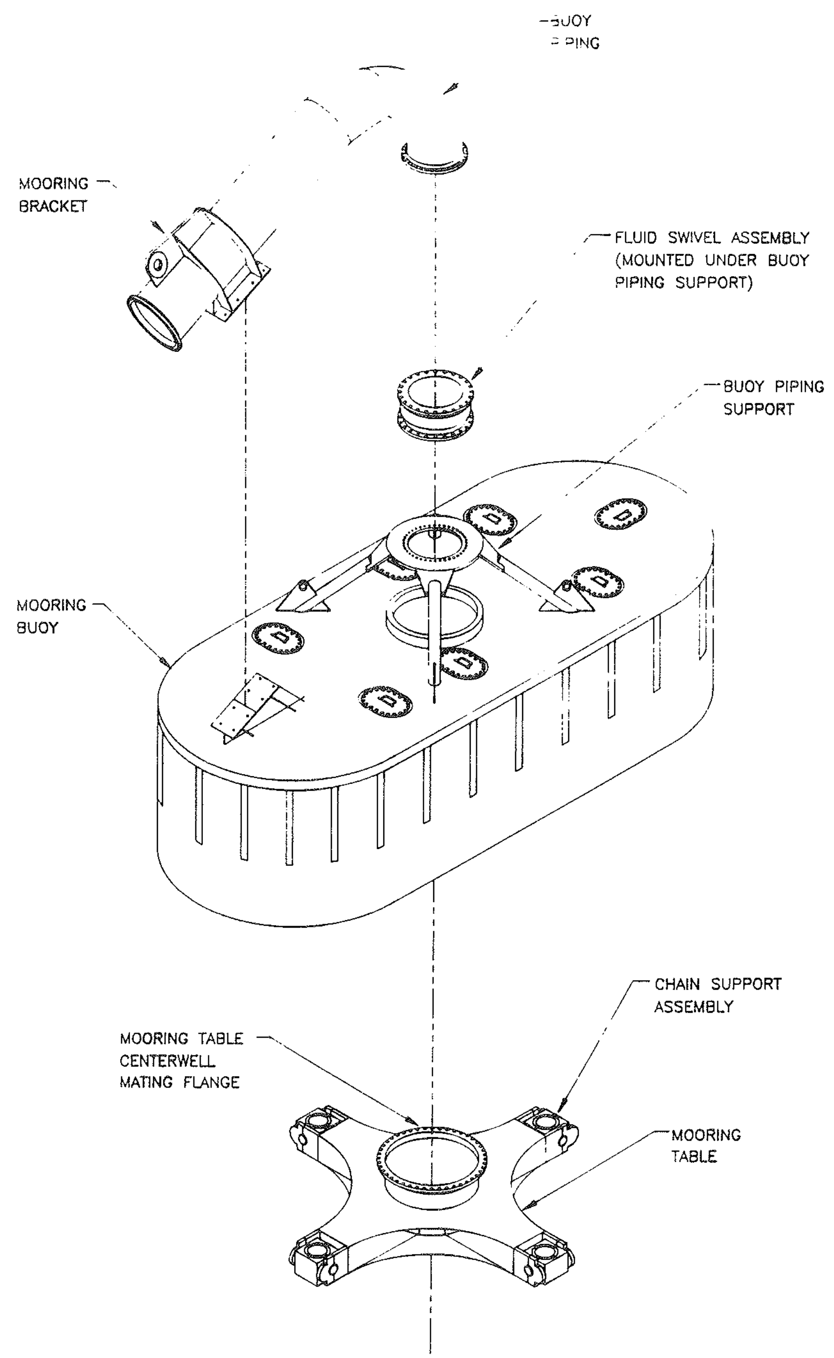
Component	Approximate Weight (Short Tons)
Buoy Piping	3.0
Fluid Swivel	3.2
Mooring Buoy	23.0
Mooring Table	8.5

Transportation

59. The mooring system is designed to be transported by standard "lowboy" flatbed tractor trailer rigs. The system can be transported by as few as 6 trucks. Preliminary analysis shows that the cargo can be transported as follows:

Component	Trucks
Buoy	1
Buoy Piping, Hawser, Fluid Swivel, Mooring Table	1
Anchors, Chain	2
Hoses	2

60. Figure 7.2 shows the buoy loaded for transport on a "lowboy" trailer. The buoy as shown is within the width dimensions of a mobile home which are commonly moved on most highways. The piping supports on the buoy could be designed to be removable which should reduce the height clearance and ease the transportation.



SOFEC INC. HOUSTON, TEXAS

DREDGE MOORING STUDY
CALM MOORING BUOY
EXPLODED ISOMETRIC VIEW

CAD FILE: EXPV	DWN. BY:	DWG. NO.	
PLOT DATE: 2/27/91	D.Mc.	667-P1-2	
PLOT SCALE: 1:96	DATE: 2/20/91	REV. 0	SHEET 1

FIGURE 7.1

CALM ISOMETRIC VIEW

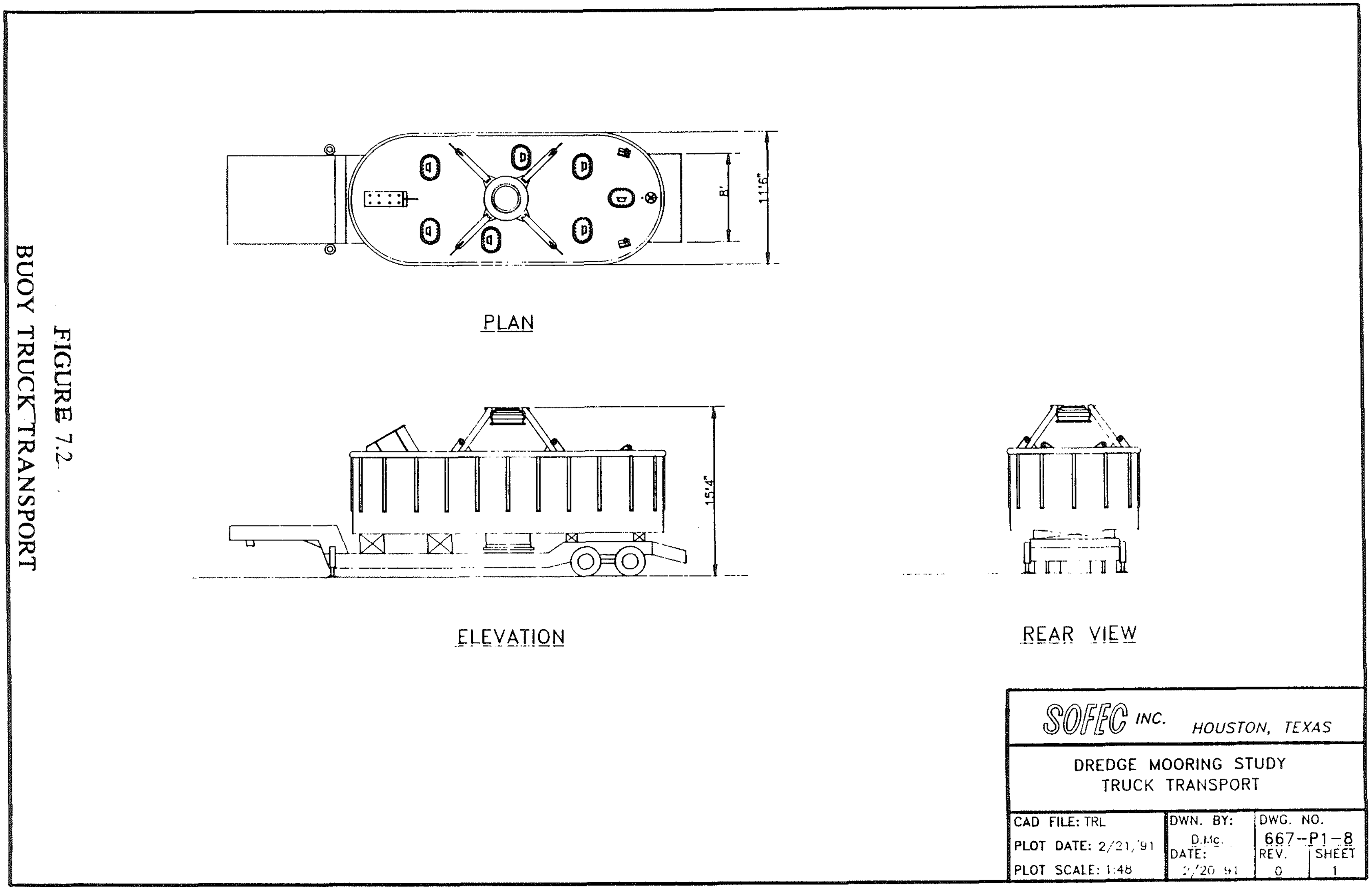


FIGURE 7.2
BUOY TRUCK TRANSPORT

61. The system has not been analyzed for rail transport on the premise that truck transport had more stringent criteria weight and cube requirements.

62. Figure 7.3 shows a the layout of the mooring system on a typical 40 ft. X 120 ft. deck barge. One barge will be able to transport the chain, anchors, hoses, hawser and an assembled buoy. The system component positions are not fixed and may be required to be relocated during final design of the layout and stability analysis of the barge.

