

DDE/ET/4063--1 (V01.2)

MASTER



**LOCKHEED**

MISSILES & SPACE COMPANY, INC. • SUNNYVALE, CALIFORNIA

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

DOE/ET/4063--1 (Vol. 2)

NOTICE MN ONLY

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It  
has been reproduced from the best available  
copy to permit the broadest possible avail-  
ability.

OTEC PLATFORM CONFIGURATION AND  
INTEGRATION STUDY -  
FINAL REPORT  
VOLUME 2  
TECHNICAL CONCEPT

APRIL 1978

LMSC-D623756

Prepared for  
UNITED STATES DEPARTMENT OF ENERGY  
DIVISION OF SOLAR ENERGY  
Under Contract EG-77-C-01-4063

Prepared by  
OCEAN SYSTEMS  
LOCKHEED MISSILES & SPACE COMPANY, INC.  
A SUBSIDIARY OF LOCKHEED CORPORATION

Supported by  
EARL AND WRIGHT  
MORRIS GURALNICK ASSOCIATES, INC.  
HYDRONAUTICS INCORPORATED

BECHTEL CORPORATION  
T. Y. LIN INTERNATIONAL  
TUNED SPHERE INTERNATIONAL, INC.

NOTICE  
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

*129*

THIS PAGE  
WAS INTENTIONALLY  
LEFT BLANK

## FOREWORD

The OTEC Platform Configuration and Integration Study was performed by Lockheed Missiles & Space Company, Incorporated, under DOE Contract EG-77-C-01-4063. Supporting Lockheed in this work were six subcontractors: Bechtel Corporation; Earl & Wright Consulting Engineers; Hydronautics, Incorporated; Morris Guralnick Associates, Incorporated; Tuned Sphere International, Incorporated; and T. Y. Lin International.

The final report is comprised of four separately bound volumes, as follows:

- Volume 0 EXECUTIVE SUMMARY
- Volume 1 SYSTEMS ENGINEERING AND INTEGRATION  
describes the systems integration and evaluation of six OTEC platform configurations and recommendations for the most satisfactory configuration for an OTEC commercial plant
- Volume 2 TECHNICAL CONCEPT  
describes the conceptual designs of two platform configurations for a 400-MW(e) (net) commercial plant
- Volume 3 PROJECT PLAN  
presents the project plan for an OTEC demonstration plant

THIS PAGE  
WAS INTENTIONALLY  
LEFT BLANK

## CONTENTS OF REPORT

Section		Page
VOLUME 0 EXECUTIVE SUMMARY		
VOLUME 1 SYSTEMS ENGINEERING AND INTEGRATION		
1	INTRODUCTION AND SUMMARY	1-1
2	OPTIMUM INTEGRATED OTEC COMMERCIAL PLANT SYSTEM	2-1
	2.1 Methodology	2-2
	2.2 Interface Considerations	2-3
	2.3 Most Satisfactory Component Options	2-12
	2.4 Platform Options	2-115
	2.5 Optimum Plant System for New Orleans Site	2-253
	2.6 Sensitivity to Requirements	2-294
3	EFFECT OF SITE VARIATION ON OPTIMUM PLANT SYSTEM	3-1
	3.1 Ocean System Variations Between Sites	3-1
4	IMPACT OF TECHNICAL ADVANCES	4-1
	4.1 Heat Exchanger Selection	4-1
	4.2 Demisters	4-4
5	SUMMARY OF CONCLUSIONS	5-1
VOLUME 2 TECHNICAL CONCEPT		
1	INTRODUCTION AND SUMMARY	1-1
2	DESCRIPTION OF INTEGRATED SYSTEMS	2-1
3	DESCRIPTION OF CONCEPTUAL DESIGN OF SHIP	3-1
4	DESCRIPTION OF CONCEPTUAL DESIGN OF SPAR	4-1
5	DISCUSSION OF RESULTS	5-1
6	SUMMARY OF CONCLUSIONS	6-1
VOLUME 3 PROJECT PLAN		
1	OTEC DEMONSTRATION PLANT	1-1

THIS PAGE  
WAS INTENTIONALLY  
LEFT BLANK

## CONTENTS OF VOLUME 2

Section	Page
FOREWORD	iii
1 INTRODUCTION AND SUMMARY	1-1
2 DESCRIPTION OF INTEGRATED SYSTEMS	2-1
3 DESCRIPTION OF CONCEPTUAL DESIGN OF SHIP	3-1
3.1 GENERAL CHARACTERISTICS	3-2
3.2 SEA WATER SYSTEM	3-13
3.3 POSITION CONTROL SYSTEM	3-25
3.4 SUPPORT SYSTEM	3-30
3.5 STRUCTURAL ARRANGEMENTS	3-34
3.6 CONSTRUCTION	3-40
3.7 DEPLOYMENT	3-46
3.8 SUPPORT FACILITIES	3-51
3.9 MAINTENANCE	3-53
3.10 CONTINGENCY CONFIGURATIONS	3-56
3.11 COSTS AND SCHEDULES	3-60
4 DESCRIPTION OF CONCEPTUAL DESIGN OF SPAR	4-1
4.1 GENERAL CHARACTERISTICS	4-2
4.2 SEA WATER SYSTEM	4-12
4.3 POSITION CONTROL SYSTEM	4-14
4.4 SUPPORT SYSTEM	4-17
4.5 STRUCTURAL ARRANGEMENTS	4-27
4.6 CONSTRUCTION	4-34
4.7 DEPLOYMENT	4-38
4.8 SUPPORT FACILITIES	4-48
4.9 MAINTENANCE	4-51
4.10 CONTINGENCY CONFIGURATIONS	4-54
4.11 COSTS AND SCHEDULES	4-58
5 DISCUSSION OF RESULTS	5-1
6 SUMMARY OF CONCLUSIONS	6-1
APPENDIX A COLD WATER PIPE CONCEPTUAL DESIGN	A-1
APPENDIX B OTEC COST ESTIMATING SHEETS AND NOTES	B-1

Section 1  
INTRODUCTION AND SUMMARY

The primary objective of this conceptual design study was to maximize the cost effectiveness of the two OTEC platform configurations, the ship and the spar with detachable modules, as they apply to commercial plants with 400 MW<sub>e</sub> net output. The results of the previous screening study, Volume 1, have identified most promising configurations of platform and provided a solid data base of platform costs and system analyses.

Early examination of potential concept arrangements for the 400 MW<sub>e</sub> plant using 25 or 50 MW<sub>e</sub> power modules revealed that traditional materials and arrangements would not be capable of attaining cost effective designs. Immersing some of the power system components in the sea water revealed remarkable design opportunities. The two conceptual designs which are described in this volume present unique concepts which seek to maximize the cost effectiveness of the OTEC commercial platforms.

The ship-type conceptual design utilizes immersed heat exchangers (50 MW<sub>e</sub>) with a combined strong-back and water duct structural design in concrete to provide a platform which is estimated to cost 690 \$/kW for each of the 2nd to 8th units for a New Orleans site.

The spar-type conceptual design, which inherently utilizes immersed heat exchangers in the detachable modules, incorporated immersed ammonia storage tanks to assist in providing net buoyancy for the core of the spar as constructed in concrete. A cost of 801 \$/kW is estimated for the spar-type platform at a New Orleans site.

Both platform concepts utilize a central control facility in the OTEC farm which provides living accommodations for service personnel and all on-site maintenance ships and supplies. No accommodations are planned for permanent personnel on the individual commercial platforms.

The following sections of this report present the results of these two parallel conceptual design studies.

## Section 2 DESCRIPTION OF INTEGRATED SYSTEMS

Conceptual design of the OTEC platforms required extensive integration of the power system and sea water systems with the hull and structure system. The requirements for these systems are presented in this section along with descriptions of the general features of these systems. Specific design details are presented in the two sections which describe the conceptual designs, Sections 3 and 4.

### 2.1 REQUIREMENTS FOR 400 MW<sub>e</sub> NET COMMERCIAL PLANTS

The major requirements for the 400 MW<sub>e</sub> net commercial platforms are presented in Table 2.1-1. Based on these requirements several design guidelines were established.

1. Drag forces from current and wind must be minimized to provide a low cost position control system.
2. Accommodations for on-site maintenance of major equipment will be minimized.
3. Cold water discharge will be vertically downward at greater than 150 meters (492 ft).
4. Warm water discharges will be horizontal near 45 meters (145 ft) depth.

Power systems physical requirements derived from Lockheed power system studies and DOE recommendations are presented in Table 2.1-2. These are based on a power system designed for optimum output at a temperature differential of 40° F. It is planned to provide initial start-up power from outside sources with subsequent start-up power derived from operating modules. Heat exchanger maintenance is planned for tube plugging on-site with shipment to shore for tube or bundle removal. Space is provided on the platform for maintenance of turbines and pumps along with appropriate cranes.

### 2.2 DESCRIPTION OF SEA WATER SYSTEMS

The nominal sea water flow rate requirement for each heat exchanger is 177 m<sup>3</sup>/s

TABLE 2.1-1

PRIMARY REQUIREMENTS FOR 400 MW<sub>e</sub> NET  
OTEC COMMERCIAL PLATFORM<sup>e</sup>

1. Provide adequate platform for 400 MW<sub>e</sub> net power plant comprised of 8 or 16 power modules (Table 2.1-2).
2. Location for baseline design is in the Gulf of Mexico - off of New Orleans.
3. Minimum operational life at sea is 40 years.
4. Energy transfer shall be by electrical transmission through ocean floor cables.
5. Construction of major platform components will be in U.S. facilities.
6. Position control system will limit horizontal excursion to a watch circle of 335 meters (1100 ft).
7. Cold water intake will be at 1000 meters (3281 ft.) depth.
8. Final power output will be at minimum cost.
9. Design shall comply with applicable codes and regulations.

TABLE 2.1-2  
 PHYSICAL DESCRIPTION OF POWER SYSTEM COMPONENTS  
 FOR 50 MW<sub>e</sub> NET POWER MODULE

1. Heat Exchanger (2/Module) (Aluminum, Integral Demister)

Diameter, Ft	73 (Spherical)	Wet Wt, LT	2512
Length, Ft	49	Immersed, LT	2469 (Buoyant)
Dry Wt, LT	1261	Immersed, LT	784.4 (NH <sub>3</sub> spaces flooded)

2. Turbines (4/Module)

Diameter, Ft	9.67	Dry Wt (for 4), LT	53.6
Length, Ft	10.5	Wet Wt (for 4), LT	53.6

3. Generator (1/Module)

Diameter, Ft	18	Dry Wt, LT	196
Length, Ft	30	Wet Wt, LT	196

4. T/G Laydown Area

Width, Ft	28	Volume of Space, Ft <sup>3</sup>	35,100
Length, Ft	76	Displ of Space, LT	1,003
Height, Ft	16.5	Displ - Wt	754 LT (Buoyant)

2 turbines on each side of gen. gen. 2' forward from rear of area - no laydown area required for gen. Alternate: 4 turbines on one side of generator.

5. Ammonia Storage Tanks (16/400 MW<sub>e</sub> Platform)

Diameter, Ft	25	Wet Wt (for 16), LT	4286
Length, Ft	50	Displ (for 16), LT	11,220
		Displ Wt (for 16), LT	6,934

6. Chlorination (120/400 MW<sub>e</sub> Platform)

Length, Ft	17	Wet Wt (for 120), LT	214
Width, Ft	3	Displ, LT	1049
Height, Ft	6	Displ, Wt, LT	835 (Buoyant)

Allow 2.5 ft clearance on length and width.

7. Ammonia Vapor Piping (2/50 MW<sub>e</sub> Evaporator)

Diameter, Ft	7	Dry Wt, LT/Ft	0.29
--------------	---	---------------	------

(6,250 cfs). Intake screens are provided with a mean inflow velocity of 0.46 m/s (1.5 fps). The large flow rates require large sea water ducts have been integrated into the hull and structures of the platforms. Therefore, details of the sea water systems are presented in the description of the conceptual designs.

### 2.3 DESCRIPTION OF COLD WATER PIPE SYSTEM

Design analysis of rigid-type cold water pipes has shown (Appendix A) that a jointed, concrete pipe is the most cost effective pipe to manufacture for this application. The high cost of deployment of the concrete pipe makes it more costly than a flexible pipe of rubber coated nylon. The light weight rubber/nylon pipe has been used as the base-line in the conceptual design studies. Capability to utilize a jointed, concrete pipe was considered in alternative designs for each platform. Details of the cold water pipe designs are presented in the conceptual design descriptions of the platform.

### 2.4 DESCRIPTION OF POSITION CONTROL SYSTEM

The position control system is required to hold the platform within the watch circle in the extreme environment. The watch circle is defined by the requirements of the riser cable for the electrical transmission system. The extreme weather condition may be expected to cause a substantial loss of thermal resource for the power system requiring power for the dynamic positioning system to be provided by fossil fuel. Low cost approaches to mooring systems have resulted in very different concepts for the two platform types. Details of these systems are described in the conceptual design sections.

### Section 3

#### DESCRIPTION OF CONCEPTUAL DESIGN OF SHIP

This conceptual design for a ship-type platform for a 400 MW<sub>e</sub> net OTEC commercial plant is a major departure from conventional ship design. The payload requirements of the OTEC power and sea water systems have been efficiently integrated with the ship structural requirements to create a unique platform concept for the commercial plant.

Initial concepts for the ship platform centered on mounting the 50 MW<sub>e</sub> net power system components interior to the concrete hull structure in arrangements that sought to optimize the sea water ducting. A major portion of the ship hull structure was devoted to providing displacement to support the power system components. Noting that many power system components themselves were pressure vessels and some displaced large volumes of water, it was decided to apply these components to provide buoyancy for the platform. The heat exchangers were immersed fully in sea water by removing the outer hull of the ship. The new strong-back-type structural arrangement of the ship then required special consideration for construction and float-out limitations. Light weight concrete was used in the upper decks to further reduce the size of hull structure. This arrangement allows the large heat exchangers to be floated into position from the open sides of the structure without having to provide large capacity cranes.

The resultant ship-type platform for the OTEC commercial plant producing 400 MW<sub>e</sub> net is approximately the same size as the previous designs which produced 100 MW<sub>e</sub> net using 25 MW<sub>e</sub> power system components mounted within the hull. The complete cost is 690 \$/kW for each of the 2nd to 8th units of the new ship-type platform.

This section presents a complete description of the conceptual design of this unique ship-type platform and all the supporting systems and functions.

### 3. 1 GENERAL CHARACTERISTICS

The OTEC Ship Platform consists of a central concrete hull, external heat exchangers attached to both sides of the hull, intake and discharge water pipes attached to the bottom, warm and cold seawater pumps in the discharge piping, and support system equipment on the Main and Second Decks. The ship has the following principal characteristics.

Length Overall	210 m	689 ft
Maximum Beam on Waterline	58 m	190 ft.
Maximum Beam Overall	73 m	240 ft
Depth to Main Deck	34 m	112 ft.
Operating Draft	28 m	92 ft
Light Ship (Dry) Weight	140,382 tonne	138,166 L. T
Displacement @ Operating Draft	257,953 tonne	253,867 L. T.
Displacement @ Operating Draft Excluding Seawater	174,448 tonne	171,644 L. T.

#### Hull

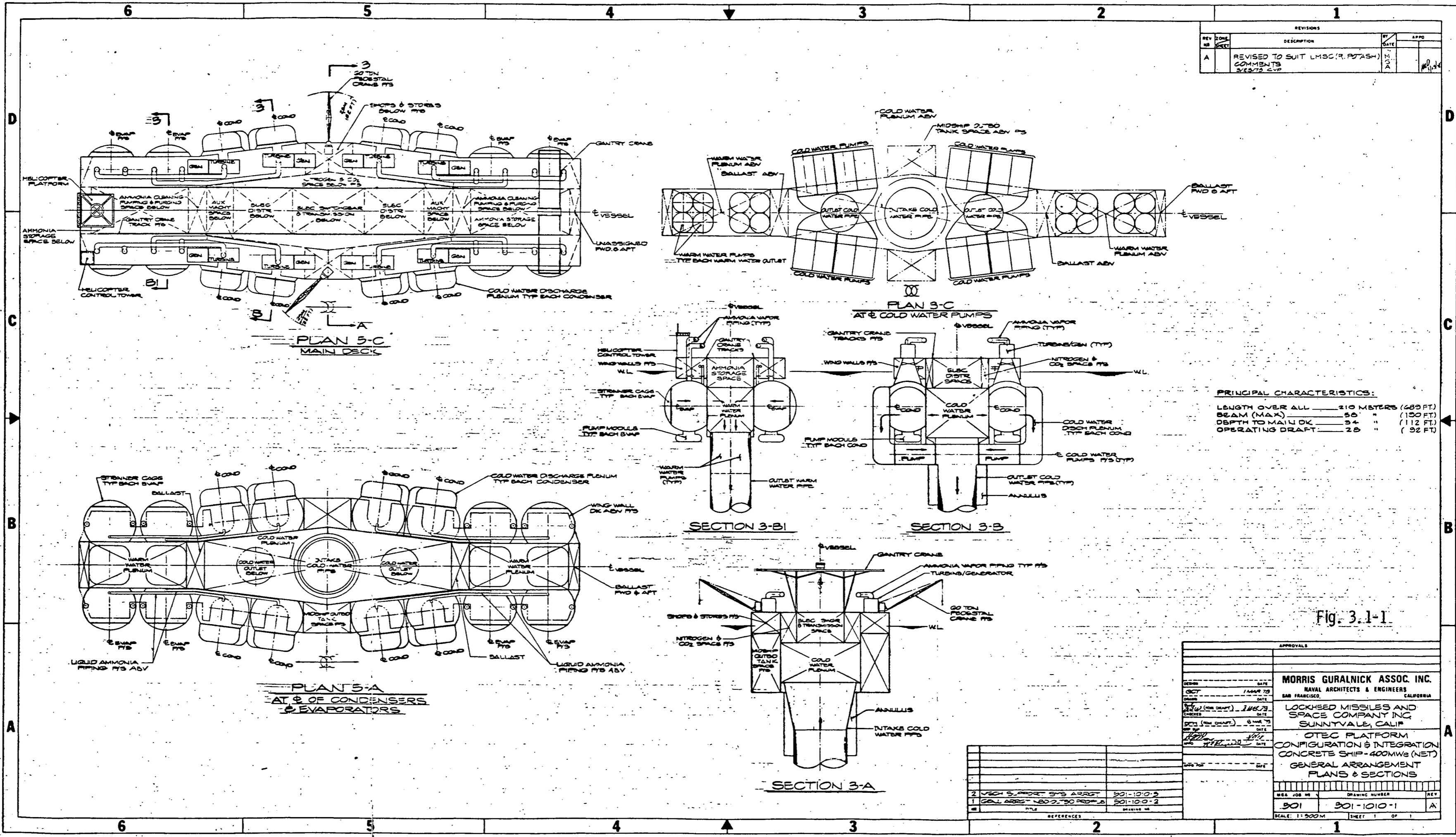
The central hull is 'T'-shaped in cross-section and wall-sided throughout. The arrangement was developed to minimize weight and cost, and yet provide sufficient buoyancy, strength, internal volume, and deck area for all required OTEC equipment under the anticipated environmental conditions. Permanent accommodations have not been provided for the moored configuration. It is anticipated that all operating and maintenance personnel will be housed ashore or in an accommodations vessel centrally moored in the energy park. Platform general arrangements are shown in plan and section in Figure 3.1-1, inboard and outboard profiles in Figure 3.1-2. Operational mode is illustrated in Figure 3.1-3.

#### Heat Exchangers

All heat exchangers will be buoyant and detachable for repair or major maintenance ashore. Attachment to the hull will be made on the under side of the wing walls and by means of mating flanges in way of the openings in the side walls of the hull.

201-1010-1

REVISIONS			
REV NO	DATE	DESCRIPTION	BY
A		REVISED TO SUIT LMSC (R. P. TASH) COMMENTS 2/2/75 EWP	



**PRINCIPAL CHARACTERISTICS:**  
 LENGTH OVER ALL 210 METERS (689 FT)  
 BEAM (MAX) 50 " (150 FT)  
 DBPTH TO MAIN DECK 34 " (112 FT)  
 OPERATING DRAFT 28 " (92 FT)

Fig. 3.1-1

APPROVALS	
DESIGNED	DATE
CHECKED	DATE
APPROVED	DATE
DATE	DATE

<b>MORRIS GURALNICK ASSOC. INC.</b>	
NAVAL ARCHITECTS & ENGINEERS	
SAN FRANCISCO, CALIFORNIA	
<b>LOCKHEED MISSILES AND SPACE COMPANY INC.</b>	
SUNNYVALE, CALIF	
OTEC PLATFORM CONFIGURATION & INTEGRATION	
CONCRETE SHIP-400MWS (NET)	
GENERAL ARRANGEMENT PLANS & SECTIONS	
DESIGN JOB NO	DRAWING NUMBER
901	901-1010-1
SCALE: 1" = 5000'	SHEET 1 OF 1

NO	DESCRIPTION	DATE
2	VECH 3, PROJET 3MS ARRBT	30-10-75
1	GEN ARR - 400 2-70 PROPLA	30-10-75

REV NO	DATE	DESCRIPTION	BY

WEIGHT	GROUP	POUNDS





Four evaporators will be located at the forward end of the vessel, (2 port, 2 starboard). The evaporators will take suction directly from the surrounding water through strainers and discharge into warm water plenums and down through discharge pipes. The eight condensers will take water from a common cold water plenum which is filled by the cold water intake pipe and then discharge outboard and down through the two discharge pipes to 150 m depth. Pump modules below each heat exchanger contain the condensate pumps for the condensers and distribution pumps for the evaporators. Ammonia piping to and from these pumps is internal to the heat exchanger shells.

#### Seawater System Piping and Pumps

Both the warm and cold water pumps are located on the discharge side of the heat exchangers with 2 pumps serving each. The warm water pumps and discharge pipe are assembled as a unit and supported from the bottom of the hull directly below the warm water plenum. Cold water pumps are located in the cold water discharge manifolds below the hull and are supported from the bottom of the outboard flange of the condensers. The pump/pipe unit for each heat exchanger module is designed to be neutrally buoyant and detachable for transport to shore facilities for major repair and maintenance.

The flexible rubber-nylon cold water intake pipe is supported from the bottom of the hull at midships on centerline.

#### Support Systems

The space between the Second and Main Decks is utilized for ammonia storage, electrical transmission and switchgear, electrical distribution equipment, auxiliary machinery, chlorinators and nitrogen and CO<sub>2</sub> storage. Wing wall spaces outboard of the main hull will be used for piping and cable runs. Ballast tanks are located at the ends of the vessel and between the warm and cold water plenums, forward and aft. The midship outboard tank spaces will be utilized for diesel fuel or ballast, as required.

The eight turbine generator sets are housed in their own enclosures on the main deck. A gantry crane and two pedestal cranes will be used to handle equipment and stores between the below deck spaces and service vessels alongside. The helicopter platform and control tower are located at the stern to avoid interferences.

#### Off-Baseline Design

The use of a concrete cold water pipe in lieu of the flexible rubber-nylon pipe would require an additional 16,000 tonnes (t) of buoyancy to support the additional weight. It is anticipated that this 16,000 t of buoyancy could come from the 35,720 t margin which is presently included in the baseline design. Alternatively, additional 11,400 t could be gained by attaching the ammonia storage tanks to the exterior of the hull below the waterline. Therefore, the present hull configuration is suitable for use with a concrete cold water pipe.

#### Weights and Centers

All weights are assumed to be symmetrical about amidships so that the ship LCG is at amidships. The weights and centers for the bare hull (launch condition) are shown in Table 3.1-1. Table 3.1-2 lists the weights and centers for the operating mode at the full load draft of 28 meters.

#### Intact Stability - Bare Hull

The ship has adequate intact stability as a bare hull at the lightship draft only if auxiliary flotation pontoons are attached. As the bare hull leaves the construction drydock for deployment of external power system components its 14 meter draft is well below the main deck wings which provide the intact waterplane needed to produce adequate stability. Therefore, pontoon-like barges must be placed at the four corners of the ship to provide temporarily the waterplane required to produce adequate stability.