Installation

63. After the system has been assembled at pier side, the system may then be towed to the installation location. Figure 7.4 illustrates the towing configuration. The floating hose is shown connected to the buoy during tow. The drag from the floating hose tends to stabilize the buoy during the tow. The need for the hose to be connected will have to be determined by the operator once the system is in operation. The operator may find that the hose may need to be removed for long tows.

64. Once the system arrives at the installation site, a winch located on the buoy will be used to pull the mooring chains into the chain stoppers located on the mooring table. The mooring chains and anchors should be installed prior to the arrival of the buoy. One chain on each side of the buoy will be pulled into the stoppers first. The buoy will then be rotated 90^{o} to expose the remaining stoppers on the mooring table and the chains will be pulled into those stoppers. All of the chains will then need to be pretensioned to achieve the correct pretension angle and to position the buoy over the underbuoy hose.

65. The winch will then be used to lift the underbuoy hose through the centerwell for the connection to the buoy piping. The floating hose will be installed if it was removed for the tow and the mooring hawser connected to the mooring bracket.

66. Figure 7.5 shows the preliminary stability curve about the longitudinal axis of the buoy in as it is free floating. Most critical overturning moment occurs during installation when the first chain is being lifted from the sea floor. At this stage there is no opposing chain to counter the overturing moment. The maximum overturning moment predicted during the installation of the chains is about 9.0 kip-ft. This will list the buoy over less than 5^{o} showing that the buoy is stable.

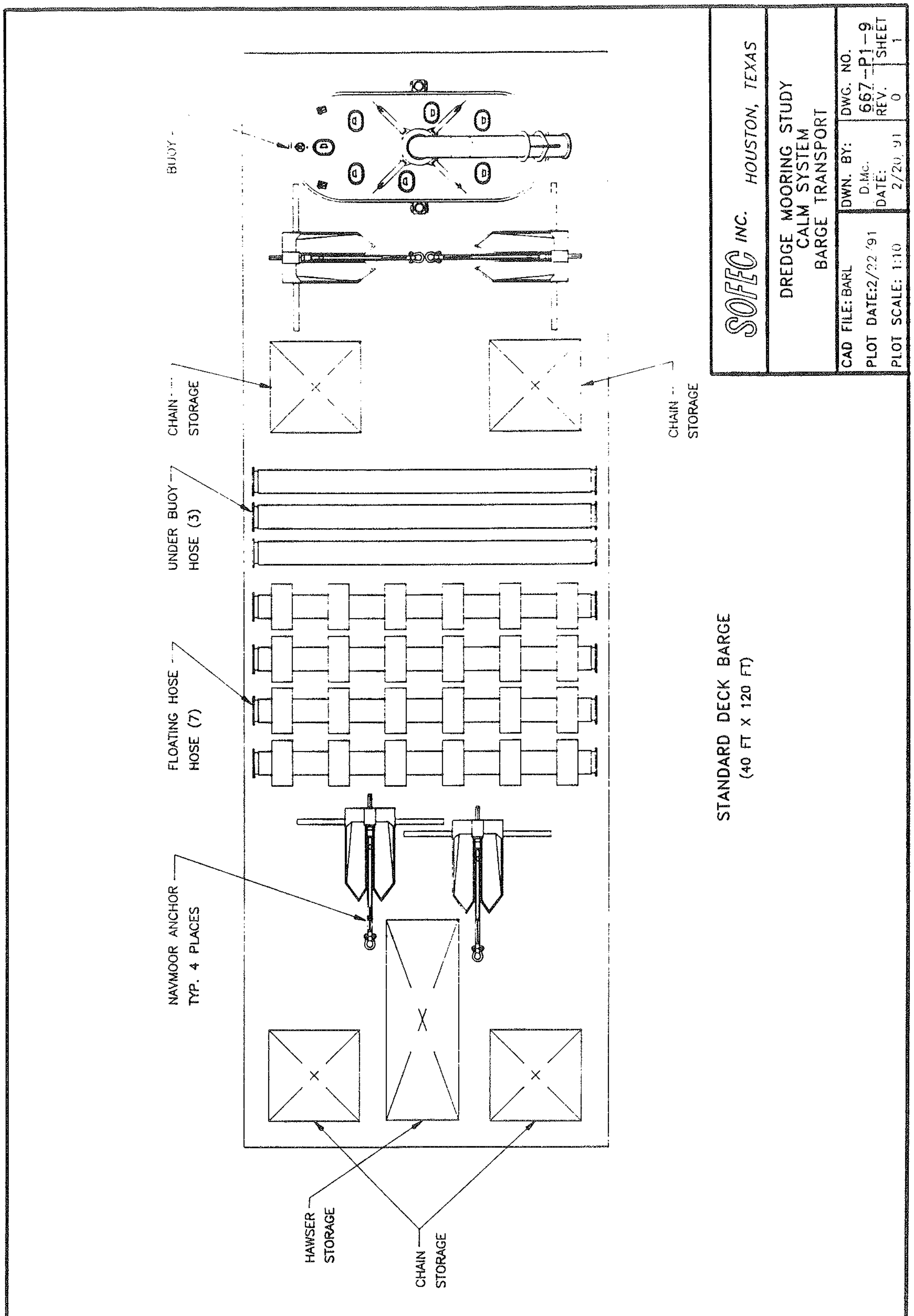


FIGURE 7.3
CALM SYSTEM BARGE TRANSPORT

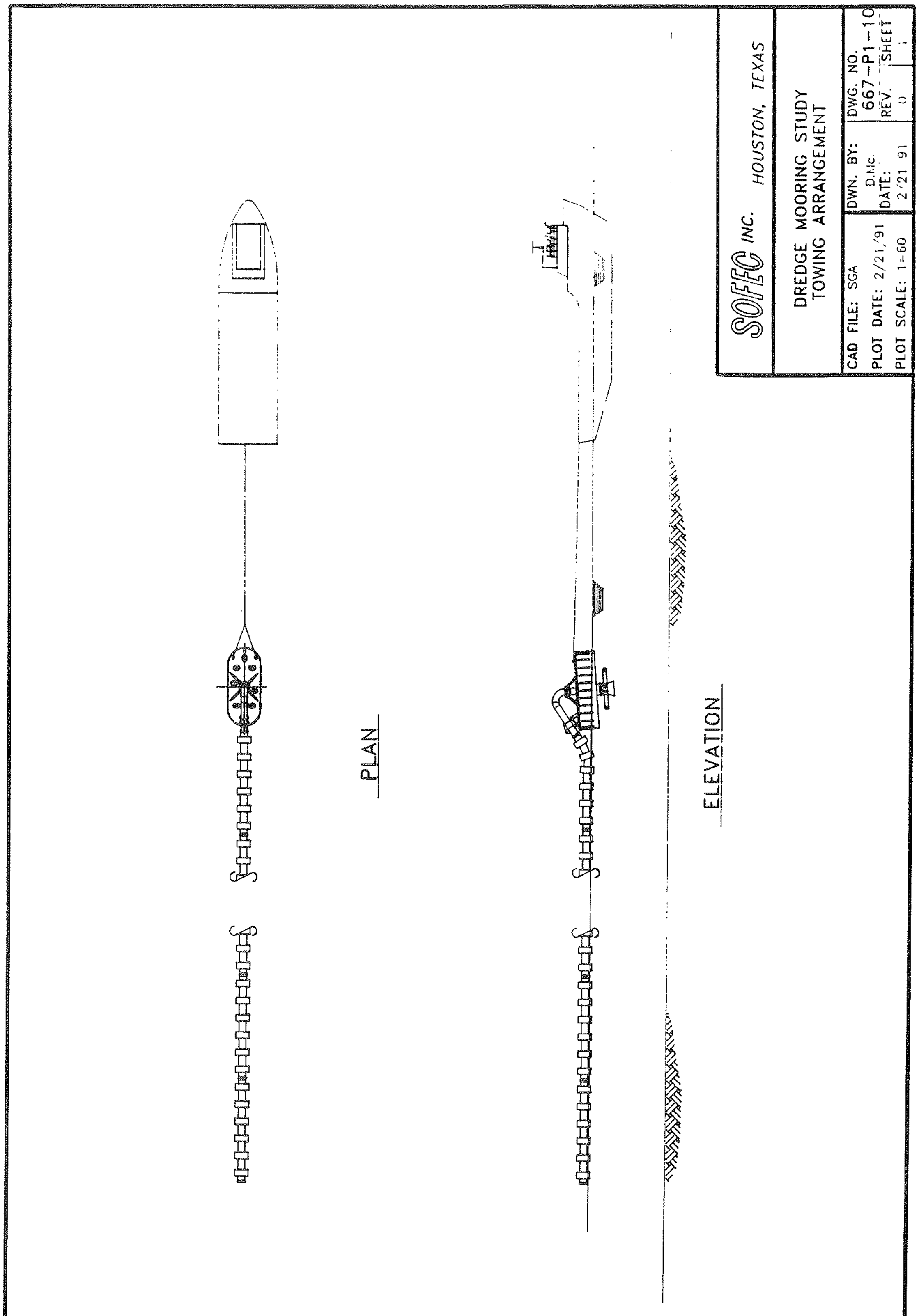


FIGURE 7.4
CALM BUOY TOWING ARRANGEMENT

SOFEC INC.