Without the barges, the bare hull stability characteristics are as follows:

TABLE 3.1-1  
WEIGHTS AND CENTERS FOR SHIP-TYPE PLATFORM:  
BARE HULL, LAUNCH CONDITION

<u>ITEM</u>	<u>VOLUME</u> (m <sup>3</sup> )	<u>DENSITY</u> (t/m <sup>3</sup> )	<u>WEIGHT</u> (t)	<u>KG</u> (m)	<u>VERT.</u> <u>MOMENT</u> (t-m)
Keel to 2m. W. L.	5,482	1.84	10,087	1.0	10,087
Bottom Plugs	517	1.84	951	.25	238
2m. W. L. to 22.8m. W. L.	14,013	1.84	25,784	14.48	373,351
Side Plugs	887	1.84	1,632	14.48	23,631
Above 22.8m. W. L.	17,116	1.84	31,493	25.6	806,231
Decks	<u>5,720</u>	1.44	<u>8,237</u>	<u>33.75</u>	<u>277,992</u>
TOTAL	43,735		78,184	19.08	1,491,530

Launch Condition: Displacement = 78,184.3 t (76,949 L.T.)  
 KG = 19.1 m ( 65 ft)

TABLE 3.1-2  
WEIGHTS AND CENTERS FOR SHIP-TYPE PLATFORMS  
OPERATING MODE

<u>ITEM</u>	<u>WEIGHT (t)</u>	<u>(L. T.)</u>	<u>KG(m)</u>	<u>VERTICAL MOMENT (t-m)</u>
Keel to 2m. W. L.	10,087		1.0	10,087
2m. W.L. to 22.8m. W. L.	25,784		14.5	373,868
Above 22.8m. W. L.	31,493		25.6	806,221
Decks	8,237		33.8	278,411
Subtotal - Concrete Hull	<u>75,601</u>	(74,407)	<u>19.4</u>	<u>1,468,587</u>
<hr/>				
Evaporators (8)	20,096		11.2	225,075
Condensers (8)	20,096		11.2	225,075
Turbogenerators (8)	2,032		36.0	73,152
Ammonia Storage Tanks (16)	11,400		28.0	319,200
Subtotal - Major Power System Components	<u>53,624</u>	(52,777)	<u>15.7</u>	<u>842,502</u>
<hr/>				
Electrical Transmission System	2,794		27.0	75,438
Ammonia Vapor & Cond. Sys.	1,543		11.6	17,899
Ammonia Fill & Purge Sys.	428		28.0	11,984
Equipment Handling & Removal System	136		44.0	5,984
Fire Protection System	111		26.0	2,886
Subtotal - Major Support Systems & Electrical Trans.	<u>5,012</u>	( 4,933)	<u>22.8</u>	<u>114,191</u>
<hr/>				
Standby Power System	91		26.0	2,366
Cooling Water System	65		26.0	1,690
Ammonia Cleanup System	59		28.0	1,652
Comp. Air System	48		26.0	1,248
Hydraulic Pressure System	20		26.0	520
Emergency Breathing System	3		30.0	90
Subtotal - Other Support Systems	<u>286</u>	( 282)	<u>26.5</u>	<u>7,566</u>

TABLE 3.1-2 (Cont'd)

<u>ITEM</u>	<u>WEIGHT (t)</u>	<u>(L. T.)</u>	<u>KG(m)</u>	<u>VERTICAL MOMENT (t-m)</u>
Warm Water in W.W. Plenum	29,350		11.7	343,395
Cold Water in C.W. Plenum	54,155		11.7	633,614
Subtotal - Internal Seawater	<u>83,505</u>	( 82,186)	<u>11.7</u>	<u>977,009</u>
<hr/>				
Cold Water Inlet (Rubber - Nylon) Pipe	505		0.0	-0-
Cold Water Discharge (Rubber- Nylon) Pipes	150		-15.0	- 2,250
Warm Water Discharge (Steel) Pipes	915		-26.5	- 24,248
C.W. Discharge Ducting (Steel)	2,500		4.0	10,000
S. W. Pumps	-0-		- 9.2	-0-
Pressure Hulls	- 860		- 2.5	2,150
Steel Structure	1,000		- 1.0	- 1,000
Subtotal - External Items (Immersed in S. W.)	<u>4,205</u>	( 4,139)	<u>- 3.6</u>	<u>- 15,348</u>
<hr/>				
<u>SUMMARY</u>				
Concrete Hull	75,601	( 74,407)	19.4	1,468,587
Major Power System Components	53,624	( 52,777)	15.7	842,502
Major Support System and Electrical Transmission	5,012	( 4,933)	22.8	114,191
Other Support Systems	286	( 282)	26.5	7,566
Internal Seawater	83,505	( 82,186)	11.7	977,009
External Items	4,205	( 4,139)	- 3.6	- 15,348
Subtotal - Summary	<u>222,233</u>	<u>(218,724)</u>	<u>15.3</u>	<u>3,394,507</u>
Margin (16%)	35,720	( 35,156)	23.0	821,560
Total	<u>257,953</u> tonnes	<u>(253,880)</u> (L. T.)	<u>16.3</u> meters (53.5) ft	<u>4,216,067</u> t-m

Displacement	=	78,184 t
Draft	=	13.9 m
TPC	=	56.0 t/CM
KB	=	6.9 m
$KM_T$	=	13.8 m
$KM_L$	=	213 m
KG	=	19.1 m
$GM_T$	=	-5.3 m

Each barge waterplane area required for  $\overline{GM}_T = +0.5$  m is 320 m<sup>2</sup>.

Length and beam required for each barge = 20 m X 16 m.

#### Intact Stability - Operating Mode

With 7.2 meters of  $\overline{GM}$  the ship has adequate stability in the operating mode. The following are the intact stability characteristics for the ship at the full load operating draft:

Displacement	=	257,953 t
Draft	=	28 m
TPC	=	107 t/CM
KB	=	14.64 m
$KM_T$	=	23.50 m
$KM_L$	=	154 m
KG	=	16.3 m
$GM_T$	=	7.2 m
$GM_L$	=	138 m

#### Damage Stability

The ship has sufficient compartment subdivision, stability and reserve buoyancy to survive flooding of any one external compartment. Flooding of internal spaces on the second deck is not analyzed since these spaces are protected by external compartments and tanks.

Results for the two damage cases considered are:

- a) For damage and flooding of one midship outboard flotation space, the vessel heels to an angle of  $5.4^{\circ}$ , and minimum freeboard remaining after damage is 2.5m (undamaged freeboard is 6m). There is no trim since flooding is symmetrical fore and aft.
- b) For damage and flooding of one evaporator at the bow or stern and the wing compartment above, the vessel heels to  $2.4^{\circ}$  and trims to  $0.6^{\circ}$  (2.1 meters), leaving a minimum freeboard after damage of 3.7m.

Stability in both damaged conditions is not significantly reduced by either free surface effects or changes in center of gravity due to flooded water.

## 3.2 SEAWATER SYSTEM

The conceptual design of the seawater system, consisting of cold and warm water intake and discharge systems, is presented in this section. The warm water components are inlet screens, discharge plenum, pumps and discharge pipe, while the cold water system components are inlet screen, cold water pipe (CWP), pipe/hull bearing, plenum, discharge water box, pumps and discharge pipe (see Table 3.2-1).

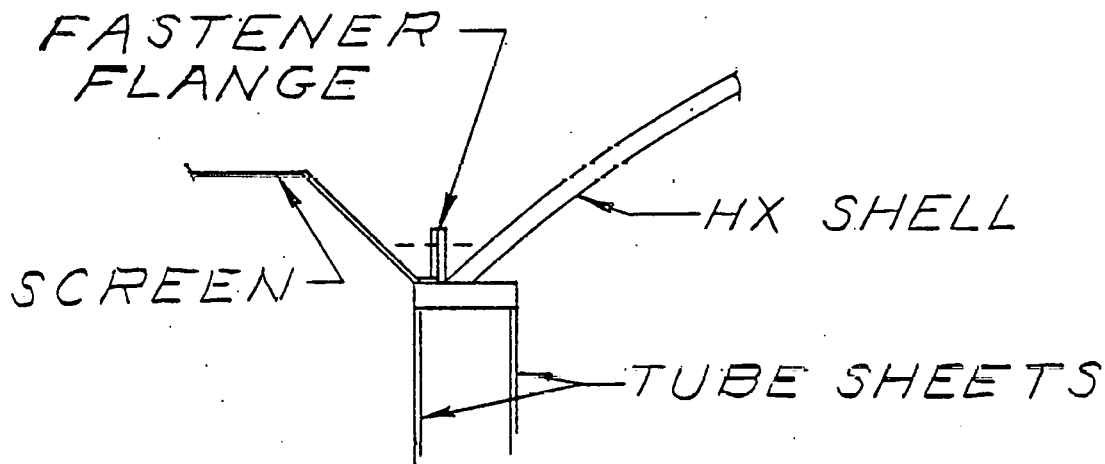
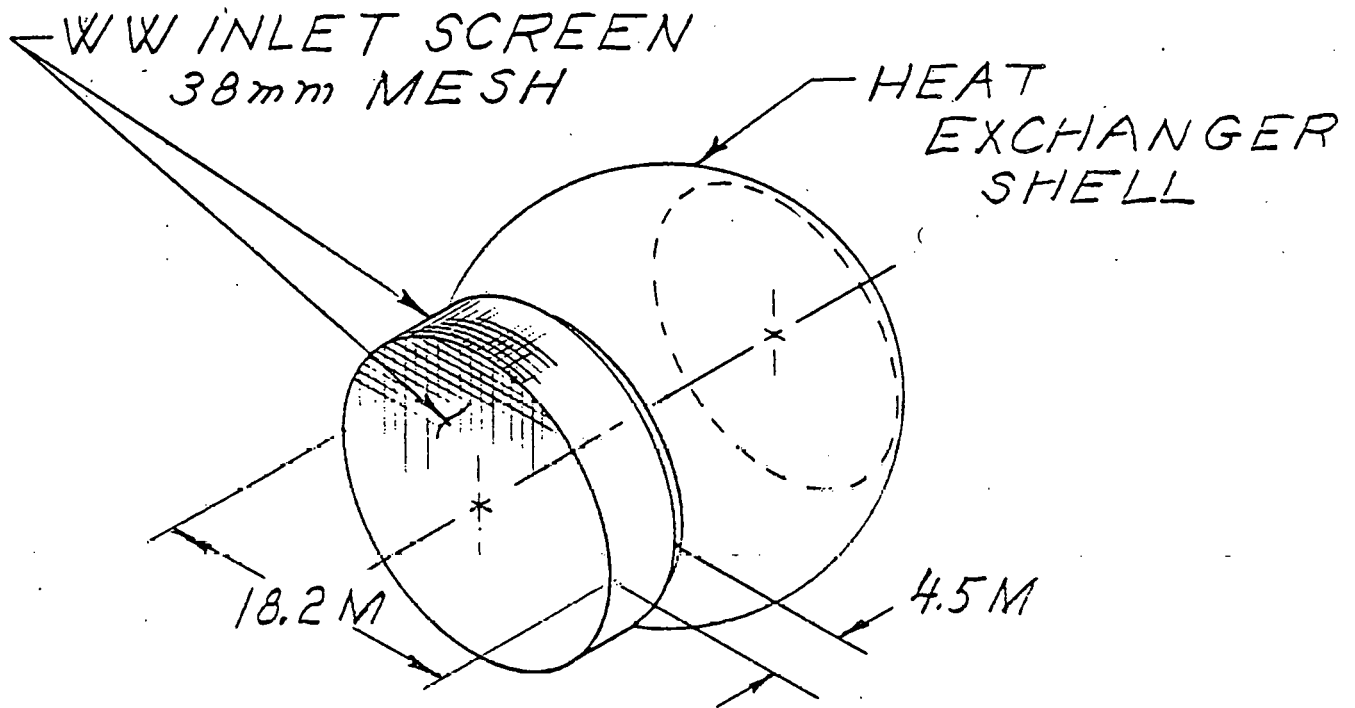
### 3.2.1 Warm Water System

The warm water system is located in the forward and aft ship quarter lengths (see Figures 3.1-1, 2, 3). Attached to the upstream side of each evaporator is an inlet screen (18.2, x 4.5m) with mesh size of 38mm (1.5 in) and 73 percent open surface area. For an inflow rate of  $177\text{m}^3/\text{s}$  (6,250 cfs) per heat exchanger, the inlet flow velocity is 0.46 m/s (1.5 fps) with a mean depth of 14 m (46 ft). As shown in Figure 3.2.1-1 the screen attachment to the tube sheet-shell flange allows for screen removal as required. Water exits from the evaporator into the warm water plenum bounded by the keel, second deck and main longitudinals. Two large cutouts in the keel permit flow into two sets of four pumps each. The pumps, mounted vertically below the keel, are removeable (Figure 3.2.1-2). A discharge pipe, mounted to each pump module, conducts warm water to a depth of 64 meters to provide isothermal discharge at New Orleans. Vertical discharge allows use of a soft pipe. This approach saves weight and reduces handling during deployment and maintenance compared with a rigid pipe. A soft pipe with ring stiffeners provides for seawater flow reversal at low rates. The buoyancy tanks formed by the pump module housing and diffuser wall as well as the water tight pump and hub provide approximately 1321 t (1300 Lt) of buoyancy per pump. With 508 t (500 Lt) pump weight and 184 t (181 Lt) pump housing weight, pump module buoyancy is approximately 629 t (619 Lt). Computations have shown that there is no significant difference in ship motions with or without attached sea water discharge pipes.

Table -1

## SHIP SEAWATER SYSTEM COMPONENT WEIGHT AND COST

Item	Material	Unit Weight (Long Ton)	Unit Cost (\$M)	Quantity Required Per Ship	Total Weight (Long Ton)	Total Cost (\$M)
<b>WARM WATER SYSTEM</b>						
Screen	Stainless Steel	32.0	1.781	8	256	14.247
Pump	Steel	500.0	2.09	16	8,000	33.4
Pump Module Housing	Steel	181.2	0.55	4	725	2.19
P.M. Interface Plating	Steel	3.2	0.009	4	12.8	0.038
Heat Exchanger/ Hull Interface	Steel/Graphite	15.3	0.031	8	244.4	0.497
Discharge Hose	Rubber/Nylon	4.6	0.173	4	73.5	0.693
Subtotal		736.3 (748t)	4.63		9311.7 (9,461t)	51.07
<b>COLD WATER SYSTEM</b>						
Screen	Stainless Steel	300.0	17.079	1	300	17.079
CWP	Concrete	46,493.0	33.0	1	46,493	33.0
CWP/Hull Bearing	Steel/Graphite	4,917.7	2.425	1	4,917.7	2.425
Water Box	Steel	96.0	0.290	8	768.6	2.324
Discharge Pipe	Rubber	25.1	0.237	8	200.9	1.893
Heat Exchanger/ Hull Interface	Steel	15.3	0.031	8	244.4	0.497
Pump	Steel	500.0	2.09	16	8,000	33.4
Subtotal		52,347.1 (53,187t)	54.92		60,924.6 (61,902t)	90.62
<b>Total</b>		<b>53,083.4</b> <b>(53,935t)</b>	<b>59.55</b>		<b>70,236.3</b> <b>(71,363t)</b>	<b>141.69</b>



DETAIL OF SCREEN  
HEAT EXCHANGER JOINT

Fig. 3.2.1-1 Warm Water Inlet Screen

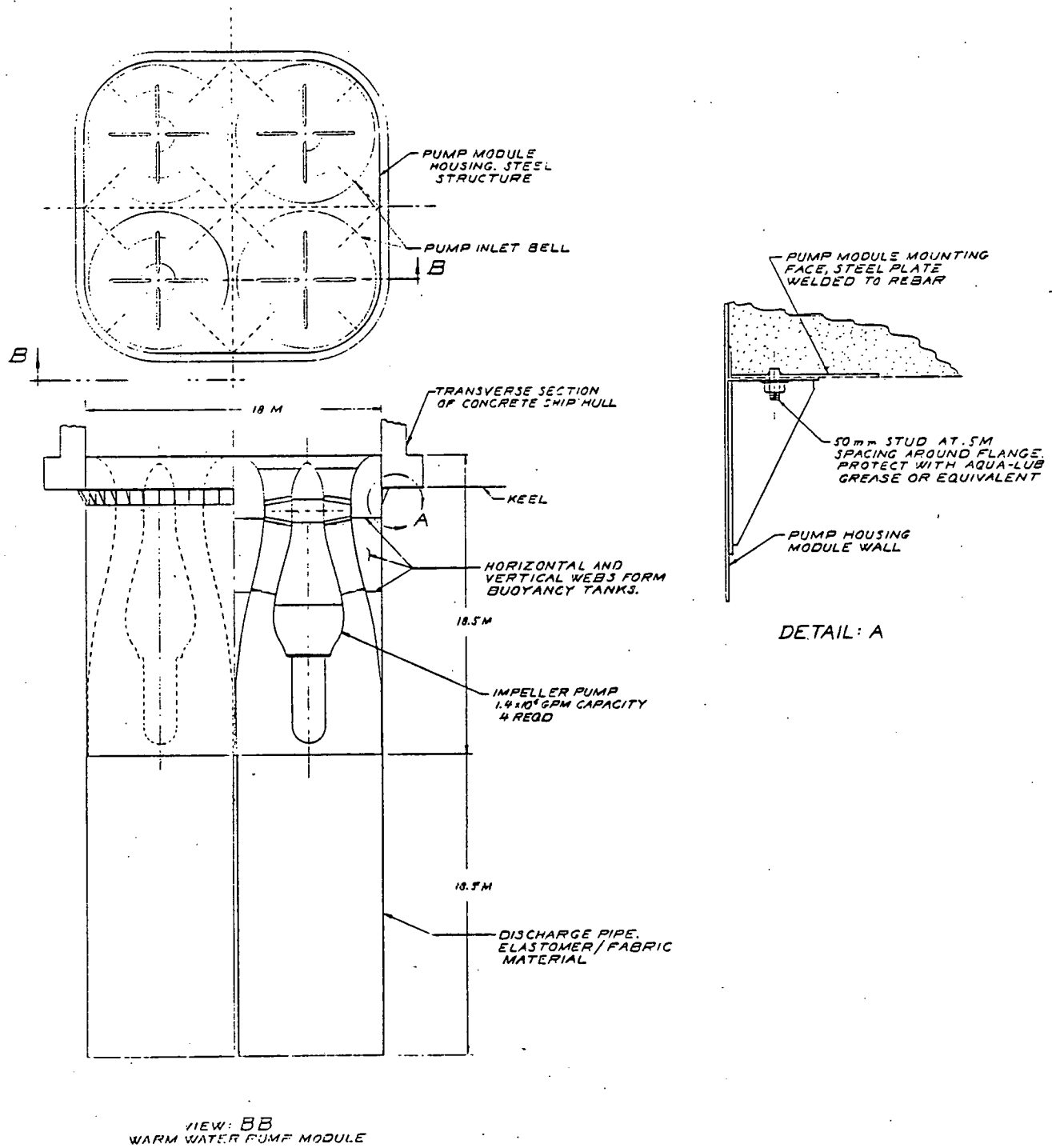


Fig. 3.2.1-2• Warm Water Pump Module Concept, OTEC 400-MW(e)

An estimate of flow loss through the warm water system in the operational model is indicated by the following breakdown:

<u>COMPONENT</u>	<u>HEAD LOSS, psf</u>
Inlet Screen	1.4
Discharge Pipe	2.5
Discharge screen (as required)	43
TOTAL WW System	<u>46.9</u>
Evaporator and waterbox	624.7
TOTAL (Warm Water)	<u>671.6</u>

### 3.2.2 Cold Water System

The general arrangement of the cold water system is shown in Figures 3.1-1, 2, and 3, and the system components in Figures 3.2.2-1 through -4. The system is located over the ship half length centered at amidships and symmetric fore and aft.

An inlet screen is attached to the cold water pipe (CWP) to prevent large objects from obstructing the system. Mesh opening is 38.1 mm x 50.8 mm (1.5 in x 2.0 in) with an opening of 80% of total surface area and an inlet velocity of 0.46 m/s (1.5 fps) for 1416 m<sup>3</sup>/s (50,000 cfs) total flow. The spherical shape is selected (46.6 m diameter), although a circular cylinder screen is less complex structurally, for its high surface area to volume ratio. In steel the screen weight is approximately 302 t (297 Lt).

The cold water pipe (CWP) assembly shown in Figure 3.2.2-1 consists of the inlet screen, pipe, pipe joints and bearing in the ship. A CWP analysis conducted in this study and summarized in Appendix A indicates that prestressed concrete is a lower cost CWP material than either GRP or aluminum. An alternate concept, the soft CWP of rubber impregnated nylon, appears to be comparable in capital cost and lower in deployment cost than the concrete CWP if the material life in seawater is equal to that of concrete. This study indicates that optimum ID is 21 to 24 m (70 to 80 ft) and inlet depth is 808 m (2650 ft) at New Orleans. Pipe thickness is approximately 0.3 m (1 ft) for

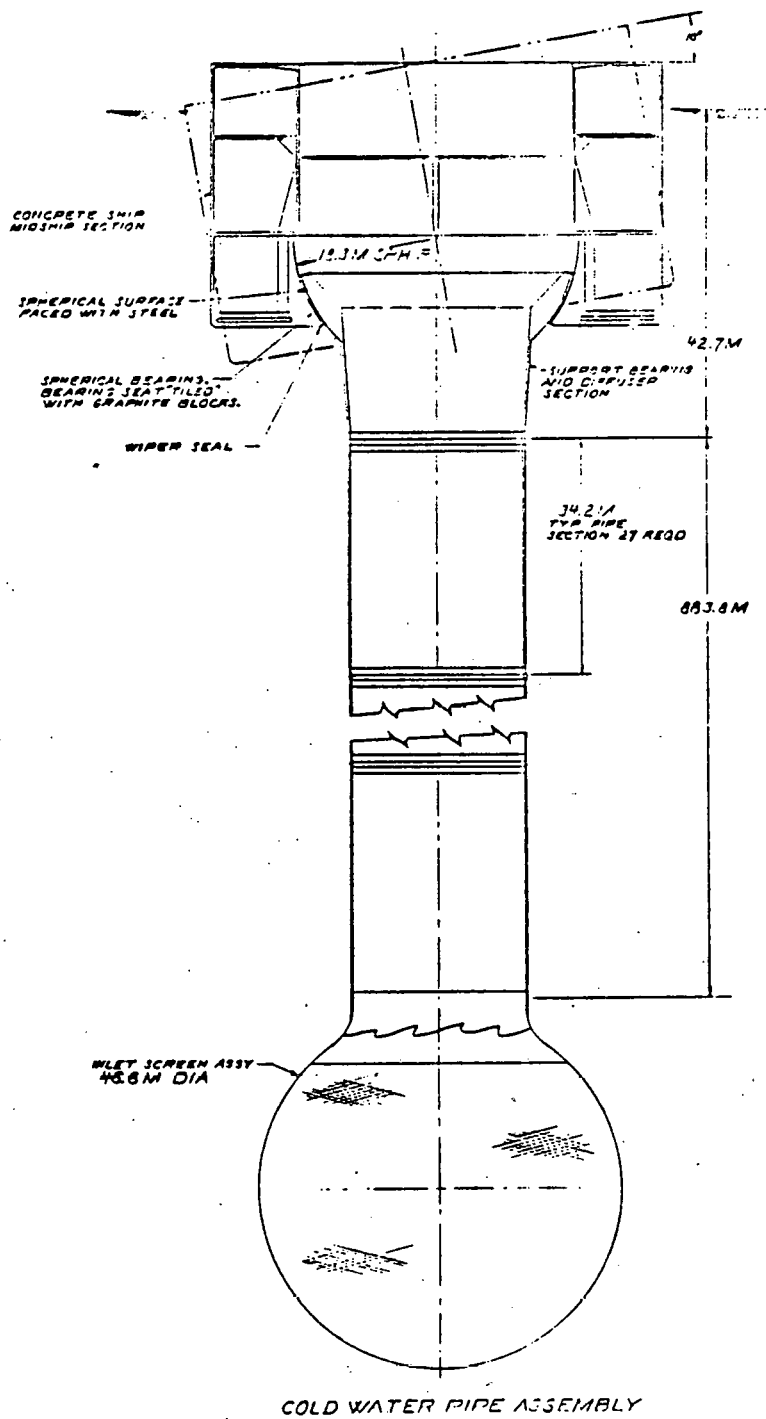


Fig. 3.2.2-1 Cold Water Pipe Assembly

concrete and 0.5 cm ( $\frac{1}{2}$  in) for rubber-nylon inner and outer walls. To achieve low wall thickness in concrete, the pipe sections, 30 m (100 ft) in length, are connected by joints which allow for full axial load transfer but limited bending moment transfer. There is one flexible joint for each pipe section.