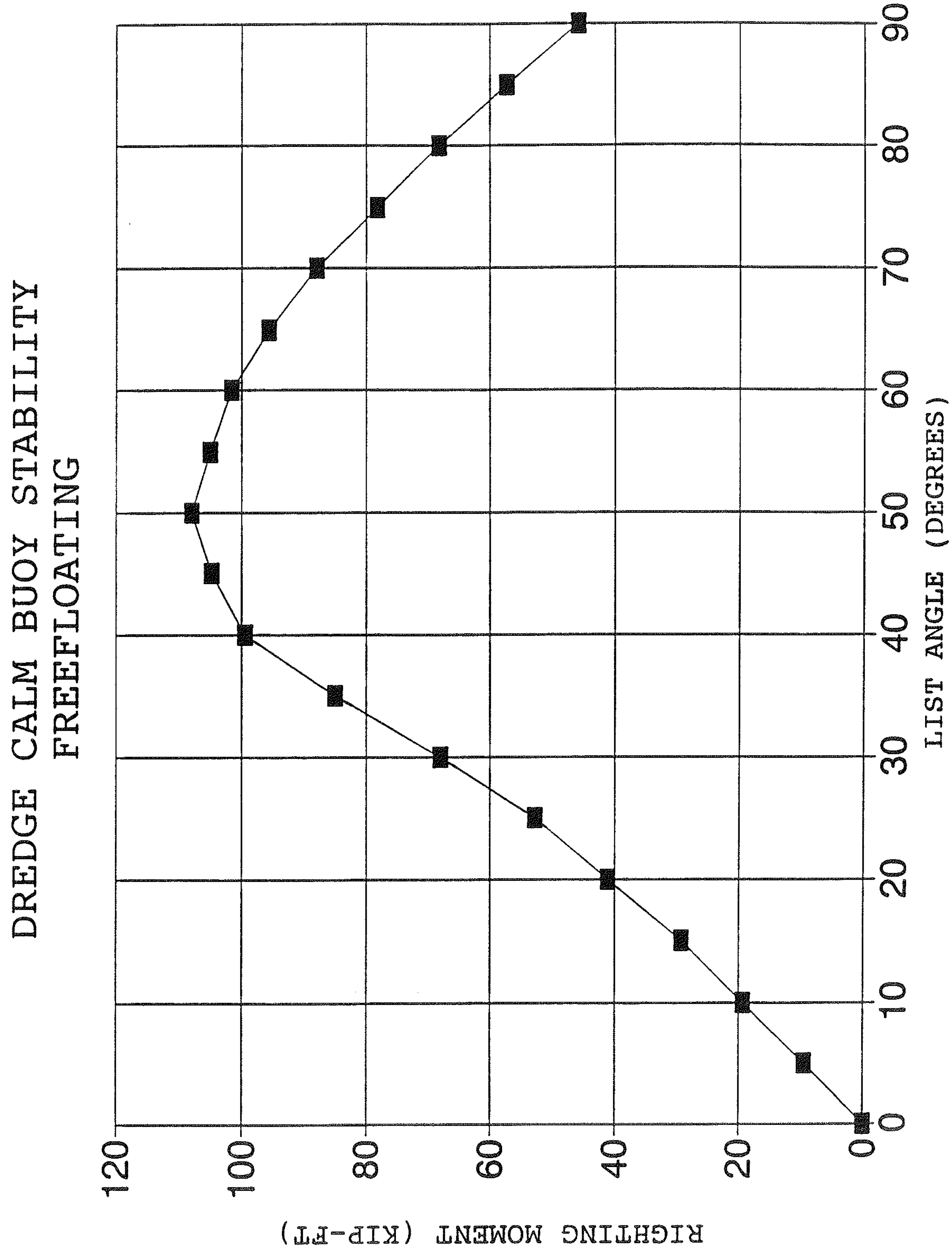


FIGURE 7.3
DREDGE MOORING FREEFLOATING STABILITY

Operation

67. The hopper dredge will arrive at the mooring buoy loaded with dredge material. The dredge will lift onboard a floating pickup rope and heave in until the mooring hawser is aboard and connected to bitts or a smitt bracket. The dredge will then pickup and connect to its piping the floating hose. The dredge material will then be discharged through the system.

68. Upon completion of the discharge, the dredge will disconnect the floating hose from its piping and return the hose to water. The hawser will be released and the dredge will return for more material.

8.0 COST ESTIMATES

Preliminary Mooring Concepts

69. Budgetary cost estimates have been prepared for each of the preliminary mooring concepts evaluated in Section 5.0. The cost estimates are based on typical fabrication and component costs for Single Point Moorings (SPM's) now being supplied under turnkey contracts by SOFEC, Inc. The cost ratios of the preliminary concepts are shown relative to the least expensive system as follows:

System	Cost Factor
CALM 3-Leg	1.00
CALM 4-Leg	1.03
SALM	2.10
GUYED TOWER	2.12
TLP	2.40

70. In comparing the systems, one notes the systems that depend upon buoyancy to achieve their righting moment characteristics are more than twice the cost of systems that rely on gravity (chain weight) to achieve their righting moment. The primary reason for this is the large and heavy weight of the anchoring base frame that is required to overcome the buoyancy and also provide the "on-bottom" weight necessary to develop resistance to sliding at the sea floor interface. The base frame costs for these type of systems is 45-50% of the cost of the complete mooring system.

71. The major cost item for the CALM systems is the hose system that is made up of approximately 10 lengths of hose (underbuoy & floating). Excluding engineering & project management, supply for the complete preliminary concept 4-Leg CALM system illustrated in Section 5.0 of the report is estimated to be $850k-$1000k.

Recommended Catenary Anchor Leg Mooring (CALM) Concept

72. The projected costs for the capsule shaped CALM concept as developed in Section 6.0 reflect the effort applied toward configuring a mooring system to meet the specific needs for the Corps of Engineers mission. Figure 8.1 shows a breakdown of the relative cost of the components which comprise the recommend CALM consept. Hose costs are the major cost item and are estimated to be 50-60% of the total hardware expenditure for the CALM system. Anchors and anchor chain are expected to be approximately 10% of the total hardware cost for the mobile system. Excluding engineering & project management, supply for this hardware is presently estimated to cost $700k-$800k.

9.0 CONCLUSIONS AND RECOMMENDATIONS

73. From the analysis of the preliminary concepts, the CALM buoy is shown to be the most cost effective, the most easily transportable and the easiest to install. With the design of the capsule shape, the system will be transportable on most of the roadways in the United States which currently allow mobile home traffic. With only four major components, the buoy can be quickly assembled and disassembled. The capsule shape should allow for an increase in towing speeds over a conventional cylindrical buoy. The overall light weight of the design will keep the fabrication cost to a minimum. The overall system will allow for a safe tool for mooring hopper dredge during direct pump out operations.

74. Based on the results from this report and meetings to discuss the development of this concept, SOFEC would like to present the following recommendations. These recommendations cover some of the key topics in the development of the design to a point where preliminary specifications for the equipment can be written.

Model Tests - Even though the design loads have been based on scaled model test data, we recommend that a small model test program be considered. The model basin costs of a preliminary set of tests would cost approximately $56,000. The test scale would be 1:35. The scale could be increased to 1:20 for a slightly increased cost. A preliminary model test plan is contained in Appendix B.

Flow Analysis - A flow analysis of the entire system should be undertaken to establish flow losses for the floating hoses, buoy piping, underbuoy hoses and the pipeline to shore. This will allow for the creation of guidelines for the location of the mooring system with respect to the dredge material fill location. Waterways Experiment Station input would be required to accomplish this task.

Pipe Arm Load & Underbuoy Hose Analysis - Analysis of the floating hose loads imparted on the pipe arm and the underbuoy hose profile and loads should be considered to establish correct forces for more detailed design.

Time Study for Assembly, Installation & Retrieval - A time study of the assembly and installation tasks will need to be accomplished to establish manpower, and support equipment and vessel requirements and to establish a baseline for operational planning.

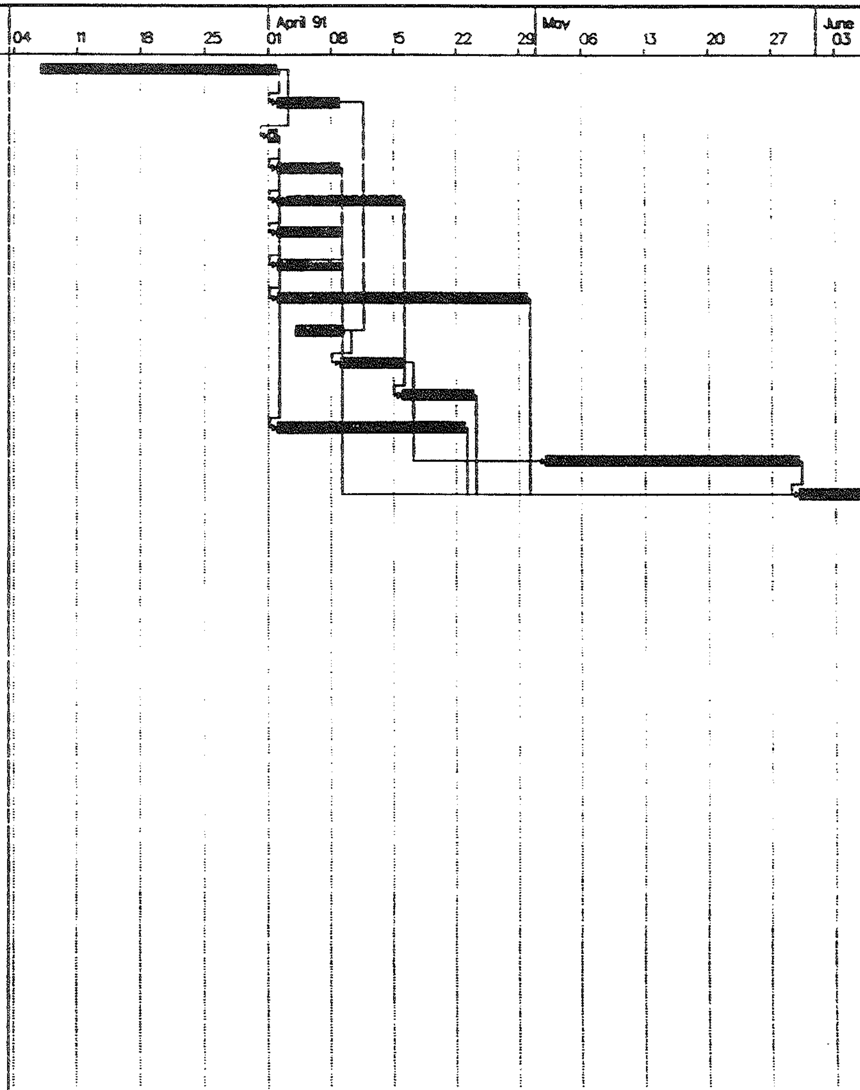
Assembly & Installation Rigging Design - The rigging required for system assembly and installation should be defined and designed to assist in the preparation of the time study.