The flexible joint shown in Figure 3.2.2-2 for the concrete CWP consists of a graphite bearing spherical segment which carries the axial load. Rubber snubber rings provide restoring moment but do not carry axial load. A total of 27 joints are required for the entire pipe string. Each joint is fitted with 232 graphite segments, 12 neoprene rubber segments of 50 Shore hardness and 193 t (190 Lt) of steel weldment, for a total joint weight of 220 t (218 Lt). Joint rotational stiffness is  $9.5 \times 10^{10}$  ft-lbs/radian. This joint, designed for maximum axial load and dynamic bending moment, would be reduced in strength for pipe sections which are more lightly loaded. An estimate to fabricate 27 joints to this design is \$0.52M (graphite), \$2.3M (rubber) and \$11M (steel) for a total of \$13.82M per CWP.

A typical pipe section (Figure 3.2.2-3) consists of the reinforced concrete shell, a ring pattern of handling lugs to aid in deployment with hydraulic jacks, and the flexible joint assembly. The saw-toothed splice rings are welded to the section lowered onto this section during deployment. Section weight of 1635 t (1609 Lt) is within the hoisting capacity of existing floating crane vessels.

The CWP/hull interface consists of a 18.3m (60 ft) radius spherical segment bearing faced in steel and fitted with graphite bearing blocks. Graphite bearing stress is 56 psi and maximum rotation is  $\pm 10$  degrees. Rotational stiffness within this limit is negligible so that the CWP connection to the ship is a pin joint. Although ship peak roll in beam 100-year storm is in excess of 20 degrees, with a single-point moor, the seas on the bow, the peak CWP pitch relative to the ship is 12.8 degrees. The design can be modified to accommodate this rotation.

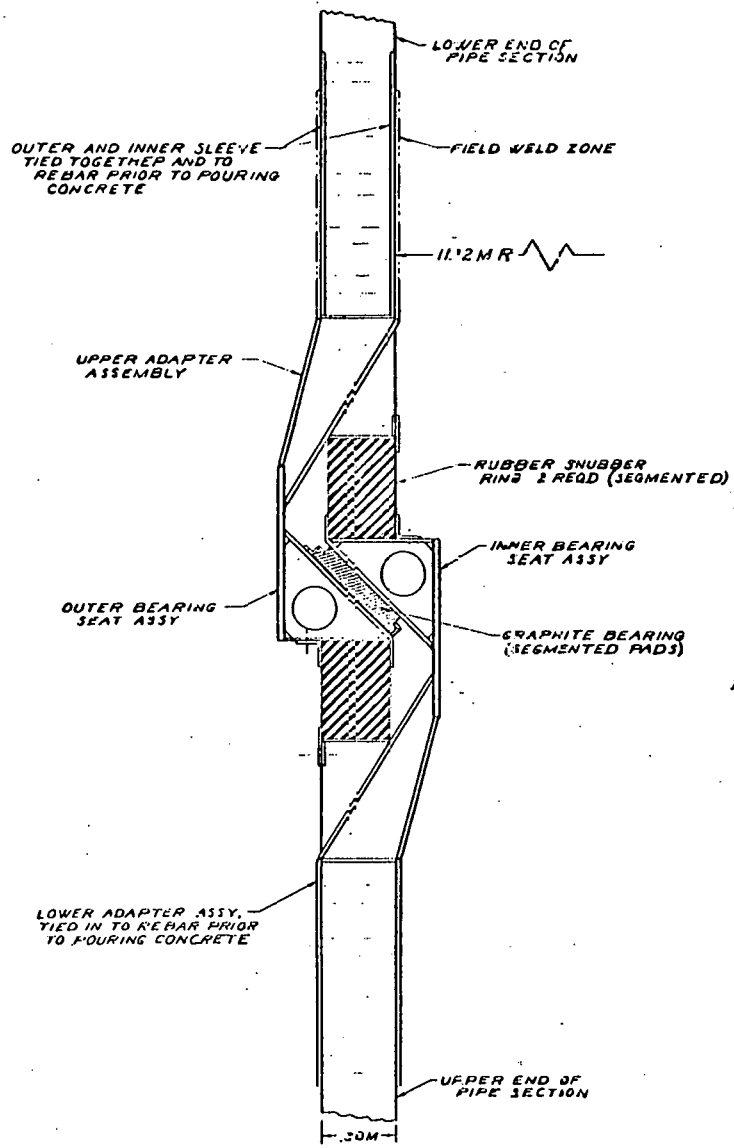
Cold water enters the plenum above the CWP/hull interface filling the entire volume, (105 m long, 16.8 m high, 18 to 36 m wide). This water then exits

Table 3.2.2-1

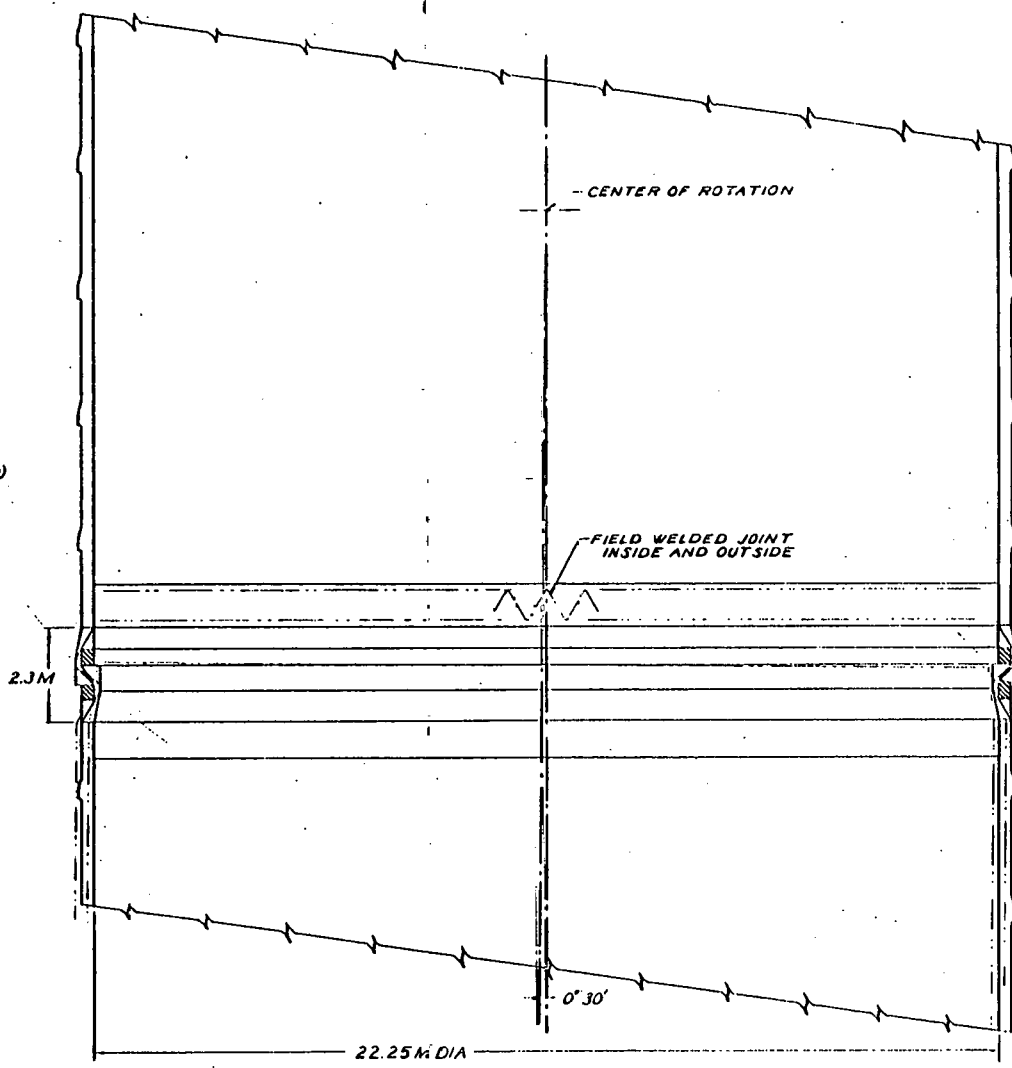
COLD WATER PIPE CHARACTERISTICS

	PRE-STRESSED CONCRETE		RUBBER-NYLON
LENGTH	808 m	(2650 ft)	Same
INSIDE DIAMETER	22.25 m	(73 ft)	Same
OUTSIDE DIAMETER	22.86-23.32 m	(75-76.5 ft)	38.1 m (125 ft)
WEIGHT	47,239 t	(46,493 Lt)	2903 t (2857 Lt)
BENDING STIFFNESS		$(0.124 \times 10^{15} \text{ lb-ft}^2)$	$(0.23 \times 10^{12} \text{ lb-ft}^2)$
<u>SECTION</u>			
LENGTH	34.2 m	(112 ft)	No Sections
WEIGHT	1635 t	(1609 Lt)	
<u>JOINT</u>			
MATERIAL	STEEL, GRAPHITE, RUBBER		No sections
STIFFNESS	95 x 10 <sup>9</sup> ft-lbs/rad		
MAXIMUM ROTATION	± 1 Degree		

3-21



SECTION: BEARING DETAIL



SECTION: PIPE JOINT

Fig. 3.2.2-2 CWP Flex Joint Concept, OTEC 400-MW(e)

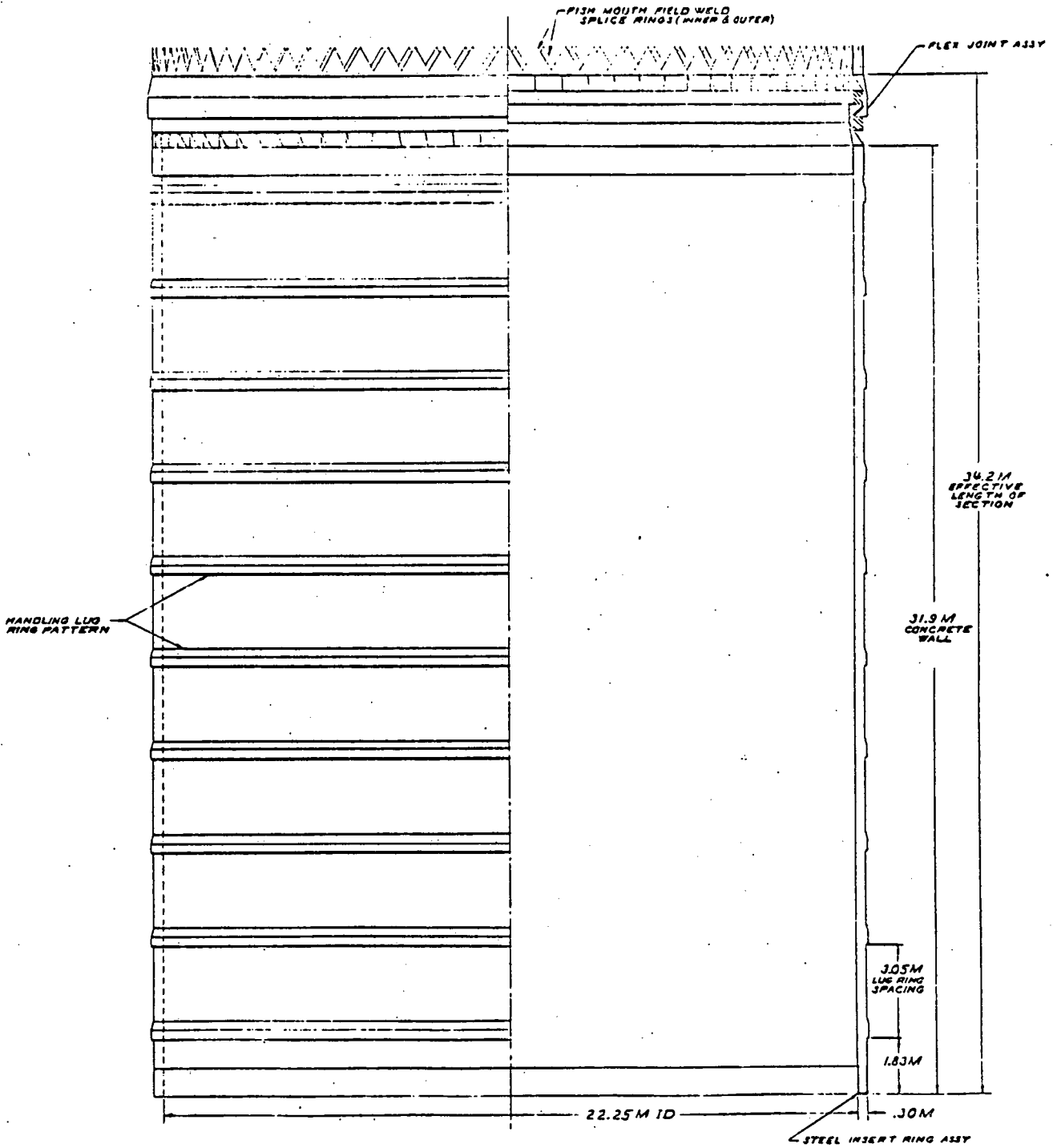


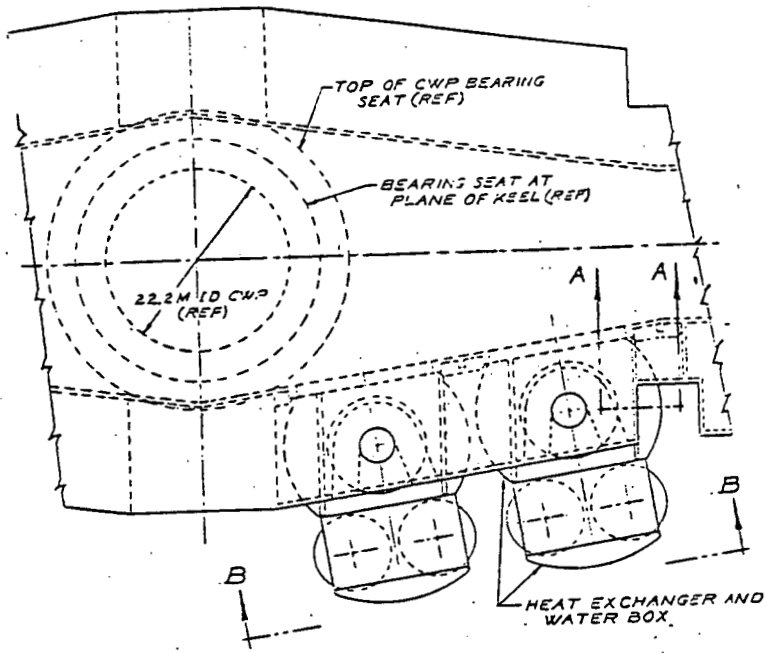
Fig. 3.2.2-3 Pipe Section Assembly, Quarter Sectioned

from the condenser into a water box and is turned through 90 degrees into a pair of vertical seawater pumps (see Figure 3.2.2-4). This pump arrangement, a change from that shown in the general arrangements drawings, reduces the required turns and simplifies attachment and deployment. A discharge pipe is hung below the pumps, one pipe per condenser, and discharges at 105 m depth. This pipe is a rubber/nylon soft pipe. The condenser module, consisting of the condenser with diffuser, waterbox, seawater pumps and discharge pumps, may be deployed as a unit and attached to the ship as shown in Figure 3.2.2-4. The heat exchanger is attached with a series of 48 hydraulically actuated toggle mechanisms equally spaced around the hull opening. Loads are transferred to the hull wing structure via two concrete saddles which are fitted with adjustable support pads which mate to the spherical shell.

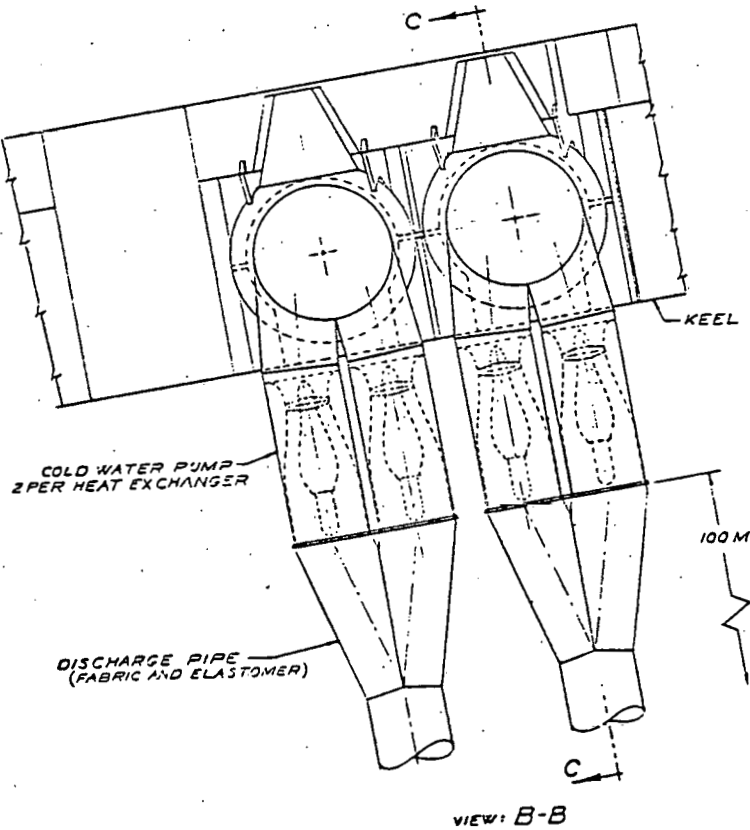
Flow loss in the cold water flow is given as follows. The static pressure drop caused by density differences in the seawater between 2650 feet and 450 feet is 119 psf. The flow losses are tabulated below.

<u>COMPONENT</u>	<u>FLOW LOSS, psf</u>
Inlet Screen	1.13
Cold Water pipe	82.86
Diffuser	7.55
Plenum	86.35
Water box	4.6
Discharge pipe	10.8
Discharge Screen (as required)	43
	<hr/>
CW System TOTAL	236.29
Condenser	443.3
	<hr/>
TOTAL (Cold Water)	679.59

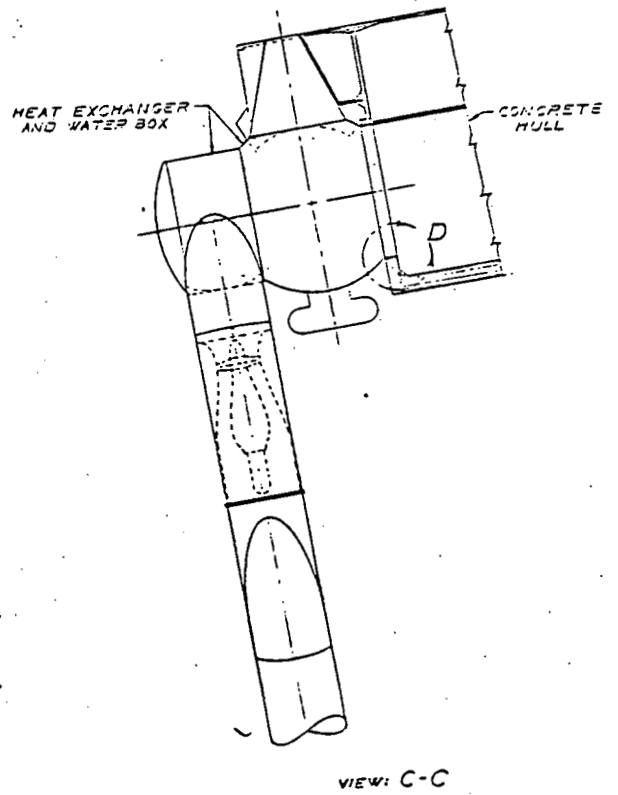
Computations have shown that there are no significant differences in ship motions with or without sea water discharge pipes.



PLAN VIEW OF HULL  
SCALE: 1 in = 240 mm



VIEW: B-B



VIEW: C-C

Fig. 3.2.2-4 Cold Water Discharge System

### 3.3 POSITION CONTROL SYSTEM

A single-point, spread mooring system is selected to position the ship plant at the New Orleans site. The configuration proposed in system integration (Vol. 1) is now modified to reflect a change in ship characteristics, watch circle requirements, and electrical transmission concepts.

The design of the position control system uses the following characteristics of the ship and discharge pipes.

Current Frontal Area, m <sup>2</sup>	5,521
Current Lateral Area, m <sup>2</sup>	31,918
Wind Frontal Area, m <sup>2</sup>	348
Wind Lateral Area, m <sup>2</sup>	1,260

The frontal area includes the ship beam at the coldwater discharge plenums (71.5 m) and draft to the bottom of the coldwater pumps (40 m), as well as projected area of a single coldwater discharge pipe (2640m<sup>2</sup>). At the mean depth of this area (54 m) the current speed is 93% of that at the surface. The lateral area includes the hull (28 m x 210 m), four warm water discharge pipes (8118 m<sup>2</sup>), and two coldwater discharge pipes (17919 m<sup>2</sup>). The current at the mean depth of 68 m is 92% of the surface current.

The extensive lateral area of the seawater discharge appendages result in high loads on a multi-point moored ship in combined beam sea, current and wind. A preferred alternative is to provide for ship weathervaning in storm conditions. In head sea and wind conditions the mooring loads are substantially reduced. With the current bow-on, the warm water intake would be normal to current serving evaporators on both sides of the ship with equal inflow conditions.

To provide weathervaning capability the ship will be moored by lines from the bow to a buoy (Figure 3.3-1). The buoy will be positioned by a three-point spread moor consisting of deadweight anchors, chain and nylon lines. The buoy, in addition to providing sufficient buoyancy to support the mooring line loads in the 100-year storm (692 Lt), will also support the electrical

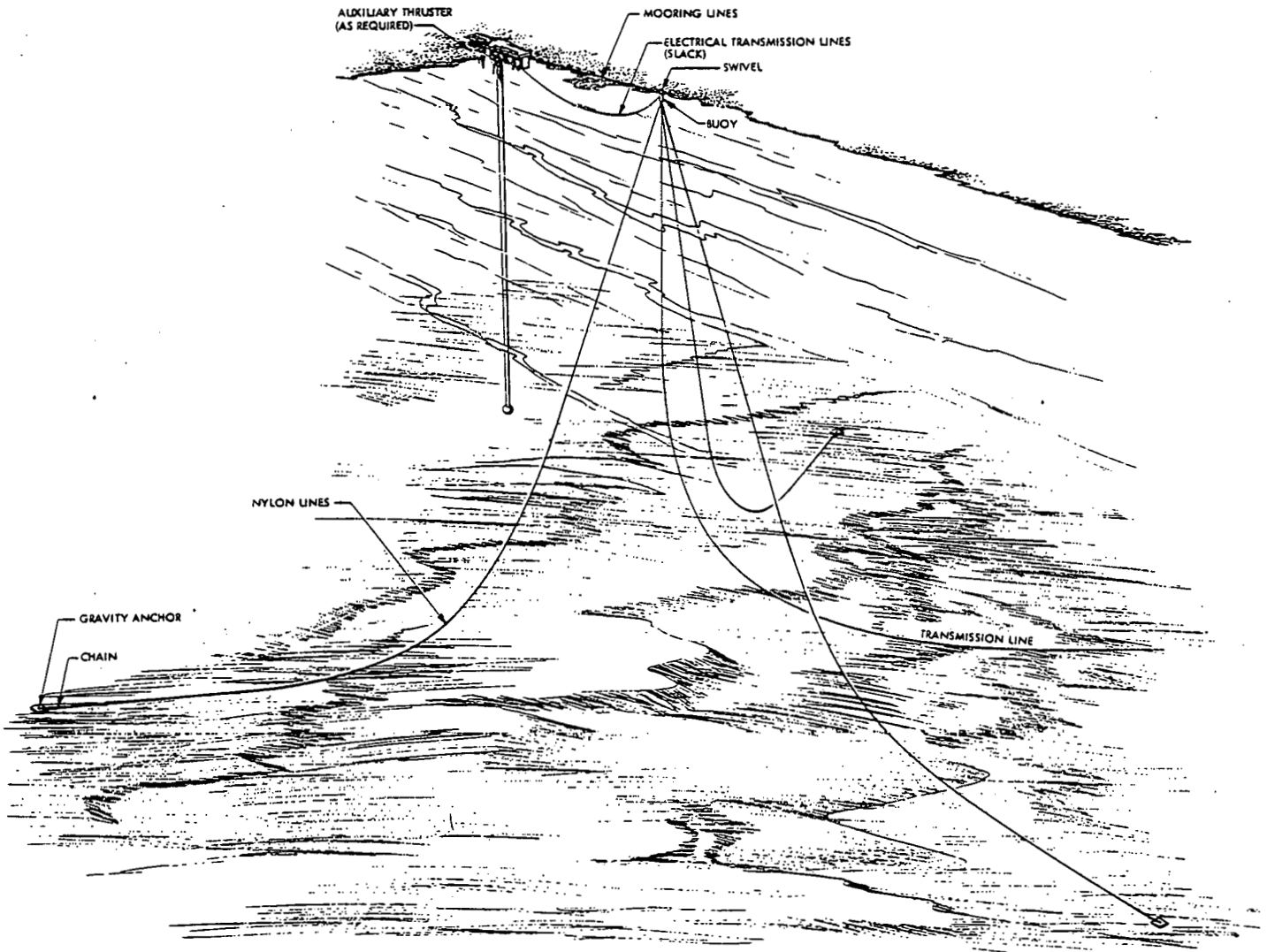


Fig. 3.3-1 Positionkeeping System - 400-MW(e) Ship

transmission lines to the ship and to the ocean floor. The single point moor concept is used successfully to transfer oil to tankers in offshore sites. A swivel at the buoy is required to allow for rotation of the ship and transmission lines about the buoy. The transmission line between ship and buoy will be slack, while the mooring line will be taut as a result of the loads on the ship. In the event of calm weather and zero current the tension in the mooring line will be maintained by an auxiliary thruster positioned on the ship stern. The line between ship and buoy will be of sufficient length to assure that seawater piping, buoy mooring lines, and electrical transmission riser are well separated.