75. Figure 9.1 shows a preliminary schedule and Figure 9.2 shows a preliminary Pert Chart for the completion of Phase II of the study. The schedule is based on a Phase II start date of April 1, 1991. Model tests are shown as part of the schedule. If the tests are undertaken, the schedule will need to be adjusted to fit the model basins schedule for testing. If the testing is not undertaken, the schedule can be adjusted to reflect the deletion of the task.

standard
02-27-91 10:07a

Project: DREDGEII.PJ
Revision: 4

Dredge Mooring Study – Phase II Schedule



Task ID	Task Name	Est Dur	Schd Dur	Scheduled Start	Scheduled Finish
001	Phase I Comments	18dy	18dy	03-07-91=	04-01-91
002	Model Test Definition	5dy	5dy	04-02-91	04-08-91
003	Phase II Start	0dy	0dy	04-01-91	04-01-91
004	Flow Analysis	5dy	5dy	04-02-91	04-08-91
005	Rigging Design	10dy	10dy	04-02-91	04-15-91
006	Under Buoy Hose And	5dy	5dy	04-02-91	04-08-91
007	Stability Analysis	5dy	5dy	04-02-91	04-08-91
008	Conceptual Dsgn Calcs	20dy	20dy	04-02-91	04-29-91
009	Model Test Plan	3dy	3dy	04-04-91	04-08-91
010	Model Testing	5dy	5dy	04-09-91	04-15-91
011	Time Study Assy,Inst	6dy	6dy	04-16-91	04-23-91
012	Develop Specs	15dy	15dy	04-02-91	04-22-91
013	Model Tst Resul Anal	20dy	20dy	05-02-91=	05-29-91
014	Assemble Final Report	5dy	5dy	05-30-91	06-05-91

Unassigned — Interrupted — Baseline — Noncritical — Critical — Milestone — Baseline Milestone