Mooring system and electrical transmission system design requirements are interwoven, particularly since the buoy functions as a single point buoy in the mooring system as well as a base for transmission line transition from ocean floor to near surface.

The functional cost model (Vol. 1) modified for bow-on loading provides cost comparisons for the mooring system, Figure 3.3-2. Real acquisition cost, including line replacement and 40 percent for engineering and burden, are shown to increase from Hawaii to New Orleans, to Brazil. Comparison between head and beam ship orientation to current, wind and waves indicates that beam orientation results in an approximate doubling of mooring costs. The dynamic positioning system cost, lower than mooring cost for the Brazil site, is the preferred system for this deep ocean site.

Mooring costs are lower for the ship fitted with concrete CWP (23 m OD (75 ft)) than for the rubber-nylon pipe (43 m (140 ft)). In New Orleans, the mooring cost for the ship with concrete pipe is \$26.8M while the rubber-nylon pipe is \$32.7M.

The requirement to limit azimuth angle subtended by the ship weathervaning about the cable buoy to  $\pm 30$  degrees (Reference 1), leads to a separate mooring for the ship. This system is designed for beam sea conditions because of the undefinable nature of the direction of the extreme environmental condition. A three-point spread moor system for the ship with the rubber-nylon

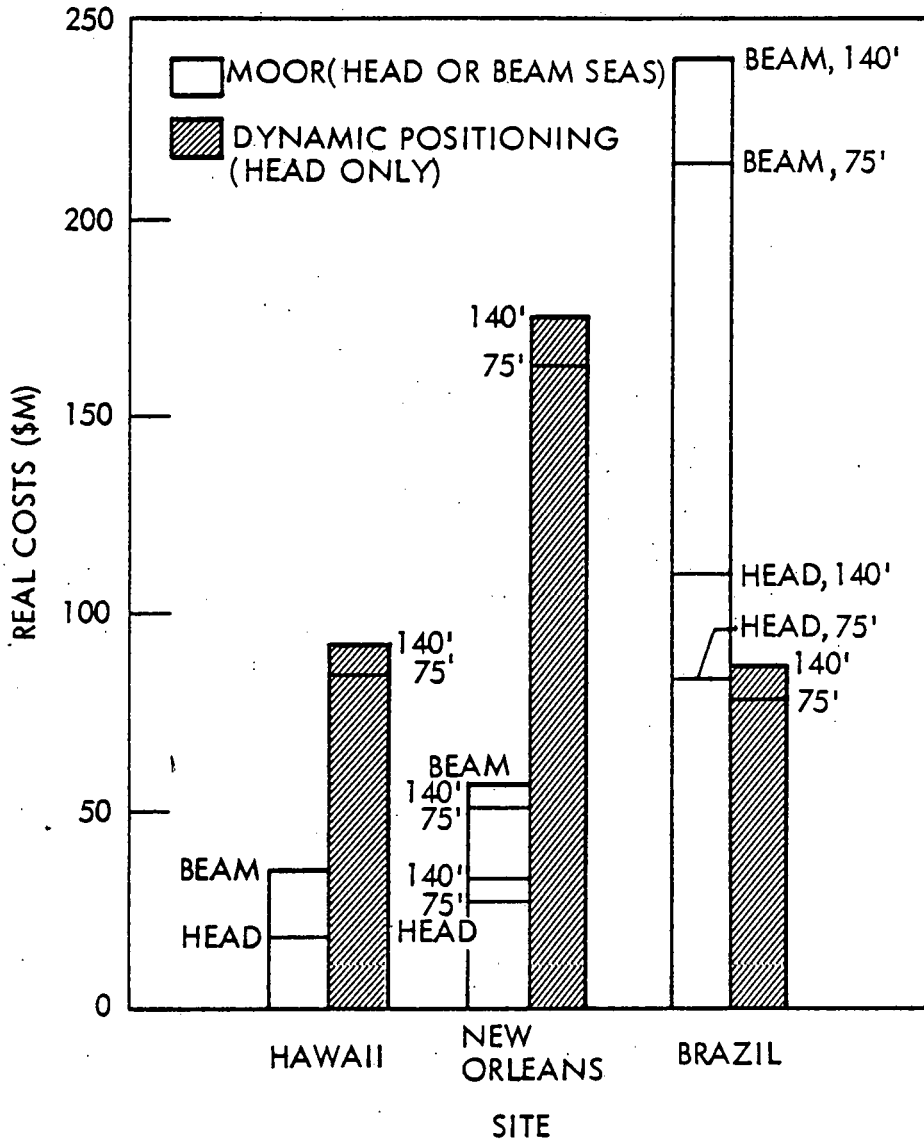


Fig. 3.3-2 Real Costs of Position Keeping System for 400 MW<sub>e</sub> Net Ship Plant

pipe at the New Orleans site, designed for beam seas, will cost \$57.7M. Thus, the requirement to limit azimuth angle in comparison with a full circling requirement results in an increase in mooring costs of \$25M. Development of a shallow-water swivel for transmission cables on the buoy would obviate the need for two separate mooring systems.

References for Section 3.3

1. Preliminary Analysis of Allowable Movement of Plant As It Affects Power Cables, Simplex Wire and Cable Company, Develop. Engrg., Report 18, October 1977.

### 3.4 SUPPORT SYSTEMS

#### Mechanical Support Systems

Included in the mechanical support systems are all machinery components required for material handling, maintenance, ventilation, ballasting, fuel handling, and diver support operations. Figure 3.4-1 presents the location and arrangement of the mechanical support systems.

On the Main Deck, a gantry crane is provided that will travel the entire length of the vessel. This crane, combined with the two pedestal cranes amidships, port and starboard, will be used to handle stores and equipment anywhere on the Main Deck and to and from the service vessels alongside.

Below the Main Deck, overhead gantry cranes and monorail cranes will be used for handling items within each space. Hatches in the Main Deck will provide vertical access for material handling.

Diver operations will be carried out from outboard spaces amidships, port and starboard. These spaces will include all necessary winches, air tanks, air compressors, and other support equipment. Access to and from these spaces will be provided by sideport doors and diving platforms near the waterline.

The auxiliary machinery spaces on the Second Deck will include all mechanical equipment normally required for operation of a vessel of this size, including bilge and ballast systems, fuel handling systems, firefighting systems, air compressors, ventilation fans and equipment and miscellaneous pumps, tanks and heat exchangers. Fully equipped work shop areas will be provided amidships, port and starboard, for onboard maintenance and repair.

#### Electrical Support Systems

The electrical support system equipment will be located in the auxiliary machinery spaces and the electrical distribution spaces which are located both forward and aft (Figure 3.4-2).

Each auxiliary machinery space will include a 4000 KW diesel generator and associated switchboards and controls. These will be used to provide electrical power for essential loads when the OTEC plant is not in operation.

The electrical distribution spaces will include the main and auxiliary transformers, switchgear, load centers, motor controllers, batteries, and other electrical equipment required for internal power feed from the turbine generators to the OTEC pumps and equipment.





### 3.5 STRUCTURAL ARRANGEMENTS

The structural system for the ship design consists essentially of a long box with variable width. The box is internally compartmented by the second deck which forms the ceiling of the plenum. Transverse girders, two for each external HE and the two upper decks extend beyond the sides of the box section to hold and support the buoyant HE by direct bearing. To resist dynamic displacement, the HE is also secured to the vessel on one side (Figure 3.5-1).

The CWP bearing is supported on a ring beam at the bottom of the vessel, which is in turn supported on the longitudinal side walls by shear stiffeners. The ship is prestressed in three directions - longitudinal prestressing of the two side walls which is concentrated in the areas above and below the openings for HE connection, transverse prestressing in the transverse girders between the main and the second decks, and vertical prestressing in the section uninterrupted by the side openings. In addition, precast pretensioned structural elements are used in the construction of the decks to save formwork and staging work.

### 3.5.1 Design Criteria

The design and analysis of the concrete hull for the 400 MW(e) ship are based on the following criteria and assumptions:

#### Material

Materials are linearly elastic and have the following properties:

Concrete:  $f'_c = 350 \text{ kg/cm}^2 = 5000 \text{ psi}$   
 $W_1 = 85 + 5 = 90 \text{ lbs./ft}^3 = 1.44 \text{ t/m}^3 \text{ (upper deck)}$   
 $W_2^* = 110 + 5 = 115 \text{ lbs./ft}^3 = 1.84 \text{ t/m}^3$   
 $E_{c1} = 33(W)^{1.5} \cdot 5000 = 2,000,000 \text{ psi}$   
 $E_{c2} = 2,900,000 \text{ psi}$

Tendon:  $f'_s = 270,000 \text{ psi}$  Grouted tendon with semi-rigid duct.

Rebars:  $f_y = 60,000 \text{ psi}$   
 $E_s = 29,000,000 \text{ psi}$

#### Allowable Stresses

Concrete: Concrete Compression:  $f_a = 0.45 f'_c = 2250 \text{ psi} = 160 \text{ kg/cm}^2$   
Shear Stresses:  $v_a = 27 \text{ kg/cm}^2 \text{ (320 psi)}$

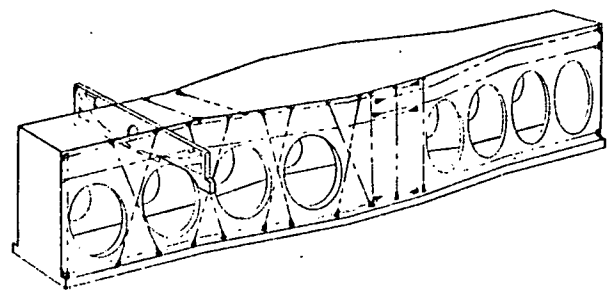
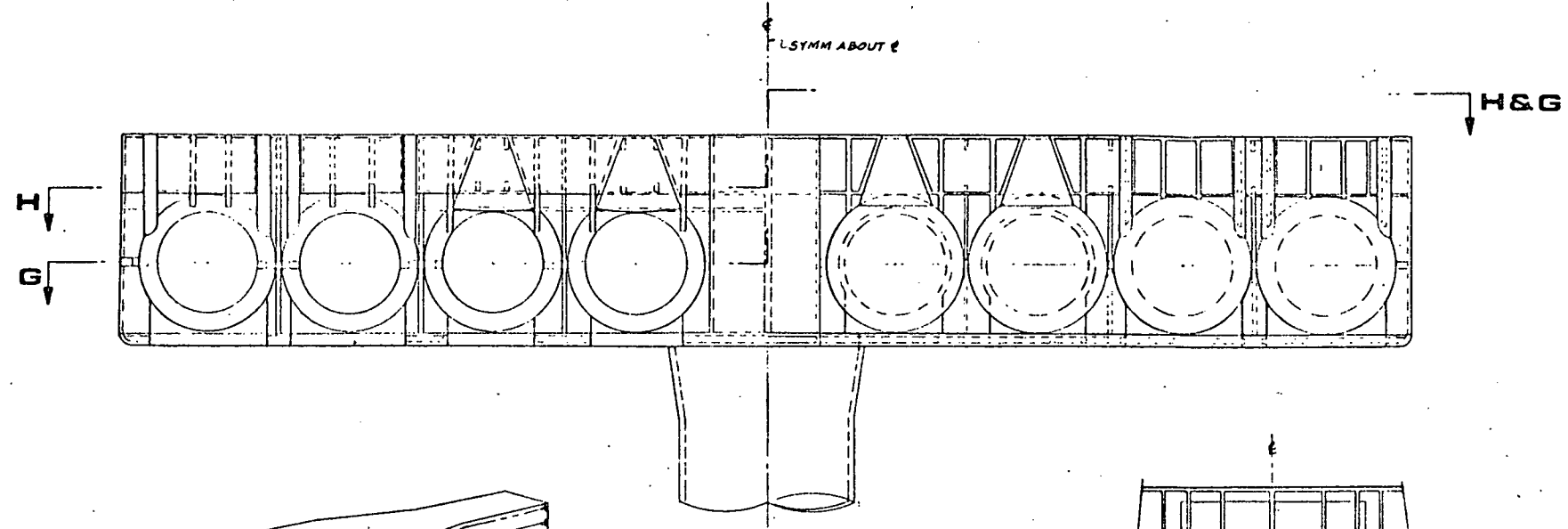
Steel Reinforcement:  $f_y = 60,000 \text{ psi}$

Steel reinforcement is used to control cracks and to facilitate construction. In the sidewalls it adds considerable amount of shear force transferring capability.

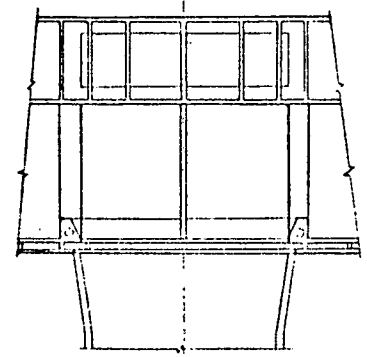
#### Prestressing:

Jacking stresses, allowable stresses and losses are calculated in accordance with ACI Code.

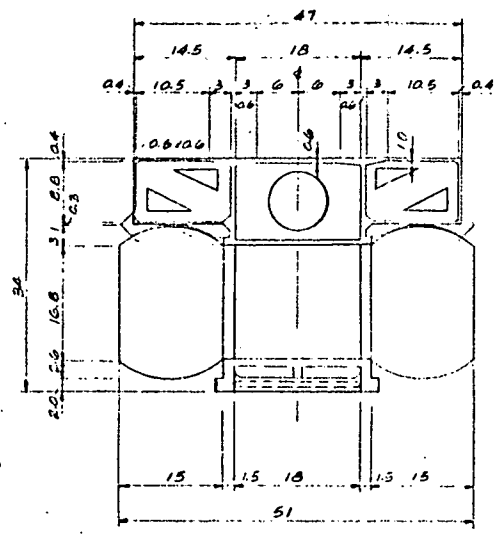
\* For long-term considerations, use  $W_2 + .20 \text{ #/ft}^3$ .



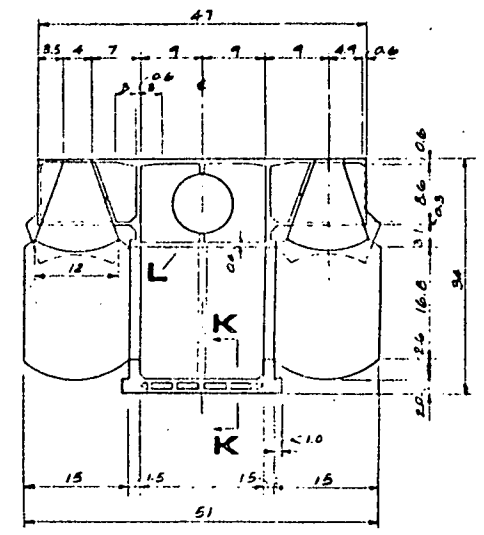
Section E



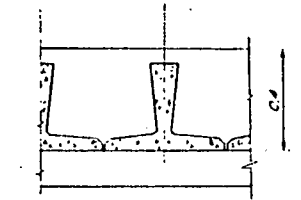
Section F



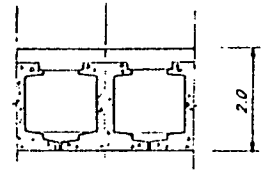
Section A



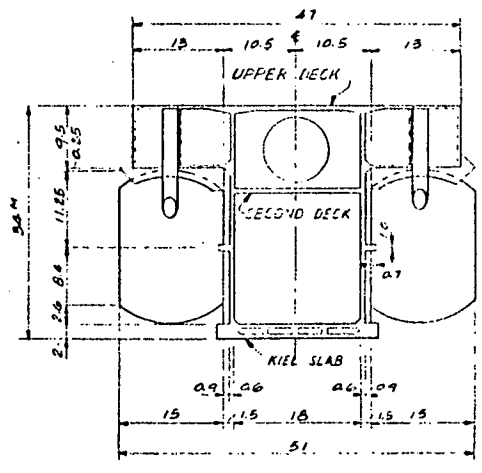
Section G



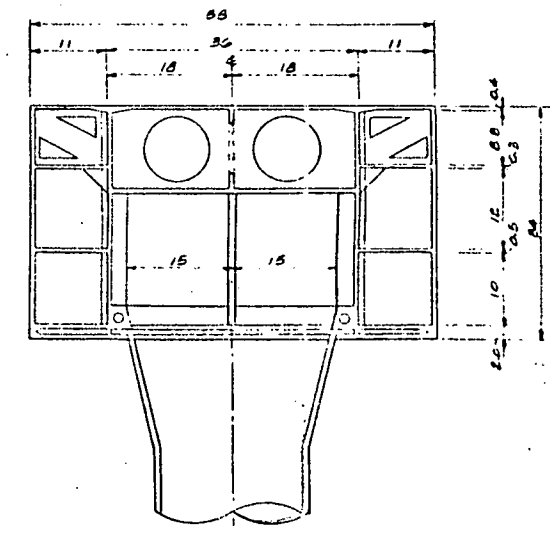
Detail L (N.T.B.)



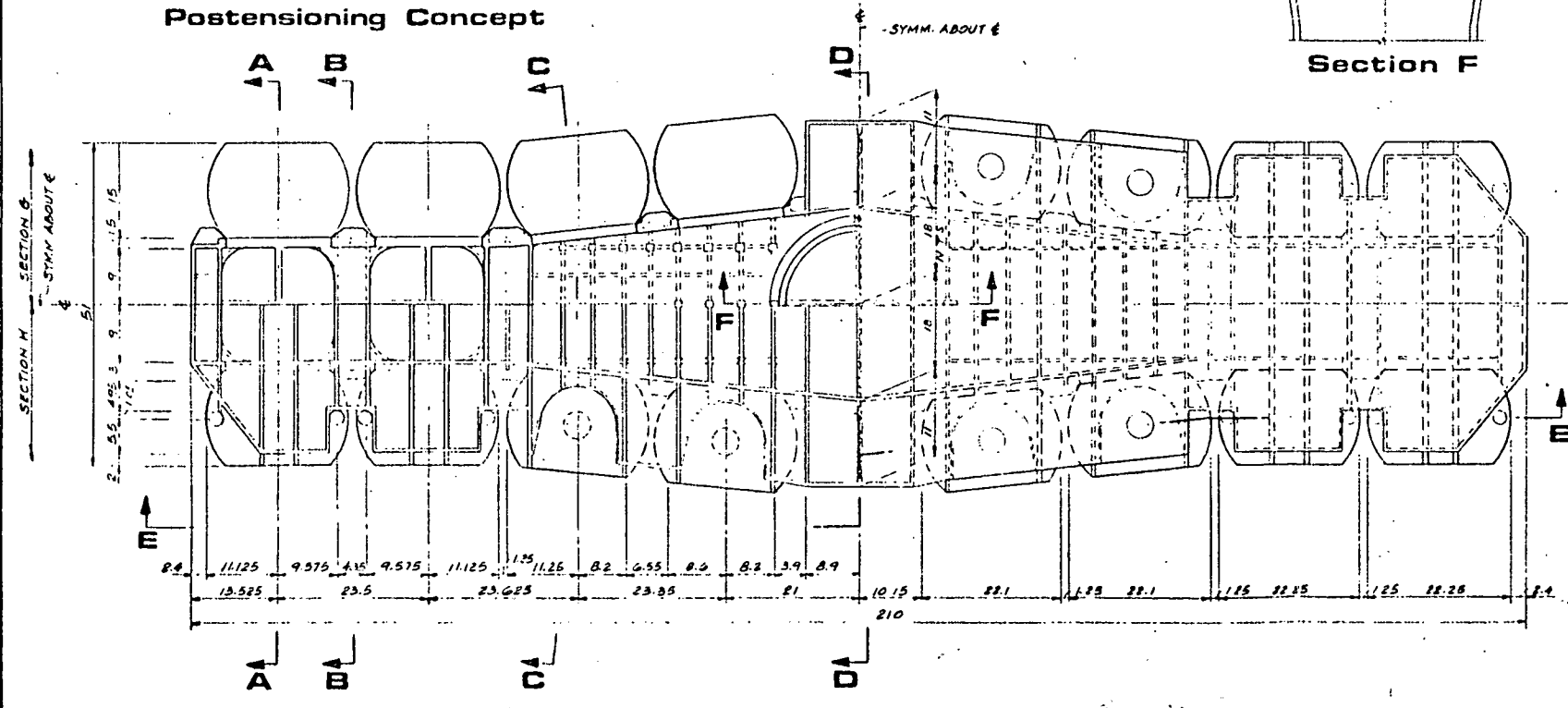
Section K (N.T.B.)



Section B



Section D



Plan Sections G & H

SCALE 1:500  
DIMENSIONS IN METERS

Fig. 3.5-1

NO	REVISION	DATE
----	----------	------



STRUCTURAL ENGINEERING  
315 Bay St., San Francisco, Ca 94133 Tel (415) 682-1050

Issued For	Date	By

SHEET TITLE: **CONCRETE STRUCTURAL ARRANGEMENT**  
400 MWe NET O.T.E.C. SHIP  
PROJECT: **O.T.E.C. PLATFORM CONFIGURATION & INTEGRATION**  
LOCKHEED MISSILES AND SPACE CO. SUNNYVALE, CA.

SHEET NO:  
**2-1**

## Loading Criteria

Maximum moment and shears due to dynamic forces are as follows.

Longitudinal direction:

$$\begin{aligned}M_{\text{sag}} &= 360,000 \text{ t} \\M_{\text{hog}} &= 340,000 \text{ t} \\Torsion &= 80,000 \text{ t} \\M_{\text{sag}} \text{ (Torsion)} &= 0.71 \times 360,000 = 256,000 \text{ t} \\Q_{\text{sag}} \text{ (Shear)} &= 6,857 \text{ T} \\Q_{\text{sag}} \text{ (Torsion)} &= (0.71 \times 6857) = 4,868 \text{ T}\end{aligned}$$

Positive buoyancy of the module: 2,500 T

Dynamic vertical forces of module:  $2 \times 2,500 = \pm 5,000 \text{ T}$

Concrete weight: See material properties

Equipment load: Second floor slab:  $1 \text{ T/m}^2$   
Top deck slab:  $2 \text{ T/m}^2$

Coldwater pipe: 3,000 T

Forces on bottom slab:

Bottom slab designed for pressure head of 10 m, which allows for loadings in the construction stages and dynamic forces.

## Safety Factors

The overall safety factor under working load condition varies from 1.5 to 2.2, according to the ACI Code.

### 3.5.2 Design Analysis

In order to obtain an analytical approach to a statical system when the ship is floating in the seaway, it has been assumed that the submerged wing-tanks provide the support. In extreme conditions, the maximum stresses occur at the quarter-points of the ship body where the cross-sectional area is minimal due to the openings required for tubesheets and pumps. The location of the ship buoyancy is well distributed along the body to avoid high stresses during operation.

The prestressing of the ship hull is designed to resist bending moment, shear and torsion produced by wave forces and statical loads. The prestressing is applied in all three directions, i.e., longitudinal, vertical and transverse. Tendons are embedded in the shell walls and diaphragm in the concrete hull, similar to the posttensioned construction in ordinary bridge structures. After the concrete is poured, the strands are threaded through the embedded ducts and stressed by a jack. Cement grout is then pumped into the semi-rigid ducts containing the multistrand tendons.

In longitudinal prestressing, full prestress is assumed for the section according to the loading specified. Therefore, an average prestressing of  $34 \text{ kg/cm}^2$  (484 psi) has to be maintained. In transverse sections, where tubesheet and pump-openings are encountered, the post-tensioning stresses will increase gradually to  $91 \text{ kg/cm}^2$  (1,300 psi). Therefore, thickening of certain structural members is necessary. Transverse prestressing is applied along the diaphragm walls to resist statical loads as well as buoyancy loads resulting from the power modules and wing chambers.

Vertical prestressing of the sidewalls is necessary to resist the torsion and bending shear resulting from the wave action. The combined shear stresses are maximum  $23 \text{ kg/cm}^2$  (328 psi). Vertical tendons are stressed at the top, with conventional dead anchor at the bottom of the wall. Localized stress disturbance from openings in the sidewall will require refined analysis. However, ringbeams such as those provided around the openings in the present design are deemed to be proper and adequate.

At the quarter-points where two side walls intersect at an angle, horizontal post-tensioning is required to take the transverse force component. Shear stresses around vertical openings all require more refined analysis by the finite elements method. Ring beams are designed to transfer stresses across the tubesheet openings. Second floor slab, spanning from one diaphragm to another, is designed for float-out pressure head as well as equipment loads.

Columns are added to the midship hull to decrease the span of diaphragm the

Cold water pipe foundation consists of a ringbeam which is partially connected to the sidewalls. In order to strengthen the cold water pipe foundation, columns are employed to connect the ringbeam to the top structure. Shear stresses due to torsion and bending moment dictate wall thickness of the hull. Additional buoyancy forces produced by the modules are transferred to the main structure through diaphragm walls.

The structural dimensions of the sidewalls are based on a slenderness analysis. Hollow bottom slab resists dynamic forces as well as temporary pressure head in the float-out position. Precast I-elements are used which span from wall to wall. This precast system simplifies construction procedure and allows better quality control. Walls and vertical beam are poured-in-place. Part of the deck slab also utilizes the precast construction technique. The sidewalls are prestressed to increase allowable shear stresses.

### 3.6 CONSTRUCTION

A search of available data was made for suitable construction facilities in the USA. The capabilities of the facilities that were surveyed constrain the design of depth and width of the ship hull in the float out condition. Efficient construction of the ship requires a building dock which is 62 m wide (203 ft), 230 meters long (755 ft), with 15 meters (49 ft) of float out depth. A candidate site for construction of the recommended graving dock is the port of Tacoma, Washington. The available depth for tow out from this site is 42 meters (138 ft) at Admiralty Head. Industrial support facilities and sheltered water of 55 meters (180 ft) depth is available for outfitting in this location in the southern end of Puget Sound.

A potential Gulf Coast facility is located on Blount Island in St. Johns River, Jacksonville, Florida. This facility partially completed in 1977, with capacity to construct platforms 115 m (377 ft) by 122 m (400 ft) with float draft of 11 m (36 ft) would require extension of the graving dock and dredging of a channel in waterway to 14 m (46 ft) depth.

Equipment commonly employed in heavy concrete construction projects is envisioned for the construction of the platforms. For the graving dock stage of construction, the usual handling equipment - gantry cranes, crawler cranes, even tower cranes - may be used depending on the preference of the contractor. The grounds should be large enough to accommodate various material stockpiles, operating room for the handling equipment, facilities for the precasting, prestressing, curing and storage of precast - prestressed structural elements, workmen's amenities and site offices. Depending on the site, the ground may require to be strengthened by piling or other means to support the construction. The basin itself may have to be sheet-piled to retain the earth around the edges of the excavation, and to reduce seepage water in the basin. Conveyor belts and concrete delivery equipment are expected to be used extensively to move concrete and concrete materials from place to place within the construction yard. Handling equipment is expected to be the heavy-duty type particularly if the precast elements are made in large pieces for economic reasons.

The following construction sequences are envisioned and are illustrated in Figure 3.6-1.

The float-out draft of 14 m (46 ft) in the graving basin, will be obtained by closing off the openings to the water plenum by plugs, converting the plenum into a temporary buoyancy chamber. The plugs will be designed for dismantling and removal after the vessel is constructed. The installation and the removal of the plugs are therefore part of the construction sequence which is described below.

STEP 1

1. Prepare site and mobilize for construction
2. Construct double slab keel on blocks with precast, prestressed "I" beams.
3. Construct ring beam around CWP pipe opening.

STEP 2

4. Construct longitudinal and transverse bulkheads (concrete walls) by slip-form method to underside of second deck. Use blockouts for openings, and dowel bar connection for protrusions from walls surface.
5. Cast walls and transverse girders to underside of upper second deck.

STEP 3

6. Place precast, prestressed inverted Tee elements
7. spanning between girders and cast second deck and
8. upper second deck.

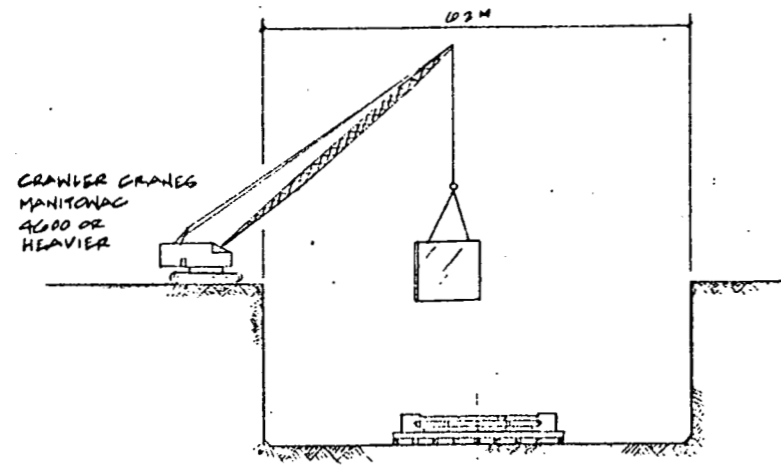
STEP 4

9. Continue constructing walls and transverse girders upward to main deck.

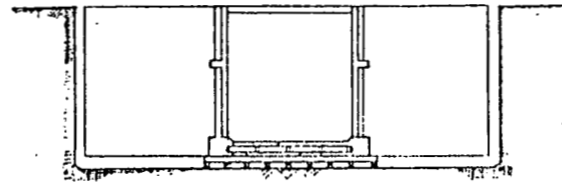
STEP 5

10. Form and concrete main deck structural system.
11. Stress tendons in all 3 directions according to stressing anchorages.

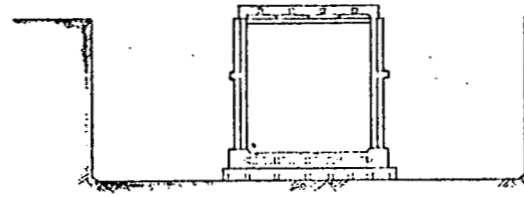
# OTEC HULL - PROPOSED CONSTRUCTION SEQUENCE OF SHIP PLATFORM USING GRAVING DOCK METHOD



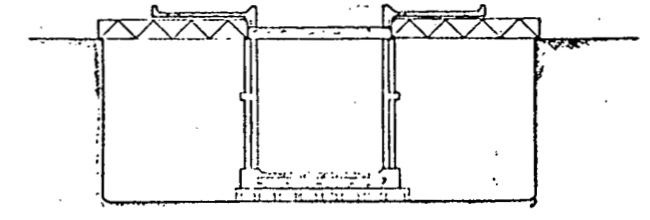
**STEP 1** PREPARE AND CONSTRUCT GRAVING DOCK. ERECT HOLLOW BOTTOM SLAB ON BLOCKS - USING PRECAST PRESTRESSED I TRANSVERSE SECTIONS



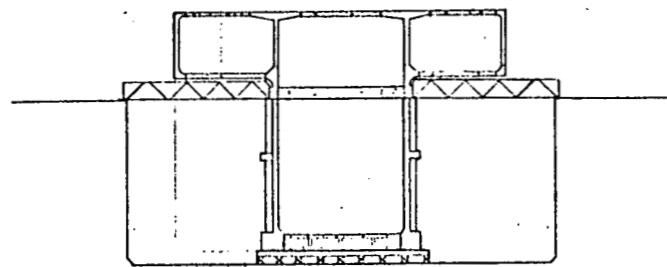
**2** CONSTRUCT SIDE WALLS, DIAPHRAGM WALLS AND BULKHEADS (INCLUDING RING BEAM AROUND CENTER WELL) TO GORFIT OF SECOND DECK. INSTALL PLUGS FOR ALL OPENINGS IN FLOW CHAMBER. (PLENUM)



**3** CAST SECOND DECK USING INVERTED T-BEAMS SPANNING BETWEEN TRANSVERSE GIRDERS AS FORMWORK. PROVIDE CONNECTION TO VERTICAL WATERTIGHT MANHOLE TO MAIN DECK IN PARTITIONS DIRECT OVER OPENING IN THE BOTTOM SLAB

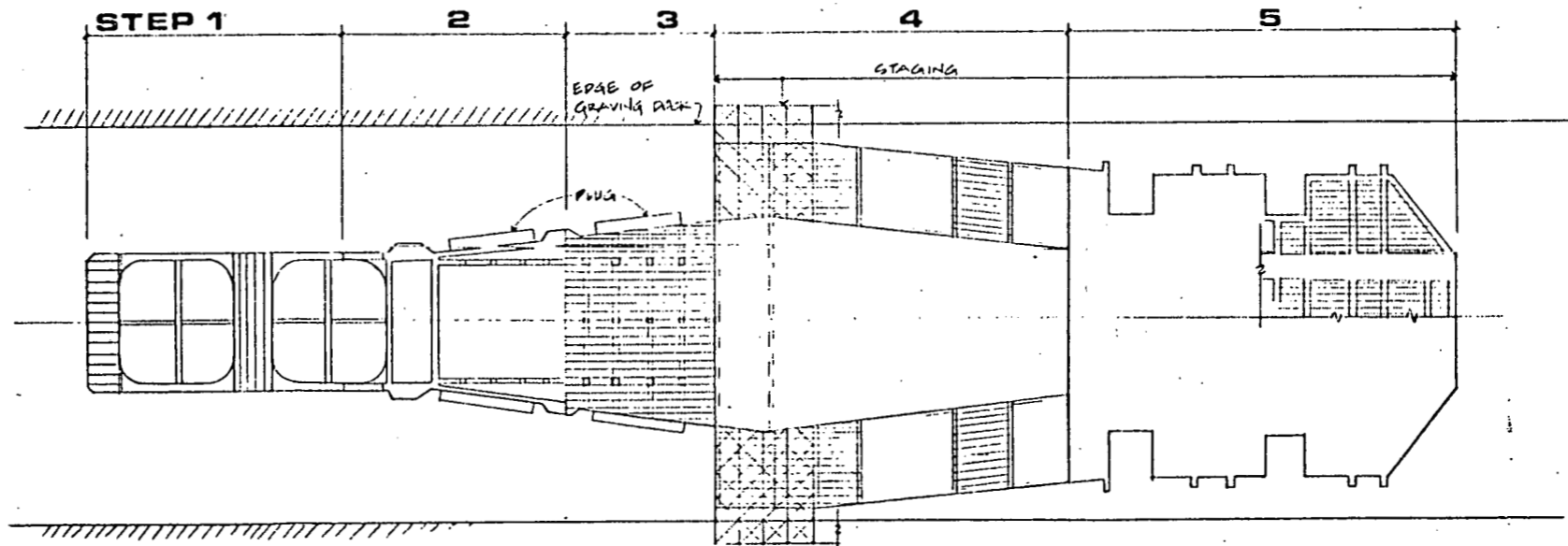


**4** CONTINUE CONCRETING SIDE AND DIAPHRAGM WALLS TO UNDERSIDE OF UPPER SECOND DECK USING GROUND SURFACE AS SUPPORT FOR STAGING AND FORMWORK.



**5** COMPLETE STRUCTURE TO MAIN DECK LEAVING DOCKS FOR EQUIPMENT INSTALLATION. STRESS VESSEL IN ALL THREE DIRECTIONS. GROUT TENDONS AND CAST PROTECTIVE COVER OVER ANCHORAGES.

**6**



PRECAST  
 POURED IN PLACE

PLANVIEW OF VESSEL IN GRAVING DOCK

Fig. 3.6-1

NO.    REVISION    DATE

After float-out, flood plenum and remove temporary plugs.

The schedule for construction of the concrete hull spans 14 months, Figure 3.6-2.

The material quantities and costs for construction of a first-unit ship hull are presented in Table 3.6-1.

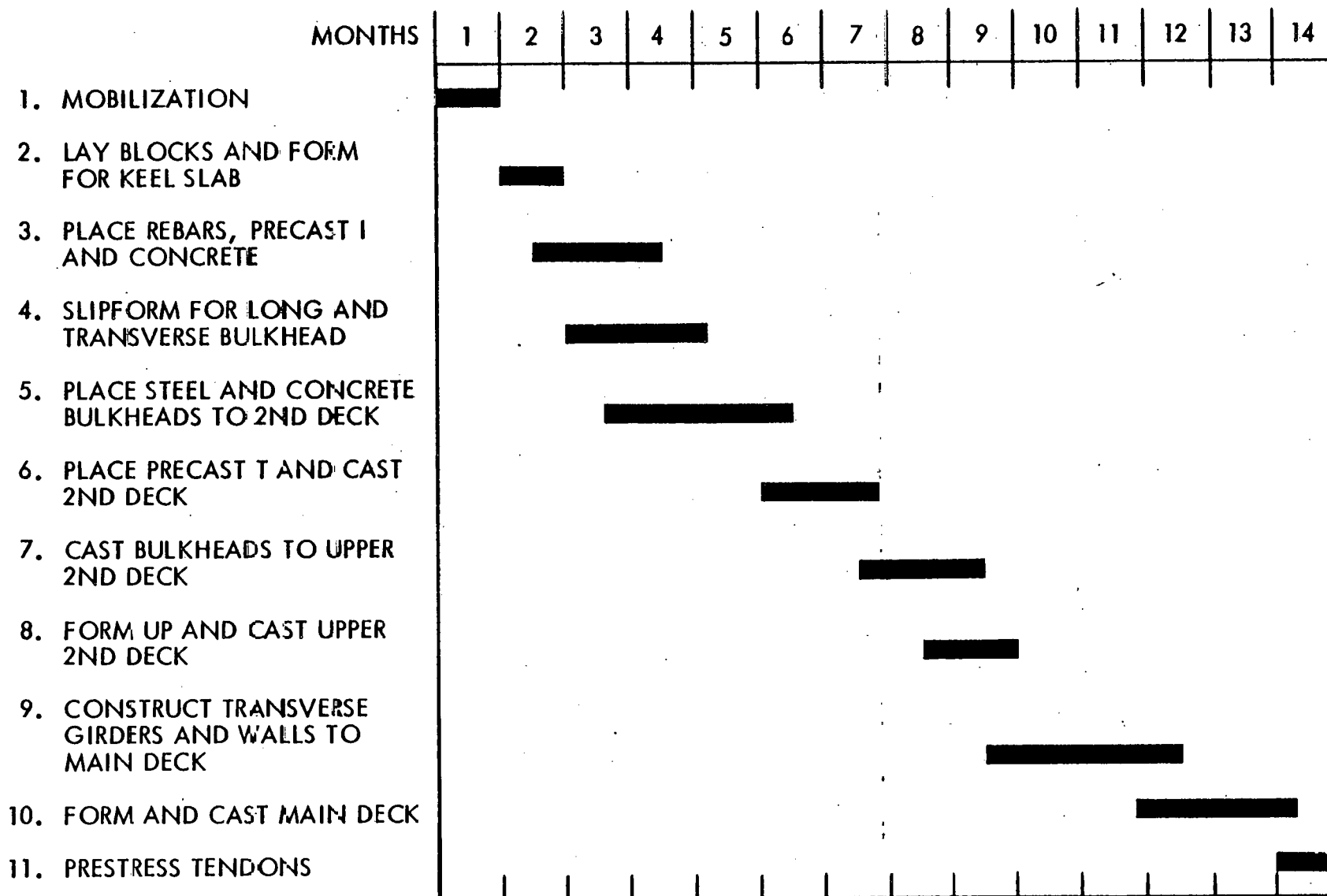


Fig. 3.6-2 Construction Schedule for Structural Concrete - Ship Hull

Table 3.6-1  
HULL CONSTRUCTION COSTS FOR SHIP - FIRST UNIT COSTS

Item	Price/cu yd	Price/m <sup>3</sup>	m <sup>3</sup>	\$1,000
Shell PIP	1,090	1,425	14,948	21,301
Shell PC	750	981	14,143	13,874
Walls	750	981	6,141	6,042
Deck	750	981	5,510	5,405
Columns Stability C	1,090	1,425	1,589	2,264
<b>TOTAL</b>	<b>(883 Ave.)</b>	<b>(1,155 Ave.)</b>	<b>42,331</b>	<b>48,886</b>

### 3.7 DEPLOYMENT

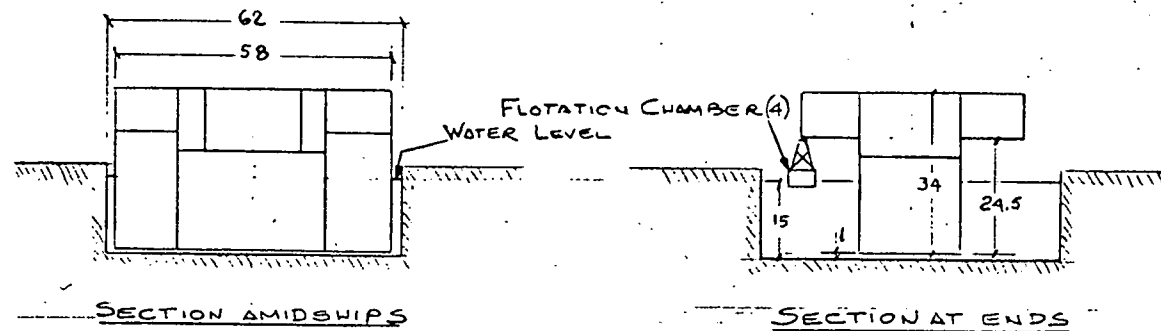
When the ship construction is complete, with major pieces of equipment installed in the second deck electrical and machinery spaces, it weighs approximately 78,000 metric tons (76,771 LT) and has a center of gravity 19 meters (62 ft) above its baseline. It floats at a draft of 14 meters (46 ft) with 15 meters (49 ft) of water in the drydock, Fig. 3.7-1. The ship has a metacenter 14 meters (46 ft) above its baseline at a 14 meter draft. The ship is unstable transversely at this draft since the center of gravity is above the transverse metacenter. Therefore, it is necessary to provide buoyancy and waterplane moment of inertia to the ship to raise the metacenter above the center of gravity. When the ship reaches a draft of 24.5 meters (50 ft) it will have acquired sufficient waterplane moment of inertia from the wing wall structure to raise the metacenter above the center of gravity. While the ship is at the light draft and until it has enough displacement to pick up the wing wall waterplane (24.5 meter draft), four barges (flotation chambers) of sufficient size will be installed at the corners of the ship under the wing wall structure to provide the required buoyancy. Calculations show that barges of the required size (20 m  $\times$  16 m  $\times$  sufficient depth for reserve buoyancy) will fit into this space.

It will be necessary to construct these barges inside the drydock or have them in place when construction of the ship begins since clearance to the inboard part of the drydock may be restricted by the midship beam of 58 meters (190 ft). Alternatively, prior to completion of construction and before the maximum beam is achieved, the drydock could be flooded at low tide and the four barges floated into position.

At a 14 meter float-out draft, there is as much as 6 meters clearance between the deck of the barge and the underside of the ship wing wall. Therefore, a hydraulic support structure will be constructed on the deck of the barge to adjust this clearance while maintaining positive contact with the ship. Adequate barge freeboard during ballasting and deployment sequences in deep water is provided by this approach.

**PHASE I HULL AFLOAT IN DRYDOCK**

HULL IS BUILT IN A DRYDOCK OF 62 M. WIDTH. UPON COMPLETION, IT WEIGHS APPROX. 78000 METRIC TONS AND HAS A CENTER OF GRAVITY 19M ABOVE BASE LINE. IT FLOATS AT A DRAFT OF 14M AND IT HAS A TRANSVERSE METACENTER 14M ABOVE BASE LINE. WHILE IN DRYDOCK, SOME OF THE EQUIPMENT IS INSTALLED IN THE SECOND DECK MACHINERY & ELECTRICAL SPACES

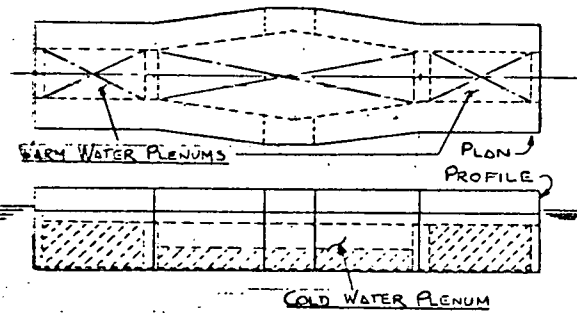


**PHASE II FLOAT-OUT**

TO FURNISH THE NECESSARY WATERPLANE AREA TO RENDER THE HULL STABLE UPON FLOODING OF DRY-DOCK, FOUR EXTERNAL FLOTATION CHAMBERS ARE ATTACHED UNDER THE HULL WINGS AND THE HULL IS THUS TOWED OUT OF THE DRY DOCK TO A SHELTERED AREA WITH APPROX. 30 M WATER DEPTH (100')

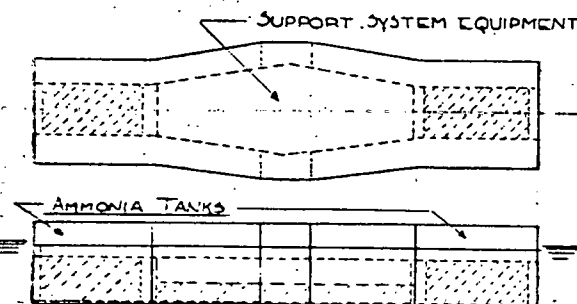
**PHASE III FLOODING PLENUMS**

WARM WATER PLENUMS ARE FILLED TO CAPACITY SIMULTANEOUSLY. COLD WATER PLENUM IS THEN FILLED TO APPROX. HALF ITS CAPACITY TO BRING DRAFT TO 24.5 M, AT WHICH DRAFT, THE UPPER HULL WITH LARGER WATERPLANE PROVIDES ADEQUATE STABILITY. FLOTATION CHAMBERS ARE THEN REMOVED.



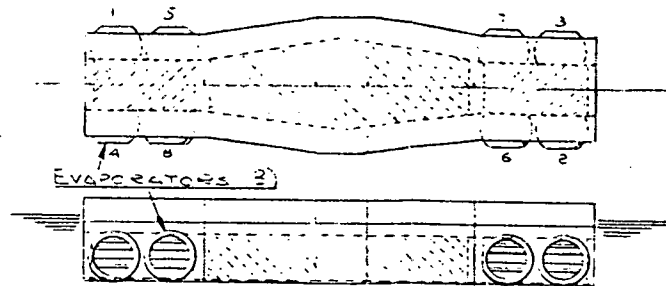
**PHASE IV EQUIPMENT & TANK INSTALLATION**

AMMONIA STORAGE TANKS AND ALL REMAINING SUPPORT SYSTEM EQUIPMENT ARE INSTALLED AT THE OUTFITTING DOCK.