FIGURE 9.1
DREDGE MOORING STUDY
PHASE II SCHEDULE

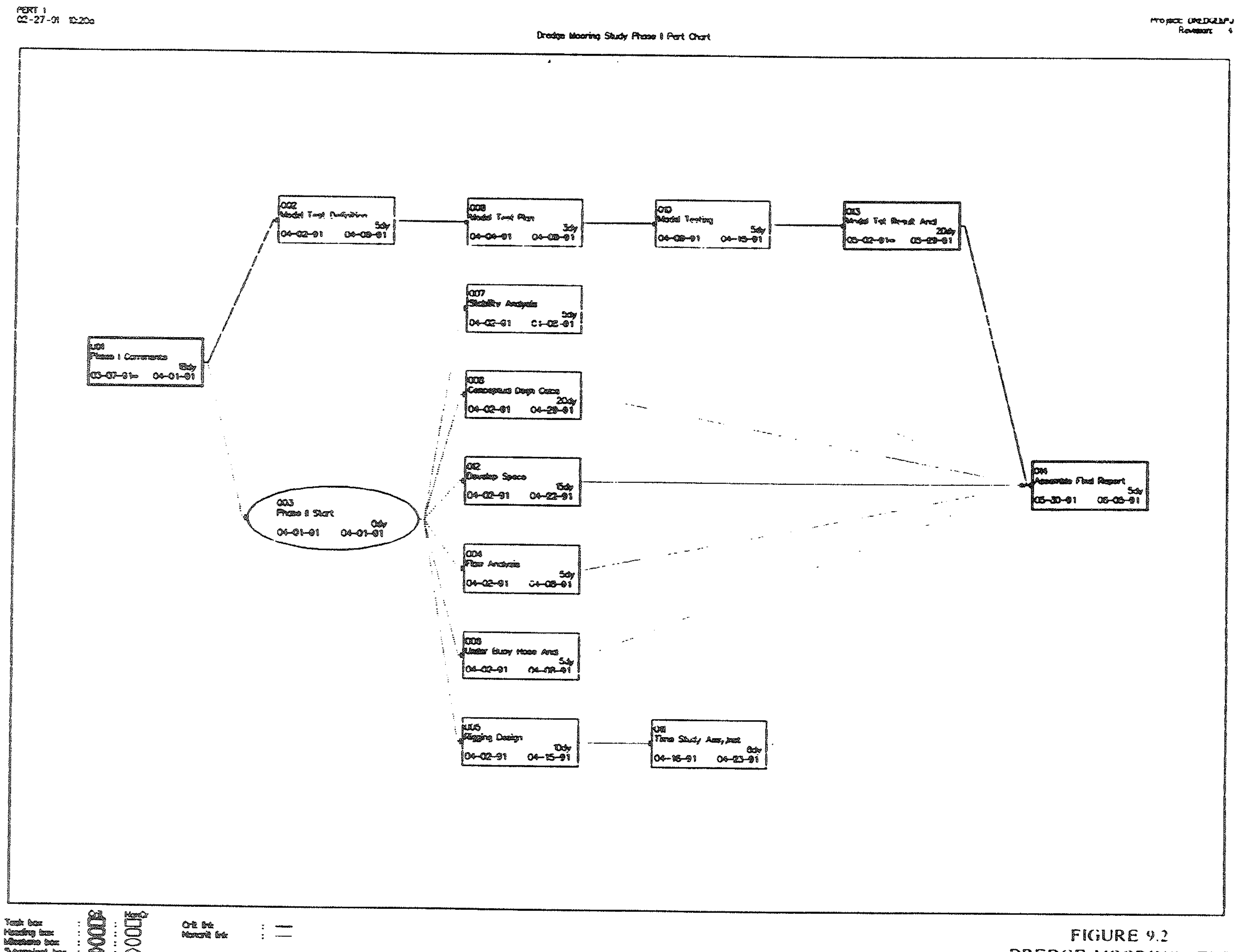


FIGURE 9.2
DREDGE MOORING STUDY
PHASE II PERT CHART

APPENDIX A

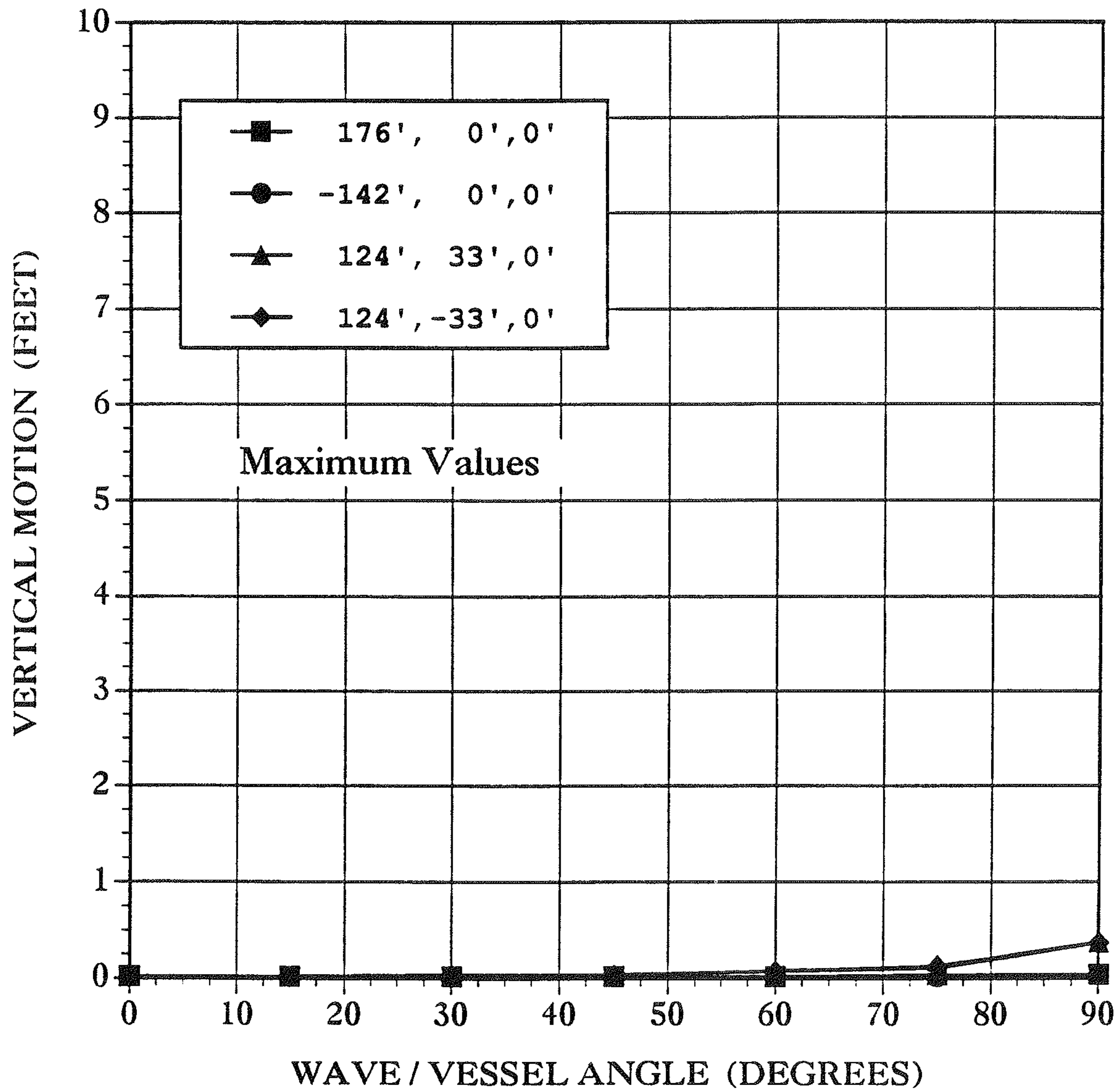
VESSEL VERTICAL MOTION ANALYSIS

HOPPER DREDGE

VESSEL VERTICAL MOTION (WITH RESPECT TO WAVES)

35.0 FOOT WATER DEPTH

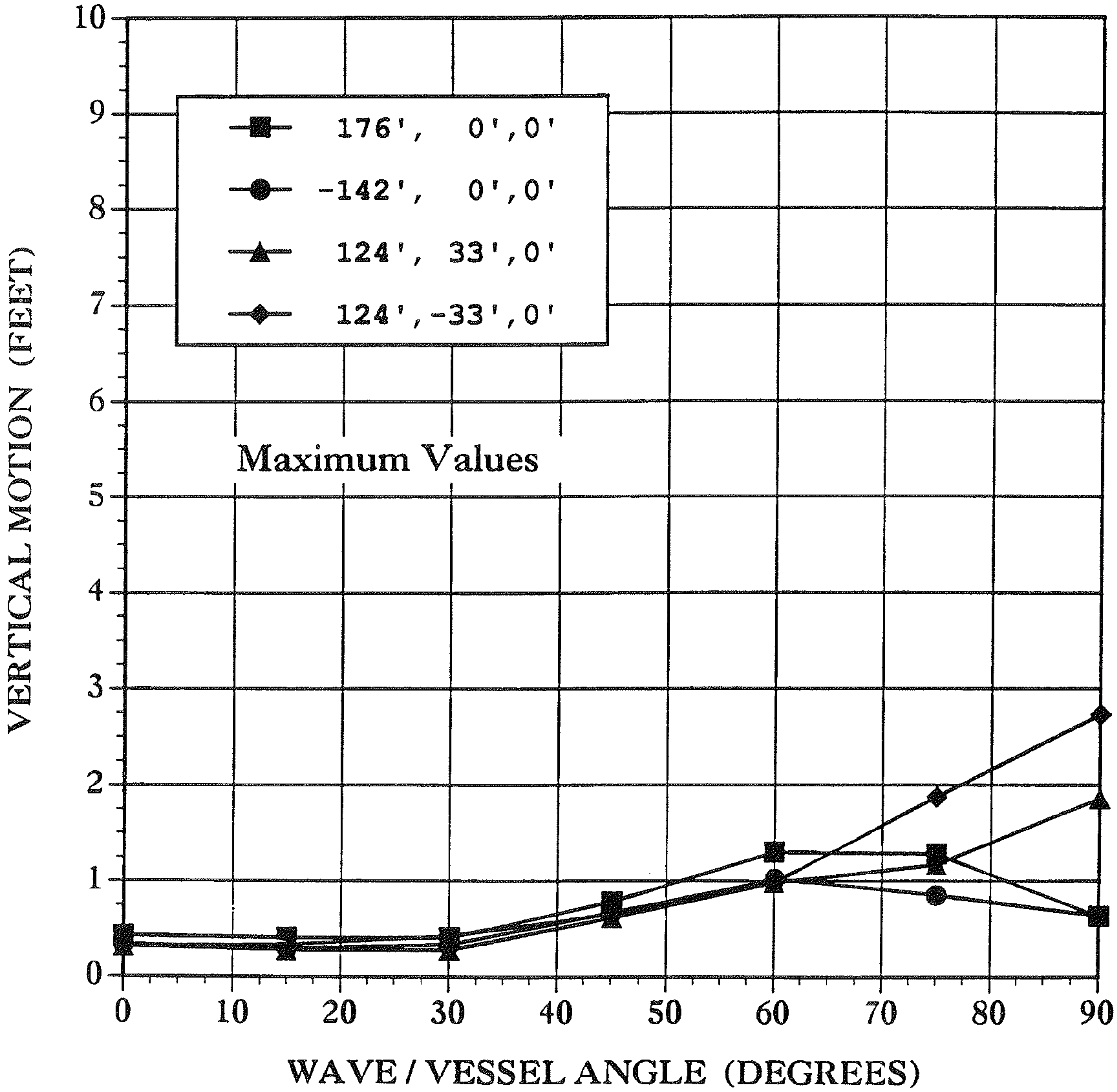
VESSEL VERTICAL MOTION
Versus
WAVE / VESSEL ANGLE



WATER DEPTH = 35 FEET
SIG. WAVE HEIGHT = 2.00 FEET
PEAK WAVE PERIOD = 3.90 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

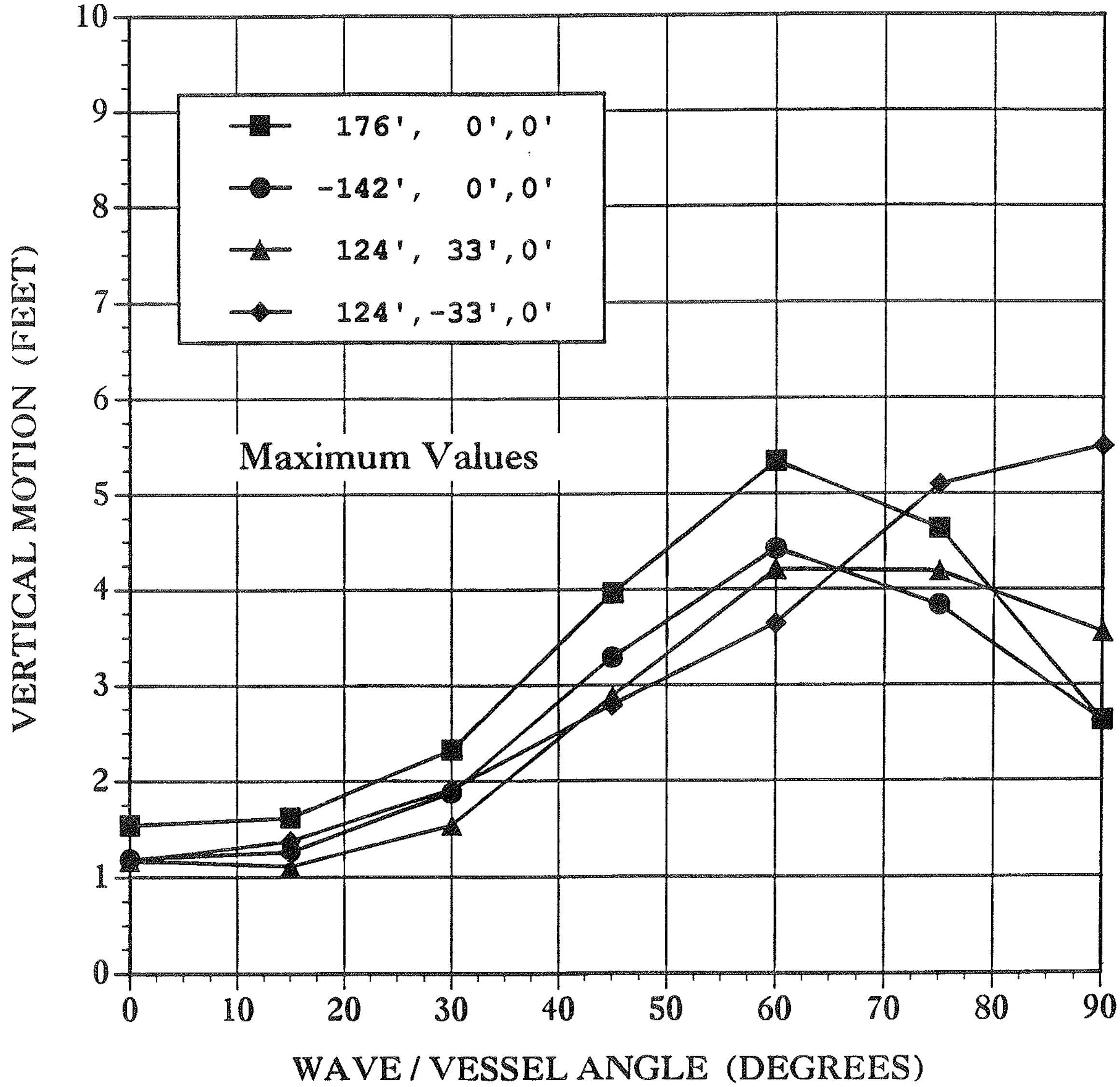
VESSEL VERTICAL MOTION
Versus
WAVE / VESSEL ANGLE