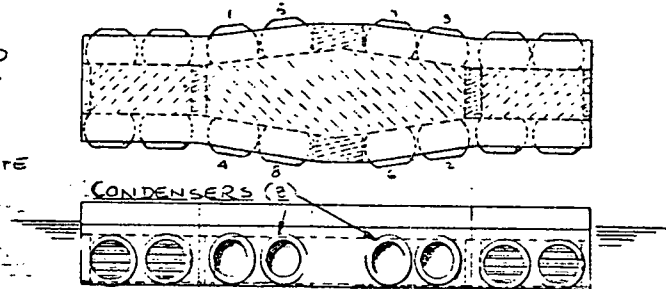
**PHASE V EVAPORATOR INSTALLATION**

EVAPORATORS ARE NOW INSTALLED IN SEQUENCE AS INDICATED. THE EVAPORATORS ARE BUOYANT, AND THEIR COMBINED BUOYANCY IS APPROXIMATELY THE SAME AS THE WEIGHT OF WATER IN THE WARM WATER PLENUMS. THIS IS COMPENSATED BY FURTHER FLOODING THE COLD WATER PLENUM CONCURRENT WITH INSTALLATION OF EVAPORATORS.



**PHASE VI CONDENSER INSTALLATION**

CONDENSERS ARE INSTALLED ON THE CANTED WALLS OF THE COLD WATER PLENUM IN A SEQUENCE SIMILAR TO THAT OF THE EVAPORATORS. BALLAST TANKS ARE FLOODED TO COMPENSATE FOR INCREASED BUOYANCY



**PHASE VII TOWING TO SITE**

THE SHIP IS NOW TOWED TO THE OPERATING SITE AND ANCHORED THERE.

**PHASE VIII INLET & DISCHARGE PIPE INSTALLATION**

ELEMENTS PROJECTING BELOW BOTTOM OF HULL ARE INSTALLED ON SITE

- 1) COLD WATER INLET PIPE (CWI) PIPE IS TOWED TO SITE AFLOAT OR ON A SERVICE VESSEL. ON SITE, THE PIPE IS SEQUENTIALLY FILLED AND UNPEDED. TUGS & BARGES ATTACH LINES TO THE SOLID FLANGE AT THE UPPER END OF THE PIPE AND TOW IT UNDER THE HULL. C.W. IS THEN HOISTED UP INTO C.W. INLET HOLE IN BOTTOM OF SHIP BY MEANS OF CABLES THRU ACCESS TRUNKS TO WINCHES ON MAINDECK. PIPE FLANGE IS THEN MATED AND SECURED TO MATCHING FLANGE ON BOTTOM OF HULL
- 2) COLD WATER DISCHARGE PIPES (2) ARE DEPLOYED AND INSTALLED IN SAME MANNER AS C.W. INTAKE PIPE
- 3) C.W. DISCHARGE PUMPS, PIPING & MANIFOLD. ASSEMBLED AS A UNIT, LAUNCHED FROM SERVICE VESSEL. GUIDED TO POSITION WITH WIRE FROM TUGS AND WINCHES ON THE SHIP. BALLASTED DOWN TO POSITION WHERE FLANGES ON PUMPS & PIPE ASSEMBLY ARE ATTACHED TO MATING FLANGES ON THE CONDENSER OUTLET AND COLD WATER DISCHARGE PIPE.
- 4) WARM WATER DISCHARGE PIPES AND PUMPS PUMPS & PIPES ARE ASSEMBLED AS A UNIT, TOWED TO SITE, LAUNCHED & INSTALLED IN A MANNER SIMILAR TO THAT USED FOR C.W. DISCHARGE PUMPS & PIPES.

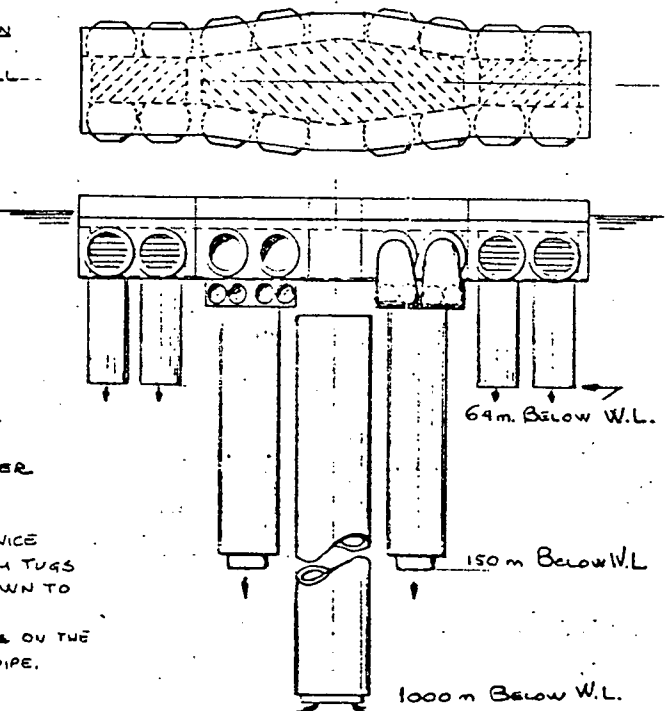


Fig. 3.7-1

DESIGN	3/10/78	DATE
DRAWN	3/14/78	DATE
CHECKED	3/16/78	DATE
GRP SUP	3/16/78	DATE
APPD	3/16/78	DATE
APPD FOR		DATE

PLAN APPROVAL		
SUBMITTED TO	SUBMITTAL DATE	APPROVAL DATE

**MORRIS GURALNICK ASSOC. INC.**  
 NAVAL ARCHITECTS & ENGINEERS  
 SAN FRANCISCO, CALIFORNIA

LOCKHEED MISSILES & SPACE CO. SUNNYVALE, CA.  
 OTEC PLATFORM.  
 CONCRETE SHIP, 400 MW<sub>e</sub> (NET)  
 DEPLOYMENT SEQUENCE.

MGA JOB NO	DRAWING NUMBER	REV.
501	501-1010-5	A
SCALE NONE	SHEET 1 OF 1	

With the four barges in position and ship construction complete, the drydock is flooded to 15 meters, the ship is floated, and towed to sheltered waters of 30.5 meters (100 ft) depth. The ship will be moored in these waters for attachment of external heat exchangers and additional outfitting.

To begin this process, the warm and cold water plenums of the ship are flooded. The warm water plenums are filled to full capacity while the cold water plenum amidships is filled to approximately half capacity. This addition of ballast water ultimately brings the ship to the bottom of the wing wall structure (24.5 meter draft) so that the ship now has positive stability. As the ship approaches this draft, the four barges will be ballasted down and pulled free of the underside of the wing wall. The ballasting of the ship is done in a sequence which minimizes bending stresses in the hull girder.

With the ship at a draft of 24.5 meters, the ammonia tanks are installed. All remaining support system equipment is added, and the turbogenerator sets and associated ammonia piping are completed on the Main Deck. The addition of these tanks and equipment will increase the displacement by approximately 20,000 tonnes.

With the warm water plenums at the ends of the ship already full of water and the barges removed, the plates covering the evaporator inlets are detached and removed. Evaporators are positioned and secured with the following procedure:

1. Attach hoist line to the top and docking lines to the side of HE. Attach temporary ballast tanks.
2. Ballast HE to slight negative buoyancy placing it under the control of the hoist line. Move HE sideways toward vessel with the top end of diffuser above water.
3. When in position, deballast to slight positive buoyancy for HE to rise and bear against outriggers which are cantilever extensions of transverse girders across the vessel (Fig. 3.2.2-4).
4. Pull HE hard against vessel with docking lines, then activate hydraulically-operated locking mechanism to secure
5. Deballast and detach ballast tanks from HE.

The cold water plenum is ballasted as necessary to prevent the net buoyant force of the evaporators from lifting the ship above the critical 24.5 meter draft.

Condensers are attached in the same way as the evaporators. The water level in the cold water plenum is brought above the condenser inlet. Inlet plates are removed. The condensers are ballasted down, maneuvered into place, and attached to the hull. As temporary ballast is removed from the condensers, further temporary ballast is added to the ship to ensure that its draft does not drop below 24.5 meters. With condensers, evaporators and all other equipment in place, the ship is towed to the operating site and anchored.

With the ship anchored on station at the operating site, the large intake and discharge appendages are installed. First, the flexible rubber-nylon cold water intake pipe is transported in a collapsed condition to the site on a service vessel. It is launched over the side of the service vessel in close proximity to the OTEC ship and allowed to sequentially fill with water and lower to an upright position. (Alternatively, the pipe could be made neutrally buoyant and towed to site afloat with a series of tugs and flotation barges). The top of the cold water pipe (CWP) has a solid fitting with a metal flange for attachment to the cold water plenum intake flange. Tugs or crane barges attach lines to this solid flange and tow the top of the filled CWP over to the OTEC ship. Lines from the deck winches above the cold water plenum intake are run down through trunks and out the cold water inlet opening and attached to the CWP flange. Crane barges and tugs on either side of the OTEC ship pull the CWP under the hull and into position for the shipboard winches to hoist the CWP up into the cold water plenum intake. With the CWP in position, divers attach the CWP flange to the mating flange on the bottom of the hull. Deployment of the concrete CWP on the ship is accomplished using hydraulic jacking up equipment as described in Section 2.3.3.1, Volume 1. Soft CWP deployment in conjunction with mooring system deployment for the spar is presented in Section 4.7.

The flexible rubber-nylon cold water discharge pipes are installed in the same manner as the cold water intake pipe.

The cold water discharge pumps and connecting pipe to the condensers are one unit. Each of these 1,281 ton units is brought to the OTEC ship on a service vessel, launched, ballasted to neutral buoyancy and towed into position at a submerged condenser by tugs and crane barges. Final positioning of these units is performed by lines from shipboard winches. Divers attach the connecting pipe flange to the condenser discharge flange and the discharge pump flange to the flange at the cold water discharge pipe manifold. This completes installation of the cold water system.

Completion of the warm water system requires installation of the warm water discharge pump and pipe unit. This unit is neutrally buoyant. The four pump/pipe units are brought to the OTEC ship on a service vessel, launched, maneuvered into position, and attached to the warm water plenum discharge flange at the bottom of the hull. With the attachment of these last discharge appendages, the OTEC ship stands ready to begin operation.

### 3.8 SUPPORT FACILITIES

Shore facilities, Fig. 3.8-1, will be provided for crews, supplies and equipment required for operation and maintenance of the OTEC ship. These facilities include:

- (1) An outfitting dock to be used for mooring supply vessels, service vessels, floating cranes and barges. Outfitting floating OTEC equipment such as heat exchangers, pumps and piping, etc., would also be carried out at dock side.

A gantry crane running the length of the dock is provided for transporting large supply and repair items between shore side buildings and the service and supply ships.

- (2) A dry dock capable of accommodating several heat exchangers, pumps and discharge pipes for their periodic maintenance and repair work.

Whirly cranes are provided for transport of items from various supply and repair shops to the dock.

- (3) A helicopter landing site is located in the area of the repair and supply shops. Helicopter service is provided for transportation of small OTEC ship and power system parts and for crew transfer service from shore facility to the ship.
- (4) Repair shops and warehouses are located adjacent to outfitting docks and dry docks for the most direct transportation of parts to work sites and service ships.
- (5) Dormitories for OTEC ship crews and shore facility crews are located close to the shops and dock for convenient access to work areas.

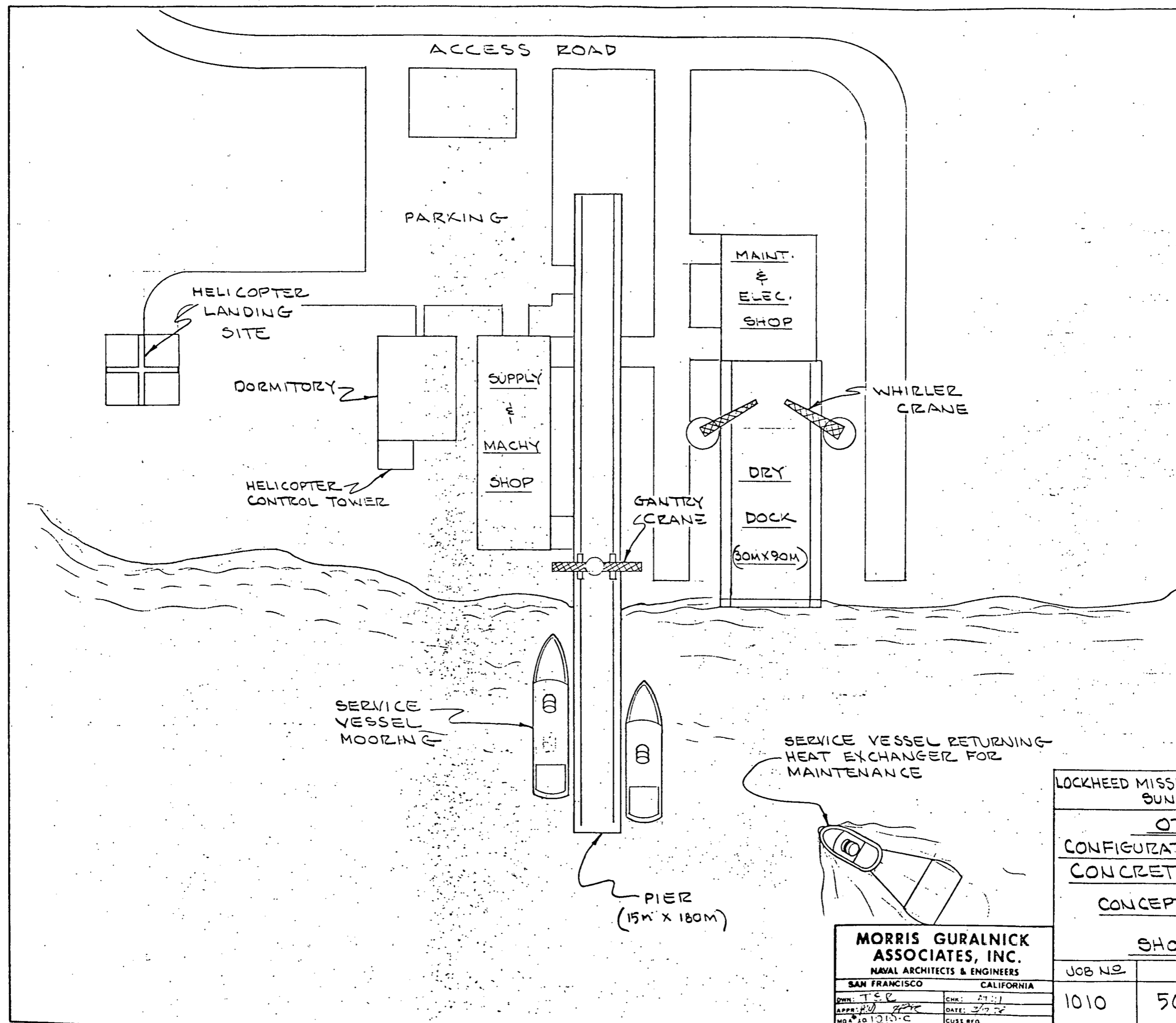


Fig. 3.8-1

LOCKHEED MISSILES AND SPACE CO., INC SUNNYVALE, CALIF.		
<u>OTEC PLATFORM</u> <u>CONFIGURATION &amp; INTEGRATION</u> <u>CONCRETE SHIP-400MWE (NET)</u> <u>CONCEPTUAL DESIGN</u> <u>OF</u> <u>SHORE FACILITIES</u>		
JOB NO.	DWG NO.	REV.
1010	501-1010-6	-

**MORRIS GURALNICK ASSOCIATES, INC.**  
 NAVAL ARCHITECTS & ENGINEERS  
 SAN FRANCISCO CALIFORNIA

DWN: T.S.P.	CHK: A.T.J.
APPR: P.W.	DATE: 3/7/78
MO: 1010-C	CUSE REQ.

### 3.9 MAINTENANCE APPROACH

The ship is configured to provide adequate access and clearance to maintain most smaller equipment items on board. Major maintenance and repairs to the large heat exchangers and seawater pumps would require transporting these items to a shore-based repair facility.

The following describes in more detail the maintenance approach considered for the various items in the OTEC system (Fig. 3.9-1).

#### HEAT EXCHANGERS

With the heat exchangers in place, some minor maintenance, tube plugging, and shell repairs could be accomplished on site with the use of divers or a submarine service vessel. The ammonia side could be isolated and purged and provided with interior access for work on site.

In the event that major work is required, such as retubing, the heat exchanger modules would be detached from the ship, floated out, and towed to a central maintenance facility. These facilities could be shore based or based on a central maintenance support vessel in an energy park. While the heat exchanger is being removed for servicing, the associated sea water openings would be temporarily plugged to provide continuous operation of the remainder of the OTEC plant. A replacement heat exchanger could be provided for long repair periods during peak demand period to maintain maximum plant output. The buoyancy module required to increase the heat exchanger's draft to that required for attachment to the ship is not shown in Fig. 3.9-1. This module would be attached to the heat exchanger underside.

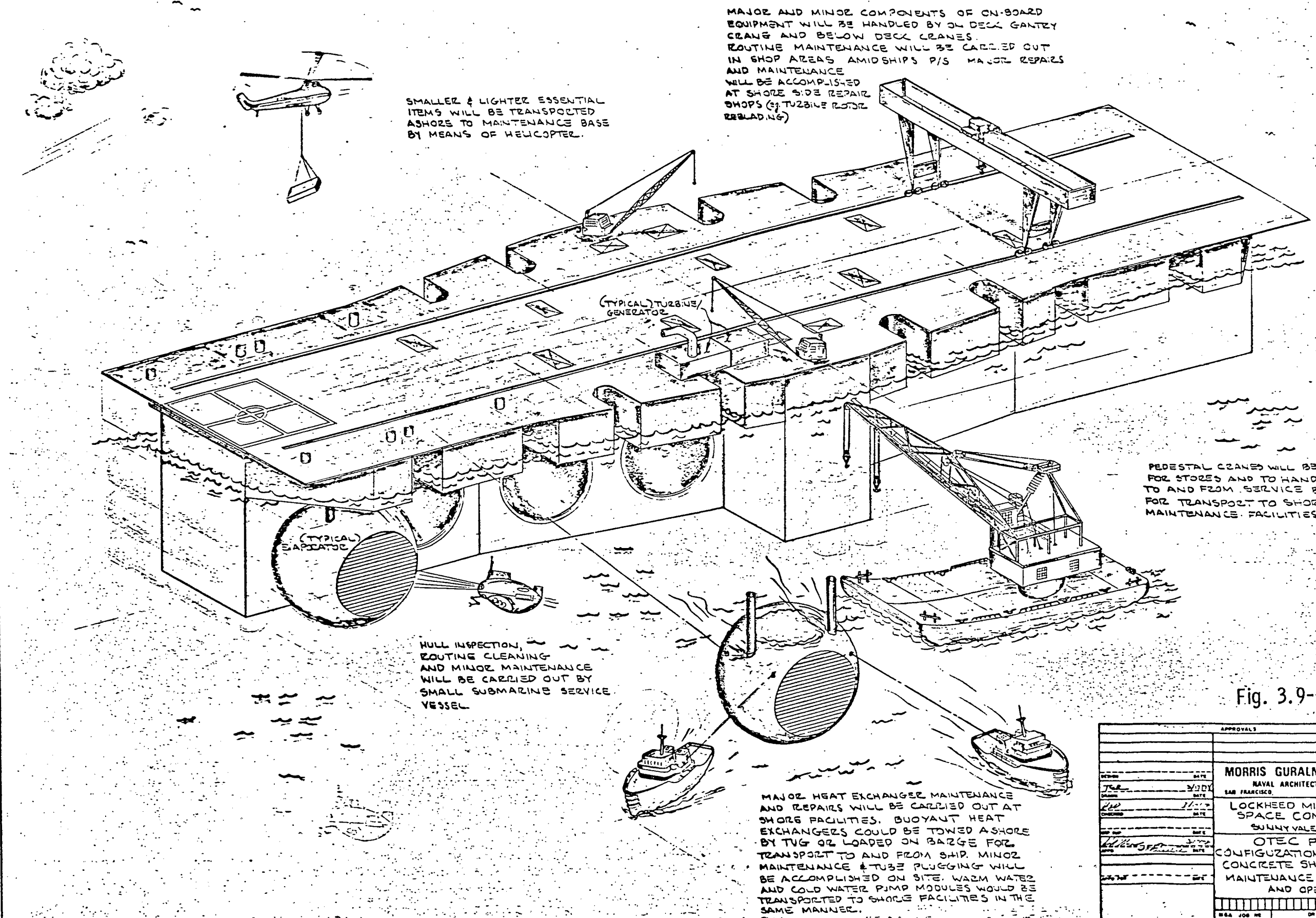
#### AUXILIARY MACHINERY AND ELECTRICAL EQUIPMENT

All onboard equipment in the auxiliary machinery spaces, electrical distribution spaces, and electrical transmission room will be provided with sufficient area around each item to accomplish in-place maintenance. Shop facilities amidships, port and starboard, will provide the necessary back-up equipment to conduct onboard maintenance and

repair. If necessary for more extensive repair, any item of equipment can be removed to the Main Deck by means of hatches and overhead cranes. From there it can be taken ashore by either helicopter or service vessel.

## HULL

The central hull is constructed of low-maintenance concrete. For routine inspection, cleaning and minor maintenance, a submarine service vehicle will be provided. More extensive repairs can be accomplished on-site by cofferdamming the area to be repaired. This work would be accomplished by repair crews and service vessels from the shore facility.



MAJOR AND MINOR COMPONENTS OF ON-BOARD EQUIPMENT WILL BE HANDLED BY ON DECK GANTRY CRANE AND BELOW DECK CRANES. ROUTINE MAINTENANCE WILL BE CARRIED OUT IN SHOP AREAS AMIDSHIPS P/S MAJOR REPAIRS AND MAINTENANCE WILL BE ACCOMPLISHED AT SHORE SIDE REPAIR SHOPS (e.g. TURBINE ROTOR REBLADING)

SMALLER & LIGHTER ESSENTIAL ITEMS WILL BE TRANSPORTED ASHORE TO MAINTENANCE BASE BY MEANS OF HELICOPTER.

PEDESTAL CRANES WILL BE USED FOR STORES AND TO HANDLE ITEMS TO AND FROM SERVICE BARGES FOR TRANSPORT TO SHORE SIDE MAINTENANCE FACILITIES.

HULL INSPECTION, ROUTINE CLEANING AND MINOR MAINTENANCE WILL BE CARRIED OUT BY SMALL SUBMARINE SERVICE VESSEL.

MAJOR HEAT EXCHANGER MAINTENANCE AND REPAIRS WILL BE CARRIED OUT AT SHORE FACILITIES. BUOYANT HEAT EXCHANGERS COULD BE TOWED ASHORE BY TUG OR LOADED ON BARGE FOR TRANSPORT TO AND FROM SHIP. MINOR MAINTENANCE & TUBE PLUGGING WILL BE ACCOMPLISHED ON SITE. WARM WATER AND COLD WATER PUMP MODULES WOULD BE TRANSPORTED TO SHORE FACILITIES IN THE SAME MANNER.

Fig. 3.9-1

APPROVALS		
DATE	DATE	DATE
7/20/71	3/20/71	1/20/71
DATE	DATE	DATE
3/20/71	3/20/71	3/20/71
<b>MORRIS GURALNICK ASSOC. INC.</b> NAVAL ARCHITECTS & ENGINEERS SAN FRANCISCO, CALIFORNIA		
<b>LOCKHEED MISSILES AND SPACE COMPANY INC.</b> SUNNY VALE, CALIF.		
OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SHIP-400MNE (NET) MAINTENANCE SEQUENCE AND OPERATIONS		
SEA JOB NO	DRAWING NUMBER	REV
501	501-1010-7	A
SCALE: NONE	SHEET 1	OF 1

### 3.10 CONTINGENCY CONFIGURATION

The following situations which would required Contingency Configuration Plans have been considered:

- (1) Loss of the cold water pipe
- (2) Loss of heat exchanger buoyancy
- (3) Collision with another vessel
- (4) A 100-year storm

The Configuration Plans described below and in Fig. 3.10-1 are proposed for dealing with these contingencies.