WATER DEPTH = 35 FEET
SIG. WAVE HEIGHT = 4.00 FEET
PEAK WAVE PERIOD = 5.52 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

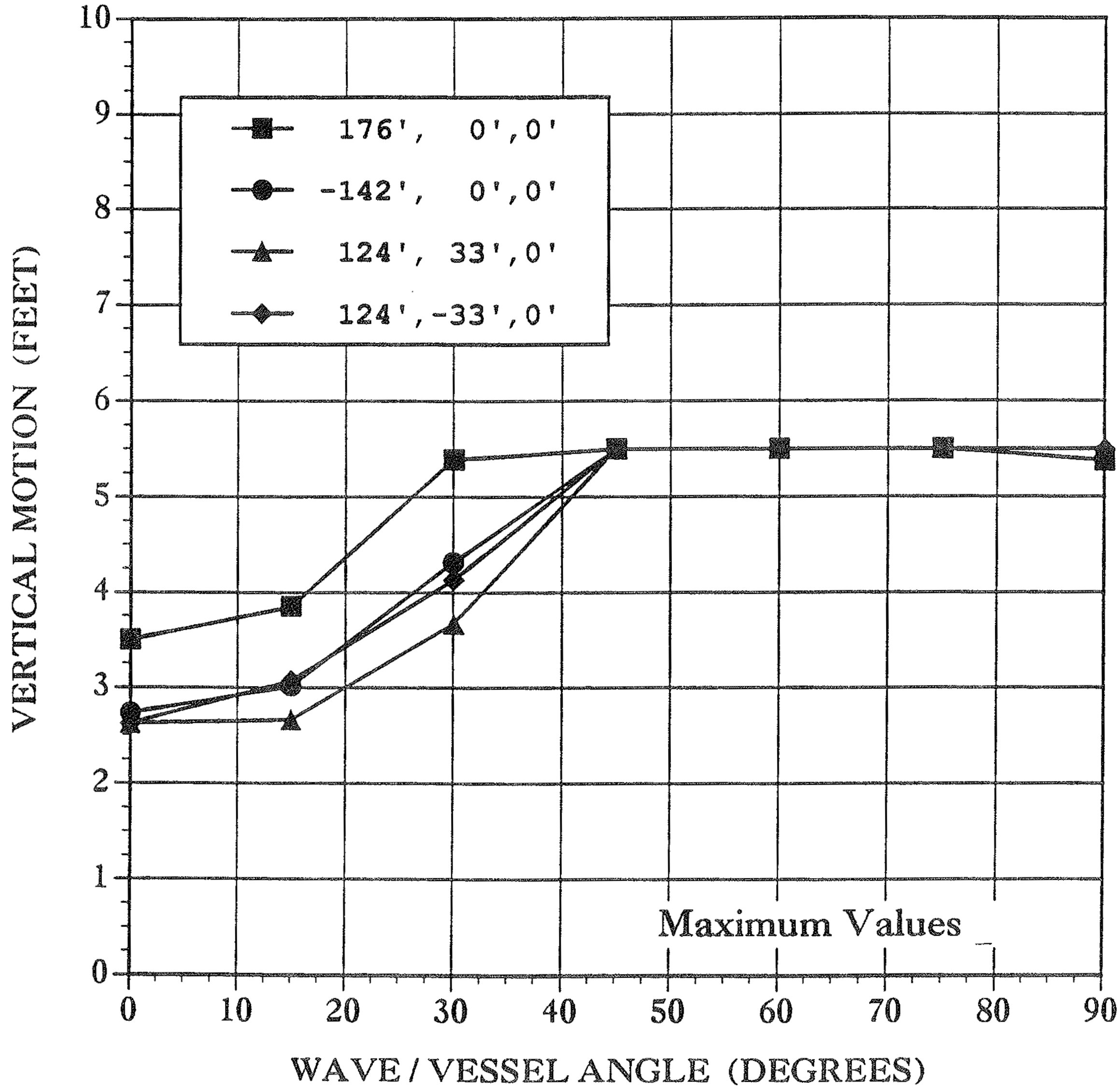
VESSEL VERTICAL MOTION
Versus
WAVE / VESSEL ANGLE



WATER DEPTH = 35 FEET
SIG. WAVE HEIGHT = 6.00 FEET
PEAK WAVE PERIOD = 6.76 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

VESSEL VERTICAL MOTION
Versus
WAVE / VESSEL ANGLE



WATER DEPTH = 35 FEET
SIG. WAVE HEIGHT = 8.00 FEET
PEAK WAVE PERIOD = 7.81 SECONDS

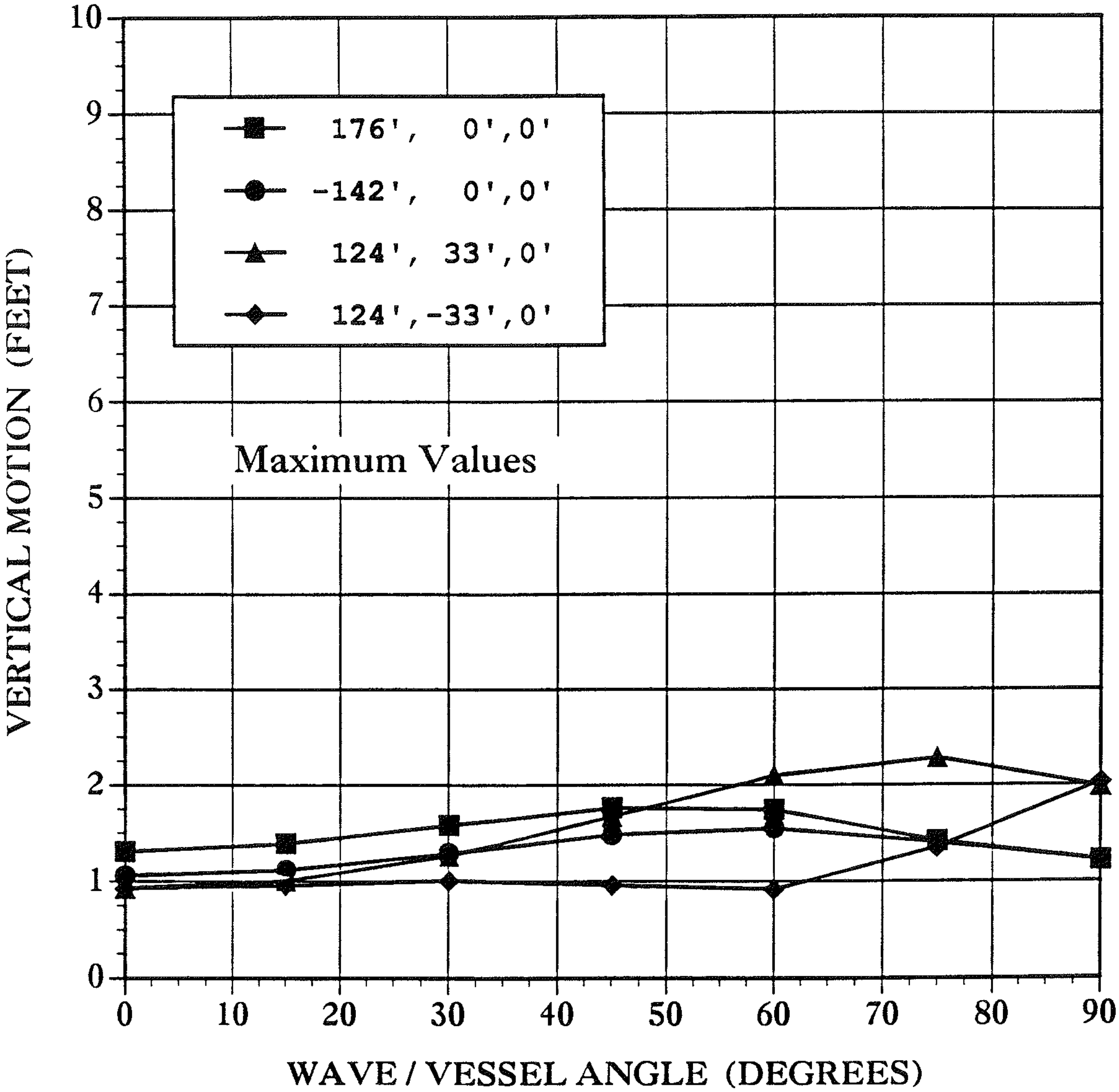
<u>Note</u>: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

HOPPER DREDGE

VESSEL VERTICAL MOTION (WITH RESPECT TO SWELL)