#### LOSS OF COLD WATER PIPE

If material failure in the flexible rubber-nylon cold water intake pipe causes the pipe to separate from the hull connection and sink, marking buoys attached at various points along the pipe's length would be automatically deployed to locate the pipe for future retrieval, if possible.

The power system would be shut down due to loss of cold water collecting capability. Diesel generators would automatically start up to carry essential loads. Decrease in the vessel's draft would be approximately 5 cm, and the effect on stability would be negligible.

If possible, the existing pipe would be recovered, repaired and re-attached after determining the cause of the failure and the measures required to correct the cause. If this were not possible, the plant would remain inoperative until a new pipe could be fabricated, towed to site, and installed in accordance with the Deployment Sequence.

#### LOSS OF HEAT EXCHANGER BUOYANCY

If failure of a tube sheet or shell causes an entire heat exchanger to flood, approximately 2500 metric tons of buoyancy would be lost. Connections of the heat exchanger

to the hull will be designed to carry the additional loads caused by flooding a heat exchanger. Calculations indicate that as many as five heat exchangers on one side could be damaged and flooded before the deck edge would be submerged. Positive stability would be maintained even under these conditions.

Loss of one evaporator at the bow or stern of the hull would cause the vessel to trim 1.4 meters and heel 1.4 deg. The loss of a condenser amidship would create 0.3 meters trim and 1.7 deg heel. The power system would have to be secured, either partially or completely, depending upon the location and extent of damage. The diesel generators would start automatically to provide power to essential electrical loads in the interim.

The hull opening in way of the damaged heat exchanger would be plugged by a service vessel similar to maintenance operations. The power system could then operate at nearly full capacity until a replacement heat exchanger is available. The damaged heat exchanger would be retrieved and repaired, if possible, or a new unit would be manufactured. Replacement of the heat exchanger would be accomplished in the same manner as in the Deployment Sequence.

#### COLLISION WITH ANOTHER VESSEL

Collision in way of a heat exchanger would result in much the same conditions as Contingency (2), Loss of Heat Exchanger Buoyancy. Maximum hull damage could occur if the ship is struck at the bow or stern, port or starboard, or amidships, port or starboard.

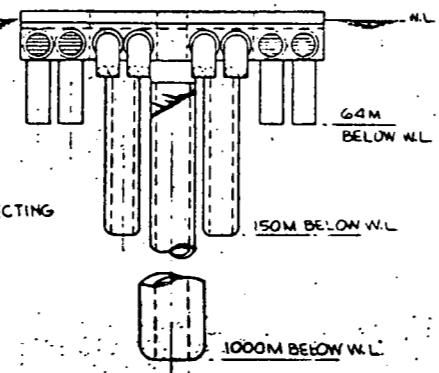
With a collision near midships, the shops and stores spaces and midship tank space would be flooded. Sufficient subdivision and structure will be provided so that damage would not be expected to extend inboard to the nitrogen and CO<sub>2</sub> tank space. Flooding caused by damage in this area would cause the vessel to heel 5.4 deg. There would be no significant loss of stability. Damage at the bow or stern would be limited to wing tanks and one heat exchanger. Maximum anticipated trim would be 2.1 meters, and maximum anticipated heel would be 0.6 deg.

201-1010-B

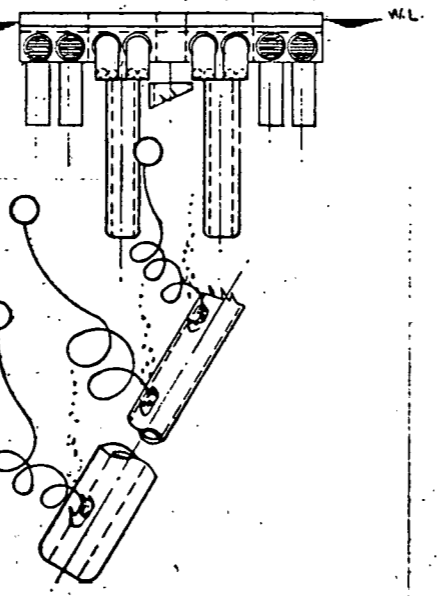
REVISIONS			
REV. NO.	DATE	DESCRIPTION	APPROV.
A		REVISED TO SUIT LMSC (R.POTASH) COMMENTS.	

**CONTINGENCY NO. 1**  
LOSS OF COLD WATER INTAKE PIPE

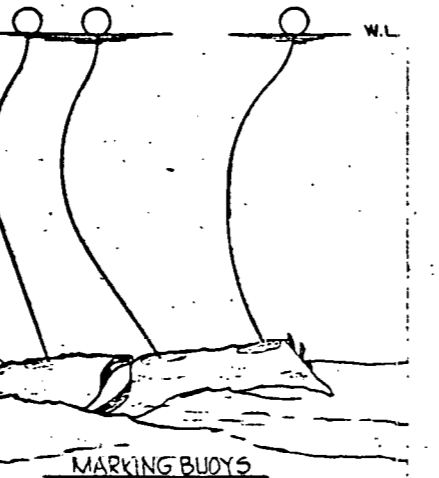
- MATERIAL FAILURE IN THE FLEXIBLE RUBBER-NYLON COLD WATER INTAKE PIPE CAUSES PIPE TO SEPARATE FROM HULL CONNECTION AND SINK. MARKING BUOYS ATTACHED AT VARIOUS POINTS ALONG THE PIPE'S LENGTH WOULD BE AUTOMATICALLY DEPLOYED TO LOCATE THE PIPE FOR FUTURE RETRIEVAL, IF POSSIBLE.
- THE POWER SYSTEM WOULD HAVE TO BE SHUT DOWN DUE TO LOSS OF COLD WATER COLLECTING CAPABILITY. DIESEL GENERATORS WOULD AUTOMATICALLY START UP TO CARRY ESSENTIAL LOADS.
- DECREASE IN VESSEL'S DRAFT WOULD BE APPROXIMATELY 5 CM. EFFECT ON STABILITY WOULD BE NEGLIGIBLE.
- IF POSSIBLE, THE EXISTING PIPE WOULD BE RETRIEVED, REPAIRED AND REATTACHED AFTER DETERMINING THE CAUSE OF THE FAILURE AND CORRECTING SAME. IF THIS WERE NOT POSSIBLE THE PLANT WOULD REMAIN INOPERATIVE UNTIL A NEW PIPE COULD BE FABRICATED, TOWED TO THE SITE, AND INSTALLED IN ACCORDANCE WITH THE DEPLOYMENT SEQUENCE DRAWING.



C.W. INTAKE FAILURE



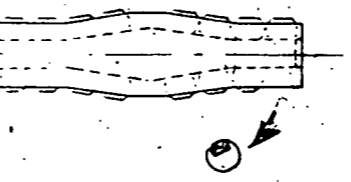
C.W. PIPE SEPARATION-BUOYS DEPLOYED



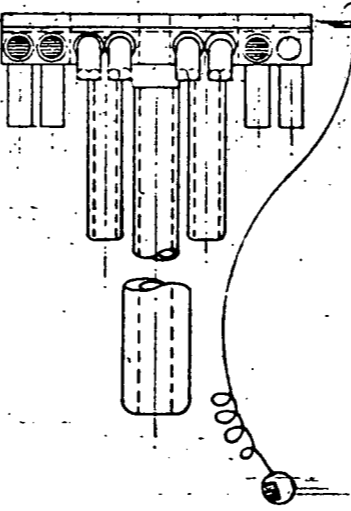
MARKING BUOYS

**CONTINGENCY NO. 2**  
LOSS OF HEAT EXCHANGER

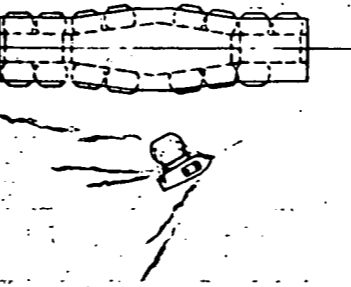
- FAILURE OF TUBE SHEET OR SHELL CAUSES ENTIRE HEAT EXCHANGER TO FLOOD, LOSING APPROXIMATELY 2500 MT OF BUOYANCY. ADDITIONAL FAILURE OF CONNECTIONS TO HULL WOULD CAUSE HEAT EXCHANGER TO SINK TO OCEAN FLOOR, AUTOMATICALLY DEPLOYING MARKER BUOY.
- LOSS OF EVAPORATORS AT THE ENDS OF THE HULL WOULD CAUSE VESSEL TO TRIM 1.4 METERS AND HEEL 1.4°. THE LOSS OF A CONDENSER AMIDSHIPS WOULD CREATE 0.3 METER TRIM AND 1.7° HEEL.
- THE POWER SYSTEM WOULD HAVE TO BE SECURED, EITHER PARTIALLY OR COMPLETELY, DEPENDING UPON THE LOCATION AND EXTENT OF DAMAGE. THE DIESEL GENERATORS WOULD START AUTOMATICALLY TO PROVIDE POWER TO ESSENTIAL LOADS IN THE INTERIM.
- THE HULL OPENING IN WAY OF THE LOST HEAT EXCHANGER WOULD HAVE TO BE PLUGGED BY A SERVICE VESSEL SIMILAR TO MAINTENANCE OPERATIONS. THE POWER SYSTEM COULD THEN OPERATE AT NEARLY FULL CAPACITY UNTIL A REPLACEMENT HEAT EXCHANGER IS AVAILABLE.
- DAMAGED HEAT EXCHANGER WOULD BE RETRIEVED AND REPAIRED IF POSSIBLE, OR A NEW UNIT WOULD BE MANUFACTURED. REPLACEMENT OF THE HEAT EXCHANGER WOULD BE ACCOMPLISHED IN THE SAME MANNER AS THE DEPLOYMENT SEQUENCE.



EVAPORATOR SEPARATION



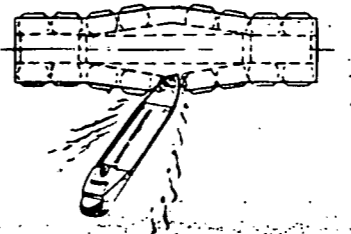
EVAPORATOR BUOY DEPLOYED



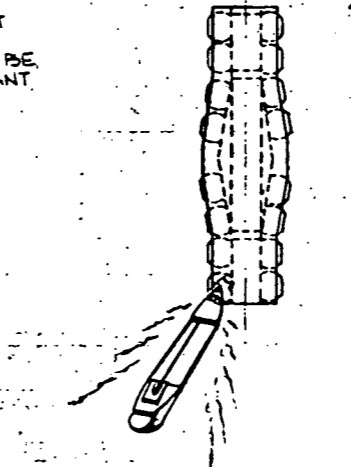
EVAPORATOR REPLACEMENT

**CONTINGENCY NO. 3**  
COLLISION WITH ANOTHER VESSEL

- COLLISION IN WAY OF A HEAT EXCHANGER WOULD RESULT IN MUCH THE SAME CONDITION AS CONTINGENCY NO. 2. MAXIMUM HULL DAMAGE COULD OCCUR IF THE VESSEL IS STRUCK AT THE BOW OR STERN P/S OR AMIDSHIPS P/S.
- WITH A COLLISION NEAR MIDSHIPS THE SHOPS AND STORES SPACES AND MIDSHIP TANK SPACE WOULD BE FLOODED. SUFFICIENT SUB-DIVISION AND STRUCTURE WOULD BE PROVIDED SO THAT DAMAGE WOULD NOT BE EXPECTED TO EXTEND IN-BOARD TO THE NITROGEN AND CO<sub>2</sub> TANK SPACE. FLOODING CAUSED BY DAMAGE IN THIS AREA WOULD CAUSE THE VESSEL TO HEEL 5°. THERE WOULD BE NO SIGNIFICANT LOSS OF STABILITY.
- DAMAGE AT THE BOW OR STERN WOULD BE LIMITED TO THE WING TANKS AND ONE HEAT EXCHANGER. MAXIMUM ANTICIPATED HEEL WOULD BE 0.6° AND MAXIMUM TRIM WOULD BE 2.1 METERS. THERE WOULD BE NO SIGNIFICANT LOSS OF STABILITY.
- DEPENDING ON THE LOCATION AND EXTENT OF THE DAMAGE THE POWER SYSTEM WOULD HAVE TO BE PARTIALLY OR TOTALLY SECURED UNTIL TEMPORARY REPAIRS COULD BE MADE. PERMANENT REPAIR ON SITE WOULD REQUIRE COFFERDAMMING THE DAMAGED AREA. PERSONNEL AND MATERIALS WOULD BE PROVIDED FROM THE SHORE FACILITY.



MIDSHIPS COLLISION



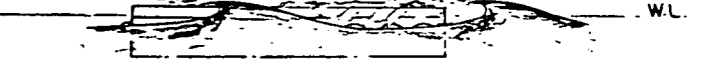
BOW/STERN COLLISION



ON-SITE REPAIR

**CONTINGENCY NO. 4**  
100 YEAR STORM

- THE HULL ANCHORING SYSTEM AND ATTACHMENT CONNECTIONS WILL BE DESIGNED TO WITHSTAND THE 50 FT WAVES AND 100 KT WINDS CREATED IN THE 100 YEAR STORM. REDUNDANCY WILL BE PROVIDED SO THAT THE VESSEL WILL BE ABLE TO MAINTAIN STATION.
- UPON NOTICE OF AN APPROACHING STORM, CREWS FROM THE SHORE FACILITY WOULD BE FLOWN TO THE VESSEL TO SHUT DOWN THE POWER SYSTEM AND SECURE ALL WATER TIGHT OPENINGS AND PORTABLE EQUIPMENT.
- DIESEL GENERATORS WOULD BE STARTED AND CONTROLLED REMOTELY FROM SHORE TO PROVIDE ELECTRICAL POWER FOR POSITIONING AND ESSENTIAL LOADS.
- ALL PERSONNEL WOULD BE EVACUATED DURING THE DURATION OF THE STORM.



WAVE PROFILE

Fig. 3.10-1

NO.	DESCRIPTION	DATE
1	DEPLOYMENT SEQUENCE	501-1010-5

APPROVALS		
DESIGNED BY	DATE	
CHECKED BY	DATE	
APPROVED BY	DATE	
SCALE NO.	SHEET	OF

**MORRIS GURALNICK ASSOC. INC.**  
NAVAL ARCHITECTS & ENGINEERS  
SAN FRANCISCO, CALIFORNIA

**LOCKHEED MISSILES AND SPACE COMPANY INC.**  
SUNNYVALE, CALIF.

**OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SHIP - 400MW<sub>e</sub> (NET) CONTINGENCY CONFIGURATIONS**

MSA JOB NO.	501-1010-8	REV	A
DRAWING NUMBER	501-1010-8		

CALCULATED WEIGHTS	ITEM	UNIT	TOTAL WEIGHT	
			NET	GROSS
WEIGHT				
GROUP				
POUNDS				

Depending on the location and extent of the damage, the power system would have to be partially or totally secured until temporary repairs could be made. Permanent hull repairs on-site would require cofferdamming the damaged area. Personnel and repair materials would be provided from the shore facilities.

#### 100 YEAR STORM

The hull, anchoring system and attachment connections will be designed to withstand the 58 ft. waves and 100 kt. winds created in the 100-year storm. Ample redundancy will be provided so that the ship will be able to maintain station.

Diesel generators would be started and controlled remotely to provide power for ship azimuthing and other essential electrical loads. All personnel would be evacuated during the duration of the storm.

### 3.11 COSTS AND SCHEDULES

This section discusses the cost and schedule considerations of building and operating eight OTEC power plants of the ship configuration. Capital cost estimates include, in all cases, allowances of 10% contingencies and 4% for contractor profit. Financing costs during construction are not included. Early 1978 dollars have been used throughout for costing purposes. Table 3.11-1 summarizes ship platform costs at the second level of the WBS for the baseline ship design at the New Orleans site. A detailed cost breakdown and discussion for each WBS element is presented in Appendix B.

Separate cost estimates have been prepared for the first platform and for each of the seven follow-on units. No labor learning has been assumed between the 1st and 8th units. Cost differences between first and follow-on units are due entirely to differences in facilities and tooling costs, design costs, and engineering, systems integration, and project management-related costs. Allocated to the first unit are all construction facility costs, all manufacturing and test tooling and equipment costs, and costs of flotation barges and tanks used during deployment. Costs for design of the platform and cold water pipe are also allocated solely to the first units. Cost elements for engineering, systems integration, non-technical project management and control are estimated as percentages of average unit plant cost (Table 3.11-2). Engineering and system integration costs are assumed to be twice as high in the first unit as in the follow-on units because they include original design costs. Project management and other related costs are assumed to be 50% higher in the first unit.

The largest cost element for the ship configuration, accounting for approximately two thirds of the total for the follow-on plants, is the platform system itself. Roughly one-half of the cost of the platform system represents seawater systems cost, including both cold and warm water pumps, while the platform hull and the mooring system each account for approximately one fifth of the cost of the platform system (WBS 1.0). The cold water pipe system (WBS 2.0) accounts for roughly one fifth of the total cost of follow-on ship platforms. Within this element, the major cost driver, representing over one-half of the total pipe cost, are the pipe sections. The next largest cost element, inlets and screens, also contribute over one quarter of total cost. All cost

Table 3.11-1  
 SHIP-TYPE 400 MW(e) COMMERCIAL PLANT COST SUMMARY  
 (NEW ORLEANS SITE)

WBS SYSTEM	COST \$M	
	1ST UNIT	2ND THROUGH 8TH UNITS
1.0 PLATFORM SYSTEM	207.6	179.8
1.1 Platform Integration and Engineering	10.0	5.0
1.2 Hull and Structure	46.7	36.7
1.3 Position Control System	34.6	32.7
1.4 Platform Service Systems	17.6	15.6
1.5 Outfit and Furnishings	0.5	0.5
1.6 Assembly Support Services	6.8	0
1.7 Seawater System	91.3	89.3
1.8 Biological and Corrosion Control System	0	0
2.0 COLD WATER PIPE SYSTEM	64.7	53.9
5.0 SYSTEMS ENGINEERING AND INTEGRATION	5.0	2.5
6.0 SYSTEM TEST AND EVALUATION	10.0	5.0
7.0-A OPERATIONAL SUPPORT	25.0	0
8.0 DEPLOYMENT	29.7	14.7
9.0 INDUSTRIAL FACILITIES	180.0	0
10.0 ENVIRONMENTAL, LEGAL, LICENSING, REGULATION AND INSURANCE	7.5	5.0
11.0 PROJECT MANAGEMENT	22.5	15.0
<b>TOTAL CAPITAL COST</b>	<b>552.0</b>	<b>275.9</b>
<b>\$/KW(e)*</b>	<b>1,380.0</b>	<b>690.0</b>
7.0-B ANNUAL OPERATIONAL COST OF EIGHT-PLANT PARK	24.2	24.2

\* BASED ON NOMINAL PLANT RATING OF 400 MW(e) NET

Table 3.11-2

ENGINEERING, SYSTEMS INTEGRATION AND PROJECT MANAGEMENT COSTS

WBS Element	Approximate Percent of Average Plant Cost (%)		Cost (\$M)	
	1st Unit	2nd thru 8th Units	1st Unit	2nd thru 8th Units
1.1 Platform Integration and Engineering	4.0	2.0	10.0	5.0
2.1 CWP Integration and Engineering	2.0	1.0	5.0	2.5
5.0 Systems Engineering and Integration	2.0	1.0	5.0	2.5
6.0 Systems Test and Evaluation	4.0	2.0	10.0	5.0
10.0 Environmental, Legal, Licensing Regulation and Insurance	3.0	2.0	7.5	5.0
11.0 Project Management	9.0	6.0	22.5	15.0

information presented in this chapter is based on the use of the flexible, rubber-nylon pipe. The conceptual design of rigid pipes with flexible joints is discussed in Appendix A.

The parametric procedure used to estimate WBS elements 5.0, 6.0, 10.0, and 11.0 has already been described earlier in this section. WBS element 7.0, operational support, has been split into two subelements, representing capital and operating costs, respectively. The first category represents the cost of purchasing or building the facilities required for a waterfront supply base and an on-site hotel and control center barge, while the latter covers the annual cost of supplying and maintaining the eight-plant OTEC park. Deployment costs have been estimated for the procedure outlined in Section 3.7, and account for less than a tenth of the total cost of follow-on platforms. WBS element 9.0, Industrial Facilities, is by far the weakest element of the estimates presented here, as it is extremely site sensitive and requires much greater design and construction sequence definition than was available in this study. The estimates presented are based on limited information on experience in Norway and the United States. The possible range of the costs is estimated to be 50 percent.

The total cost of the first ship-type OTEC platform is estimated at something less than 550 million dollars, or approximately 1380\$/Kw; roughly 40% of this cost represents nonrecurrent facilities and design costs. Thus, the cost of each of the seven follow-on units is expected to be approximately 275 million dollars, which is under 700 \$/Kw. It should be emphasized that no labor learning has been assumed for these units. Should a labor learning curve be assumed with a slope of 0.95 (reasonable for shipyard construction), the cost of the eighth unit would be roughly 85%, and the average cost of the seven follow-on units would be 90% of that shown in Table 3.11-1 for the 2nd - 8th units.

Figure 3.11-1. shows the construction schedule for the eight-plant OTEC park, based on the individual schedule discussed in section 3.6. All ship construction takes place in a graving dock. There is no opportunity for schedule compression through simultaneous work on two or more platforms. The total construction time required therefore is eight times that required for a single plant, one hundred and twelve months.

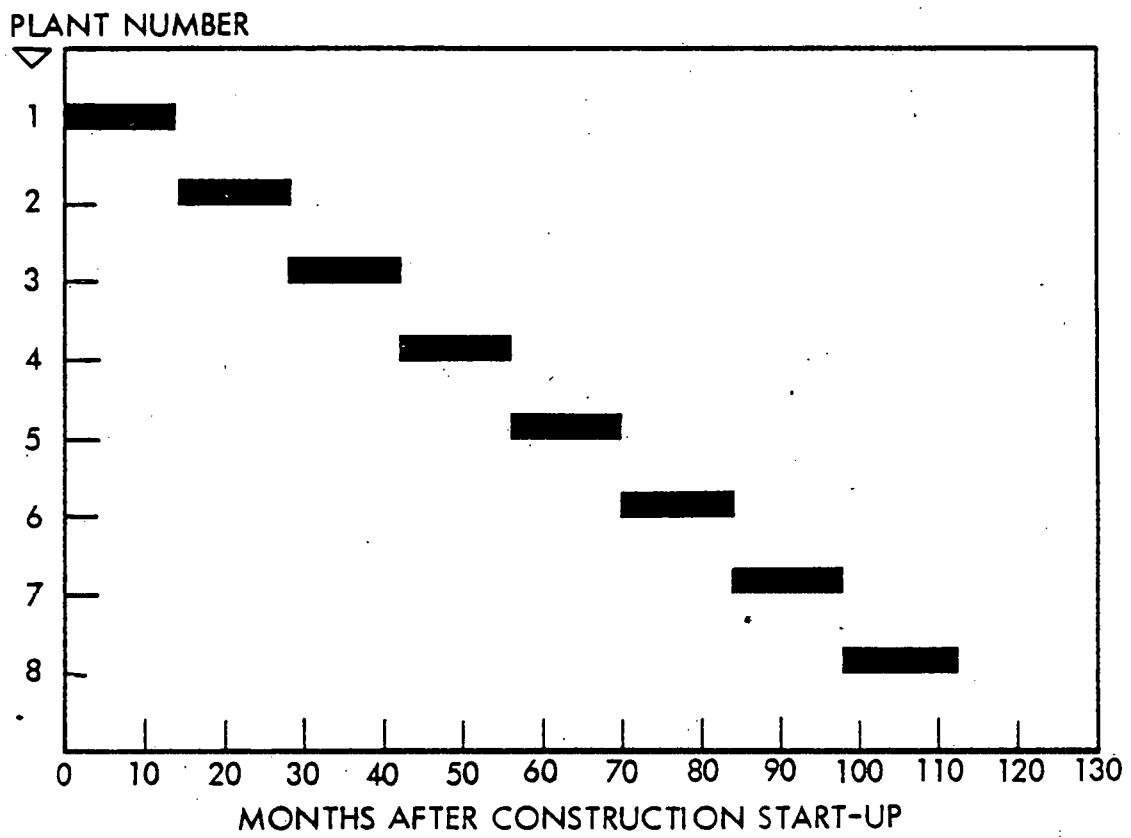


Fig. 3.11-1 OTEC Park Construction Schedule for Eight Plants of Ship Type  
3-64

A second dock would allow for a reduction in span of time for delivery of the complete park at the expense of doubling the cost for industrial facilities for the second new graving dock.