35.0 FOOT WATER DEPTH

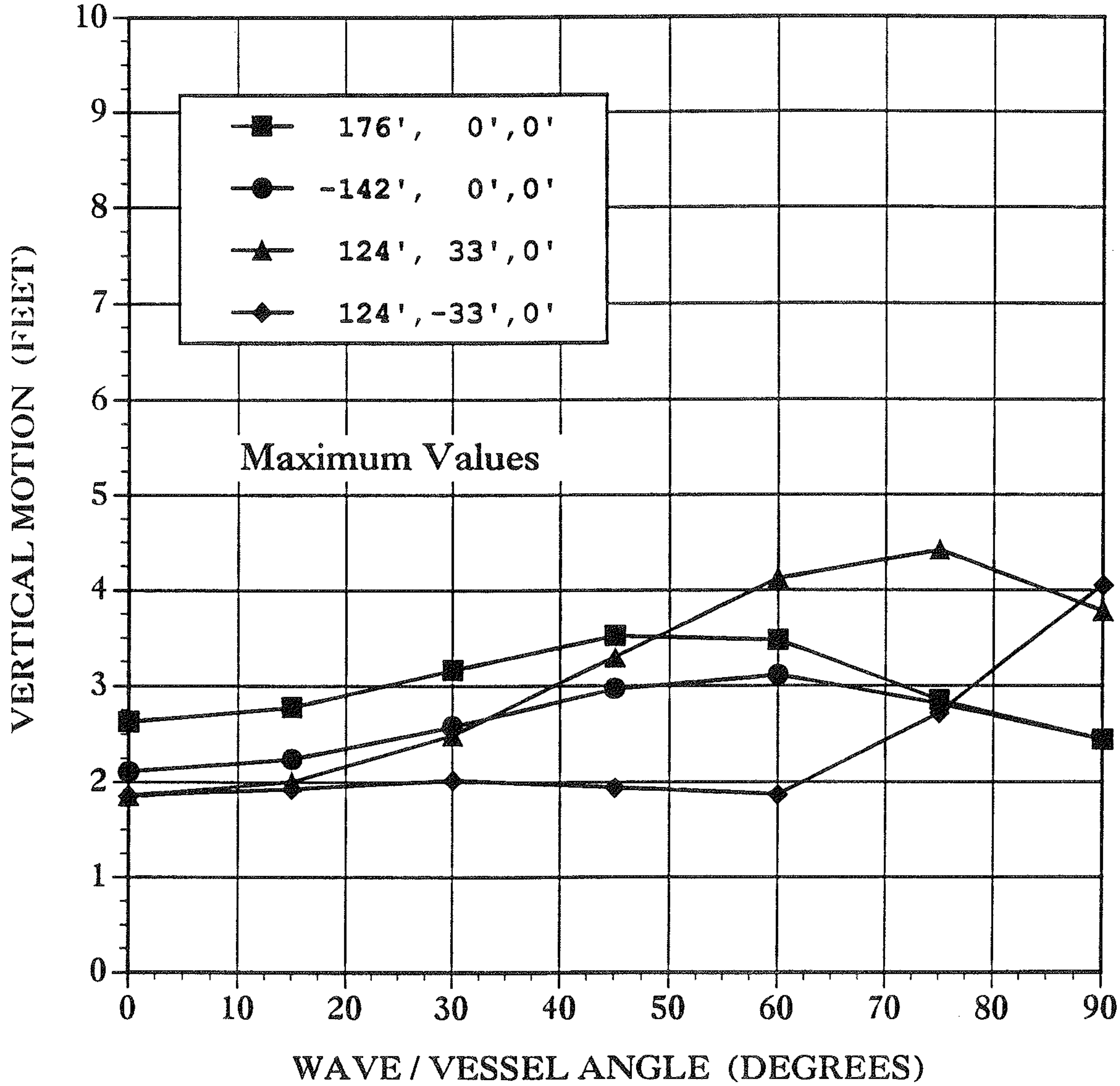
VESSEL VERTICAL MOTION
Versus
SWELL / VESSEL ANGLE



WATER DEPTH = 35 FEET
SWELL HEIGHT = 2.00 FEET
PEAK WAVE PERIOD = 11.00 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

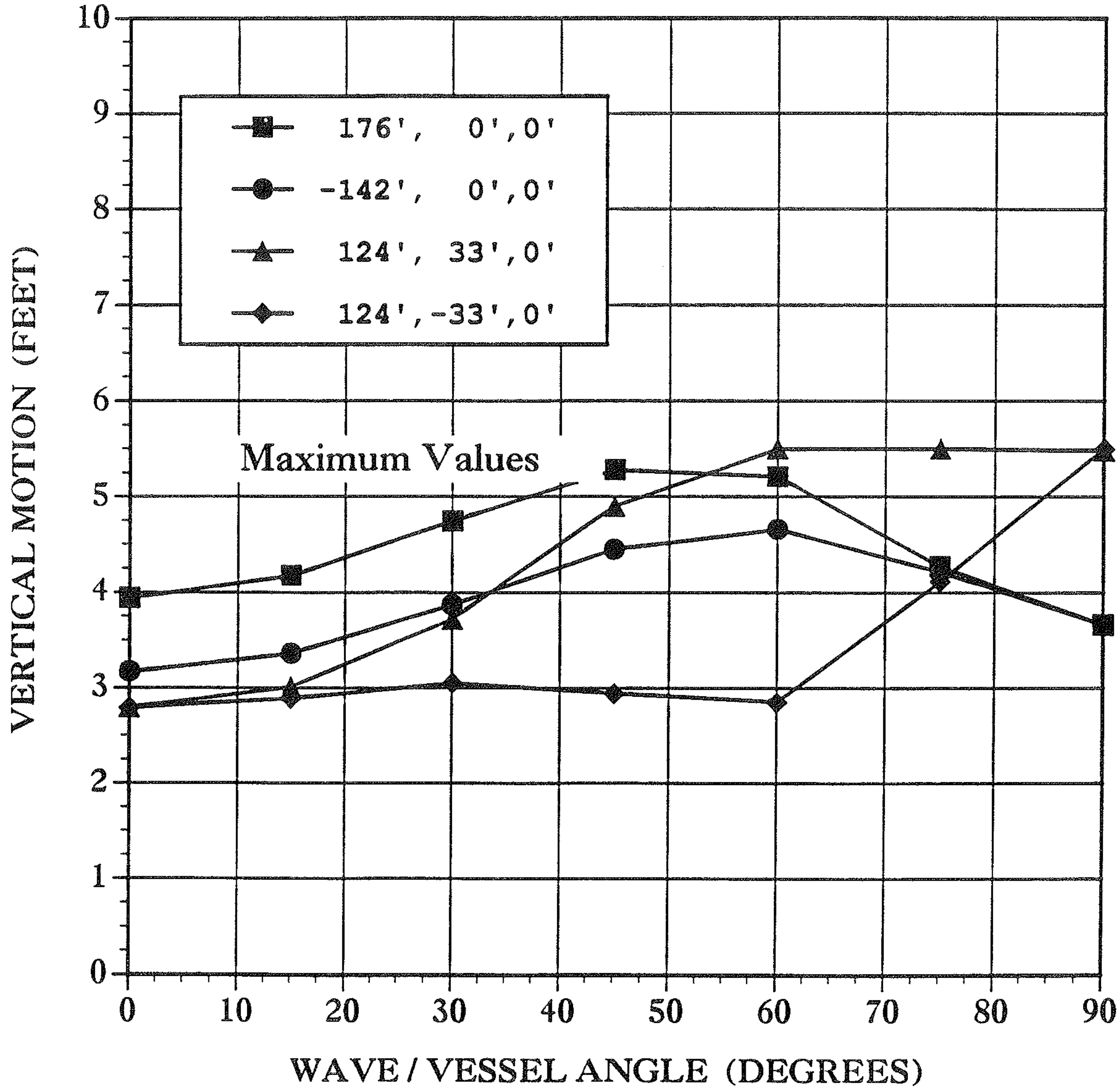
VESSEL VERTICAL MOTION
Versus
SWELL / VESSEL ANGLE



WATER DEPTH = 35 FEET
SWELL HEIGHT = 4.00 FEET
PEAK WAVE PERIOD = 11.00 SECONDS

<u>Note</u>: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

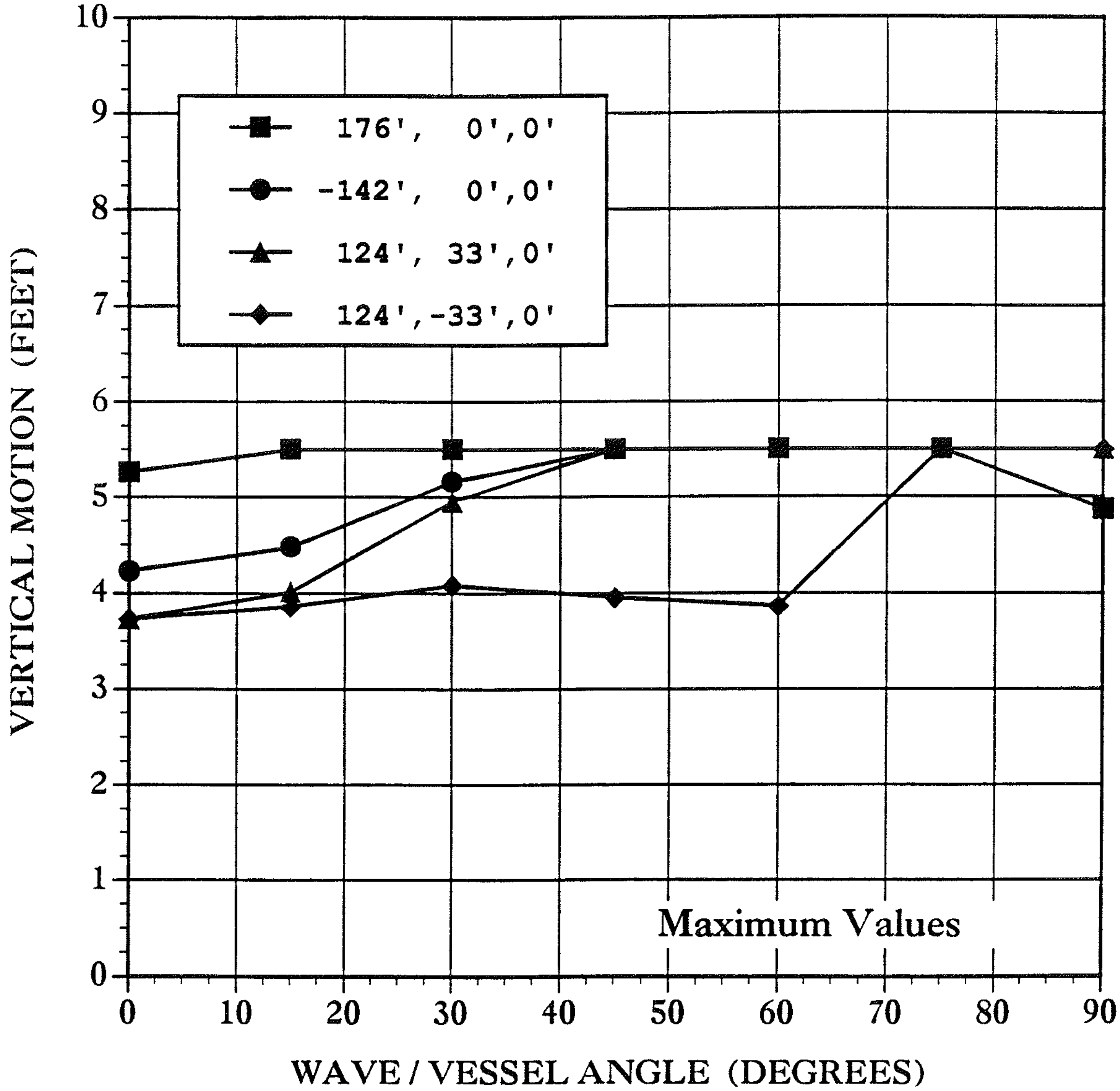
VESSEL VERTICAL MOTION
Versus
SWELL / VESSEL ANGLE



WATER DEPTH = 35 FEET
SWELL HEIGHT = 6.00 FEET
PEAK WAVE PERIOD = 11.00 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

VESSEL VERTICAL MOTION
Versus
SWELL / VESSEL ANGLE



WATER DEPTH = 35 FEET
SWELL HEIGHT = 8.00 FEET
PEAK WAVE PERIOD = 11.00 SECONDS

Note: x,y,z coordinates are referenced to the center of the dredge at the keel (0,0,0).

APPENDIX B

PRELIMINARY MODEL TEST PLAN

HOPPER DREDGE
(Preliminary) MODEL TESTS

A. Model Test Scale Factor

The model tests shall be conducted at a scale factor which is the largest permitted by the basin facilities.

B. Water Depth

The mean water depth at the site location is 35.0 ft.

C. Mooring System Description

The mooring system selected to be model tested is a CALM (Catenary Anchor Leg Mooring) system. The main characteristics of the CALM system are as follows:

Mooring Buoy

- (Refer To The Attached Sketch)

Anchor System

# Of Mooring Lines	4	
Chain Size	2.00	In.
Breaking Strength	324	Kips
Min. Chain Length	660	Ft

The fairlead plan angles are 0, 90, 180, and 270 degrees. The pretension angle is 55 degrees.

D. Hopper Dredge

The vessel to be moored to the CALM, by means of a bow hawser, will be the hopper dredge USACE "WHEELER".

The general characteristics of this vessel are as follows:

- L.O.A. 408.3 Ft
- L.B.P. 384.0 Ft
- Beam 78.0 Ft
- Moulded Depth 39.1 Ft
- Loaded Draft 29.5 Ft

E. Vessel Ballast Conditions

The dredge will be tested in three load conditions; completely loaded, 50 percent loaded and light (refer to the attached data sheet for the dredge characteristics at each load condition).

F. Environmental Conditions

Wind, wave and current will be modeled. The mooring system will be tested in at least the following environmental conditions.

1. Survival Storm

   - Significant Wave Height 10.0 Ft
   - Current Velocity 2.0 Knots

2. Maximum Operating Environment

   - Significant Wave Height 6.0 Ft
   - Wind Velocity 30.0 Knots
   - Current Velocity 2.0 Knots

G. Model Characteristics

1. CALM System

   The model shall reproduce the force deflection characteristics of the prototype mooring.

2. Hopper Dredge

   The hopper dredge shall reproduce the supplied dimensions and longitudinal and transverse radius of gyration of the prototype vessels.

3. Mooring Hawser

Load elongation characteristics shall be properly modeled.

H. Environmental Modeling

1. Waves

The modeling of waves shall be such that their spectrums closely match the desired wave spectrums. Specific emphasis will be given to matching the peak wave frequency of the spectrums. For all tests it will be necessary to generate a continuous non-repeating wave spectrum of one and a half hours prototype duration.

2. Wind

Wind shall be modeled by scaling to a desired wind force instead of scaling the actual wind velocity. Wind coefficients, for small vessels, shall be used to determine the wind force. A simple wind test should be conducted on the vessel in each load condition to determine the correct wind velocity to produce the desired force.

3. Current

An actual flow of water will be generated in the model basin to simulate current.

4. Directions

- Wind at 030 degrees to the waves
- Current at 090 degrees to the waves

I. Measurements And Instrumentation

1. Environmental

- Wave characteristics
- Wind characteristics
- Current characteristics

2. Vessel Motions

- Surge
- Sway
- Heave
- Pitch
- Roll
- Yaw

3. Anchor Chain Forces

- Axial forces in all chains

4. Bow Hawser Force

J. Data Recording

1. All quantities to be measured and calculated shall be recorded and stored on computer media.

2. Strip chart records shall be made on selected data channels.

3. High speed filming may be done on selected tests.

4. Overhead video tape coverage shall be conducted during all tests.

K. Statistical Analysis

As a minimum the following statistical analysis shall be performed on all measured and calculated data channels:

- Mean values
- Standard deviations
- Maximum values
- Minimum values
- Significant values of peaks
- Significant value of troughs
- Significant double amplitude values
- Maximum double amplitude values
- Number of oscillations
- Low / High frequency separation of recorded data
- Distribution plots of total and separated signals
- RAO plots (Vessel Motions)

L. Reporting

1. Statistical analysis of all measured and calculated data channels shall be available immediately after each test run.

2. Frequency splits and distributions shall be available within one working day.

3. A preliminary report containing all data and a brief description of the tests shall be required within one week after the completion of the model tests.

4. A final report, covering all aspects of the model tests shall be required within one month of the completion of the model tests. This report shall contain, as a minimum, the following:

   - A comparison between measured and theoretical wave spectrums
   - Wind and current force and field descriptions
   - Test set up description
   - A description of the models with relevant drawings
   - The location of all instrumentation used on the models
   - All measured and calculated test values
   - A summary containing the test sequence, environmental conditions, dredge loadings, etc.
   - High / Low frequency splits
   - Distribution plots
   - RAO plots of selected channels

M. Test Series Description

Operating Environments

Test Number	Ballast Condition	Significant Wave Height	Current Velocity	Wind Velocity
1	100%	6.0 ft	2.0 kt	30.0 kt
2	100%	6.0 ft	1.0 kt	30.0 kt
3	100%	6.0 ft	0.0 kt	30.0 kt
4	50%	6.0 ft	2.0 kt	30.0 kt
5	50%	6.0 ft	1.0 kt	30.0 kt
6	50%	6.0 ft	0.0 kt	30.0 kt
7	0%	6.0 ft	2.0 kt	30.0 kt
8	0%	6.0 ft	1.0 kt	30.0 kt
9	0%	6.0 ft	0.0 kt	30.0 kt

Survival Test

Test Number	Ballast Condition	Significant Wave Height	Current Velocity	Wind Velocity
10	None	10.0 ft	2.0 kt	30.0 kt

N. Additional Tests

- A static force deflection test shall be conducted
- Decay / Damping tests shall be conducted

Waterways Experiment Station Cataloging-in-Publication Data

Dredge mooring study : conceptual design : phase I report
/ by SOFEC, Inc. ; prepared for Department of the Army, U.S. Army Corps of Engineers ; monitored by Coastal Engineering Research Center.
84 p. : ill. ; 28 cm. — (Contract report ; DRP-92-1)
Includes bibliographic references.
1. Mooring of ships. 2. Dredges. 3. Anchorage. 4. Single-point moorings. I. SOFEC, Inc. II. United States. Army. Corps of Engineers. III. Coastal Engineering Research Center (U.S.) IV. Dredging Research Program. V. U.S. Army Engineer Waterways Experiment Station. VI. Series: Contract report (U.S. Army Engineer Waterways Experiment Station) ; DRP-92-1.
TA7 W34c no.DRP-92-1