## Section 4

### DESCRIPTION OF CONCEPTUAL DESIGN OF SPAR

This conceptual design of the spar platform for an OTEC commercial plant utilizing detached power modules has successfully integrated several new considerations into the design and realized significant reductions in platform cost compared with previous spar designs.

The detachable power module utilizes the immersed heat exchanger arrangement. The detachable feature of the power module allows for convenient handling of the heat exchangers and power generation equipment for installation and for major repairs. The immersion of the ammonia storage tanks, which are attached to the core of the spar, provides net buoyancy which contributes to the support of power conversion and transmission equipment, the cold water pipe, and to tensioning the mooring system. The use of light weight concrete in the interior of the core combined with elimination of permanent personnel facilities and equipment further contributed to the reduction in size and cost of the spar-type platform. The estimated complete cost for the 400 MW<sub>e</sub> net spar platform is 801 \$/kW for the 2nd to 8th units.

This section presents a detailed description of the conceptual design of this refinement of the OTEC spar platform with detachable power modules.

## 4.1 GENERAL CHARACTERISTICS

The OTEC 400 MW<sub>e</sub> net spar conceptual design is a development of the detachable module spar concept. This section of the report presents the highlights of the design development process and a description of the General Characteristics of the conceptual design. The basic requirements for the commercial OTEC platform, Section 2, apply to the spar.

### 4.1.1 Design Development

The main goal of the design is to provide a minimum cost platform which will support a 400 MW<sub>e</sub> net OTEC plant and satisfy as well as possible the design requirements imposed by considerations of the power system, electrical conversion system, sea water system, structural integrity, environmental conditions, watch circle, buoyancy, and stability.

Early decisions were:

1. Use concrete as structural material.
2. Platforms will be unmanned except for periodic visits of maintenance and repair crews.
3. Major maintenance of power system components will be carried out when detachable module is returned to shore.
4. Cold water vent to atmosphere is not required.

The central core developed as a pressure vessel containing primarily electrical conditioning equipment, a base structure acting as cold water pipe support and cold water distribution plenum, and a column above the pressure vessel through the water surface. The ammonia storage tanks are placed outside the pressure vessel in order to take advantage of their buoyancy. Initially, a laterally extended core base structure was conceived as a landing base for the modules, but this idea was abandoned in face of the required 150 meter cold water discharge depth.

Several module design concepts were advanced providing different compromises among the requirements. The primary items affecting module design are:

1. Power plant considerations:
  - Horizontal vs. vertical heat exchangers
  - Desired short ammonia lines
  - Efficiently shaped ammonia diffuser
  - Accessibility of ammonia condensate and reflux pumps
  - Ease of maintenance of turbines and generator.
2. Sea Water System:
  - Desired inlet and discharge depths
  - Minimum length of sea water paths
  - Minimum number of turns in sea water path
  - Required diffuser length between pumps and heat exchangers.
3. Weight and Buoyancy:
  - Near-neutral buoyancy and zero buoyancy moment in attached condition desirable for module
  - Simplicity and ease of module attachment
  - Proper draft and trim during construction and tow.
4. Maintenance:
  - Space to pull generator shaft
  - Ability to retube or remove heat exchangers in dry dock.
5. Structure:
  - Low cost, i.e., lightweight
  - Simplicity for ease of construction and structural integrity.

Of the approximately twenty different module configurations studied, two were chosen for more detailed development. One represents a design with horizontal heat exchangers; the other contains vertical heat exchangers. The horizontal heat exchanger design, shown on Figures 4.1-1 and 4.1-2, was carried through the entire conceptual design process. The vertical heat exchanger design is shown on Figures 4.1-3 and 4.1-4.

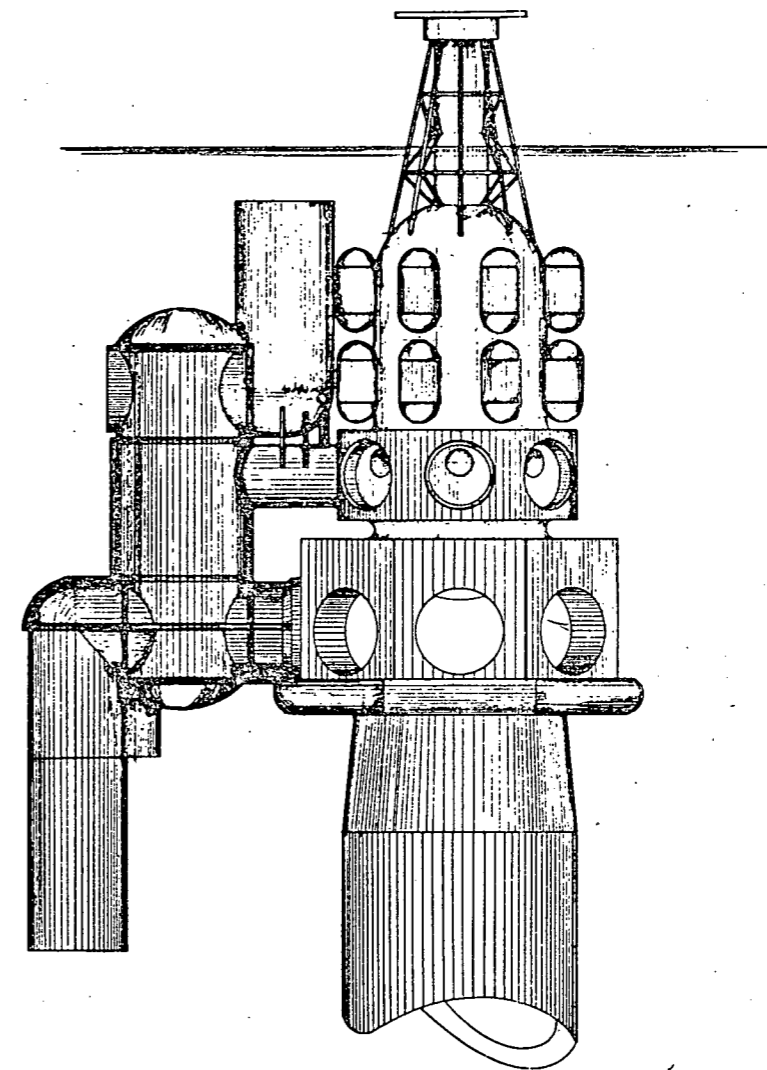
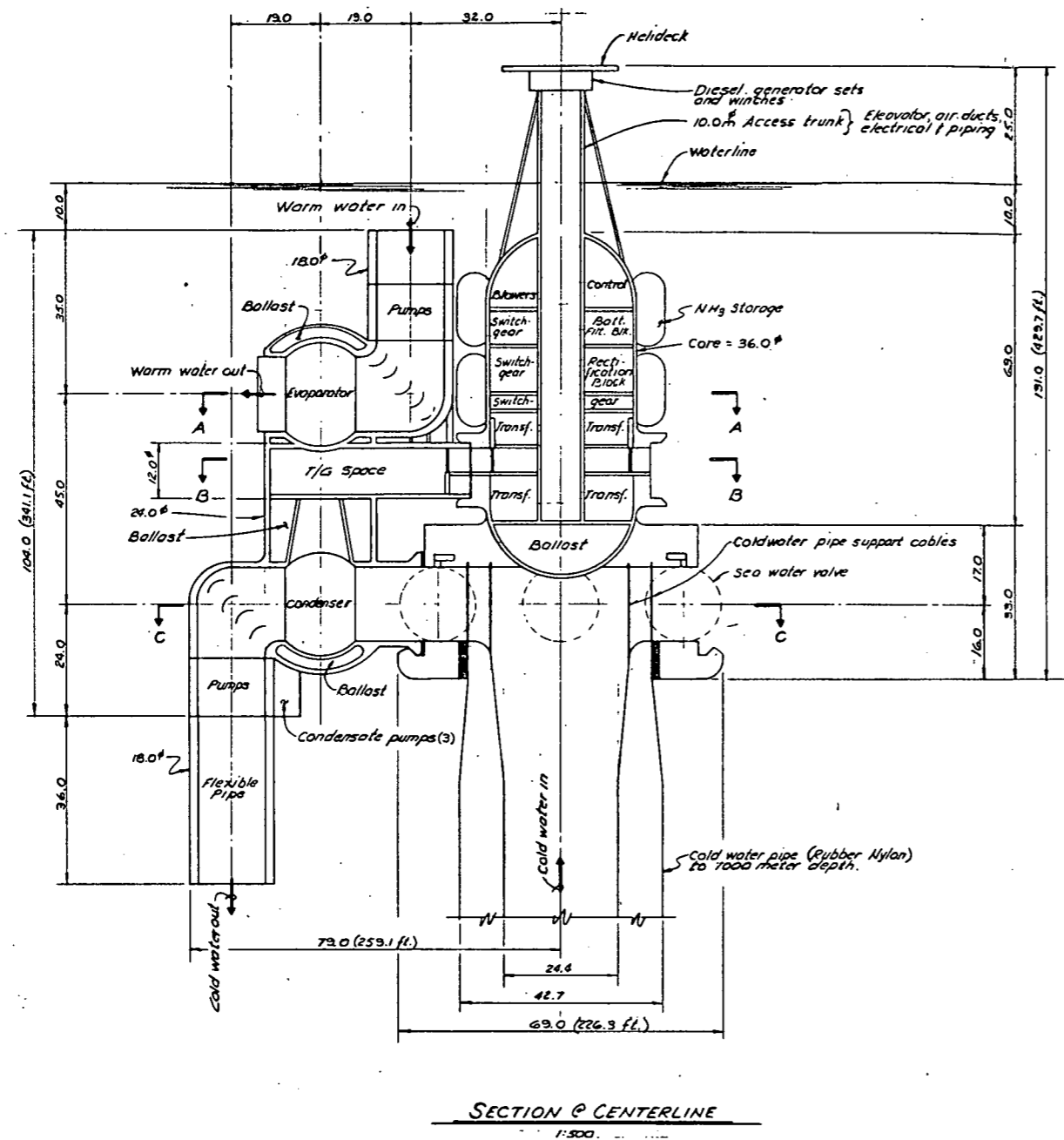
#### 4.1.2 Description of Horizontal Heat Exchangers Design

The OTEC Spar Platform consists of a central core supporting the cold water pipe and eight detachable power modules of 50 MW<sub>e</sub> (Net). The core contains power conditioning equipment, supports the ammonia storage tanks which are immersed in the water, and forms the cold water distribution manifold. The power modules each contain the seawater pumps, heat exchangers, piping, turbine generators, and ammonia valves and pumps. The spar (with horizontal heat exchangers), arranged as in Figs. 4.1-1 and 4.1-2, has the following principal characteristics.

Diameter Overall	158 m	518 ft
Diameter on Waterline	10 m	33 ft
Diameter of Core (@ base)	69 m	226 ft
Width of Modules	60 m	197 ft
Overall Height	139 m	456 ft
Height of Modules	104 m	341 ft
Operating Draft	114 m	374 ft
Light Ship (Dry) Weight	244,000 tonne	240,157 L.T.
Displacement @ Operating Draft	438,000 tonne	431,112 L.T.
Displacement @ Operating Draft Excluding Seawater	256,000 tonne	251,969 L.T.

#### Hull System

The hull system consists of a core and the eight detachable power modules. A 10-meter diameter column extends through the water surface, providing access to the atmosphere. Each module consists of a main cylinder housing the power plant components with attached parallel cylinders at each end holding sea water pumps and ducts. The module and core are connected at the cold water inlet and at the turbo-generator space access position.



**PRINCIPAL CHARACTERISTICS**

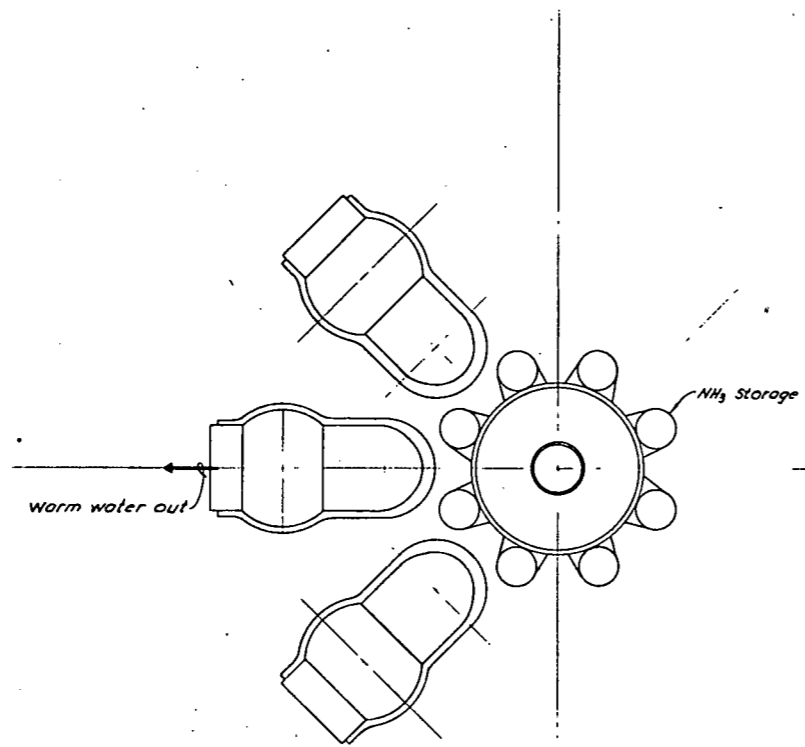
**CORE:** Overall height — 131m (429.7 ft.)  
Max. Width — 69.0m (226.3 ft.)

**MODULE:** Overall height (w/o flexible cold water pipe) — 154m (505.1 ft.)  
Width Overall — 60m (196.8 ft.)

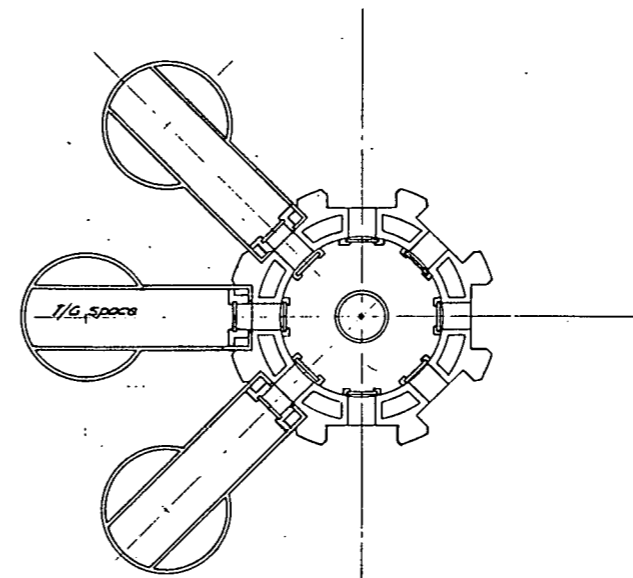
**NOTE:**  
All dimensions are in meters

Fig. 4.1-1

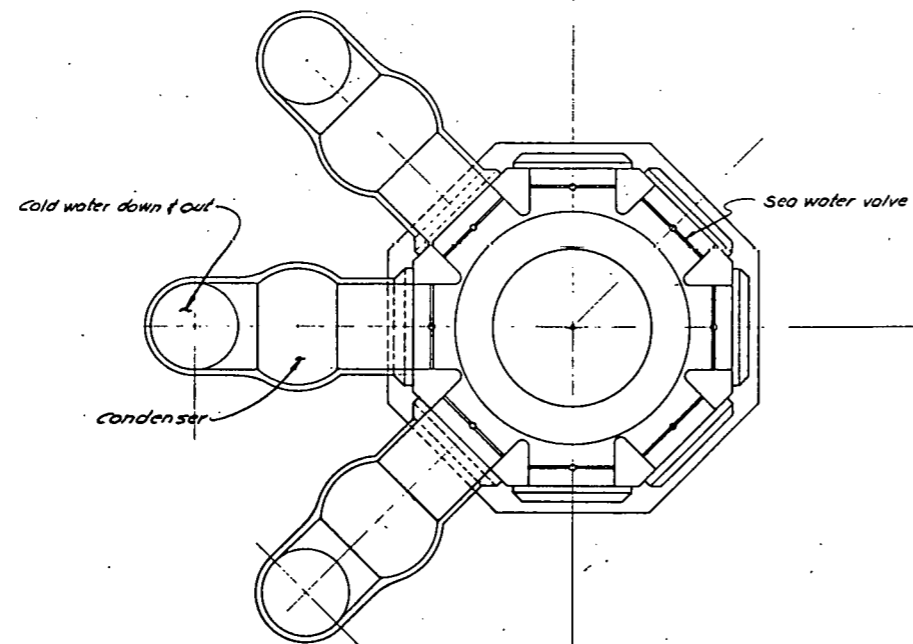
NO.	DATE	APPROV.	DESCRIPTION
LOCKHEED MISSILES AND SPACE COMPANY INC. SUNNYVALE CALIF. OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SPAR - 400 MWe (NET) ARRANGEMENTS HORIZONTAL HEAT EXCHANGER INBOARD & OUTBOARD PROFILES			
S&B AND WRIGHT CONSULTING ENGINEERS ONE MARKET PLAZA - SPAN STREET TOWER - SAN FRANCISCO, CALIFORNIA 94115			
DRAWING NO.	770392-3		
DESIGNED BY	R.K.R.	CHECKED BY	AS NOTED
APPROVED BY	M.G.B.	DATE	MAR 17, 1978



SECTION A-A  
1:500



SECTION B-B  
1:500



SECTION C-C  
1:500

Fig. 4.1-2

DATE	REVISED	DESCRIPTION	BY
		LOCKHEED MISSILES AND SPACE COMPANY INC. SUNNYVALE CALIF.	
OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SPAR - 900 MW <sub>e</sub> (NET) ARRANGEMENTS HORIZONTAL HEAT EXCHANGER PLANS			
EARL AMT WRIGHT & CONSULTING ENGINEERS ONE MARKET PLAZA - BEAR STREET TOWER - SAN FRANCISCO, CALIFORNIA 94105			
DRAWING NO.	DESIGNED BY	SCALE	DATE
770932-4	R.K.R.	As Noted	MAR 17, 1978
	CHECKED BY		
	M.G.B.		

### Structural System

The core and modules are constructed from lightweight concrete. Section 4.5 contains a discussion of the structural system.

### Seawater System

The cold water rises through a rubber-nylon pipe from a depth of 1,000 meters to the cold water distribution plenum at the base of the central core. It then passes into the modules, through the condensers, and through the S.W. pumps to exit downward at a depth of 150 meters.

The warm water enters each module 10 meters below the water surface, passes through the pumps and evaporators, and exits horizontally 45 meters below the surface.

The seawater system is further described in Section 4.2.

### Power System

Each detachable module contains all power system components for generation of 50 MW(e) (net) power. The electrical power is fed from the eight power modules to the electrical conditioning equipment in the core.

Each 50 MW(e) (net) module consists of a closed-loop ammonia cycle, with four ammonia turbines driving a generator in the turbo-generator space. The ammonia is vaporized in the evaporator, dried in the demister contained within the evaporator shell, and piped to the turbines. From the turbines, the ammonia enters the condenser through the diffuser. Condensed ammonia is pumped from the condenser through lines contained within the module to the evaporator sump. Distribution pumps direct this liquid and extra non-vaporized liquid from the evaporator sump to the appropriate locations within the evaporator. The system is recharged from the core ammonia storage. Inert gas, also stored in the core, can be used to purge the system.

## Electrical Conditioning System

The main Electrical Conditioning System is contained entirely within the core.

Module power is provided via step-down transformers within each module. The residual power is directed to a combining bus within the core, and core electrical requirements are met via step-down transformers in the core.

The remainder of the power is led to the main step-up transformers in the core, through the main switchgear to the rectification equipment, and then to the 500 kvdc transmission lines.

## Support Systems

Platform support systems are contained primarily within the core. They are discussed in Section 4.4.

## Position Control System

The mooring system is described in Section 4.3.

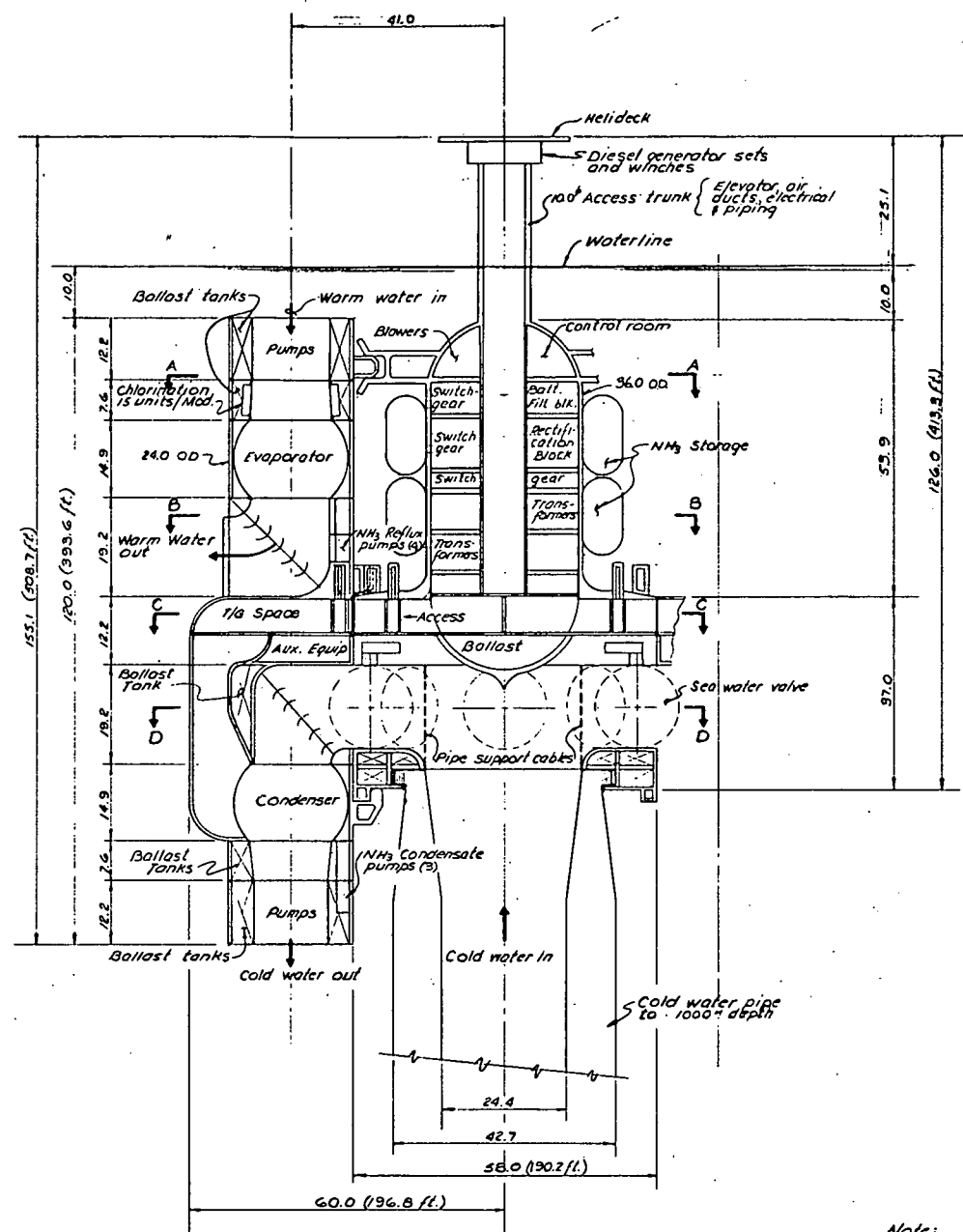
## Access

Normal access for maintenance and repair crews is down through the column on an elevator to any of the levels within the core. The modules are reached by a passage into the turbo-generator room. Access to remote areas, such as the condensate pump room, is achieved through special trunks containing elevators and/or ladders.

Emergency escape from the underwater portions of the module must be provided via escape capsules located in the modules and core.

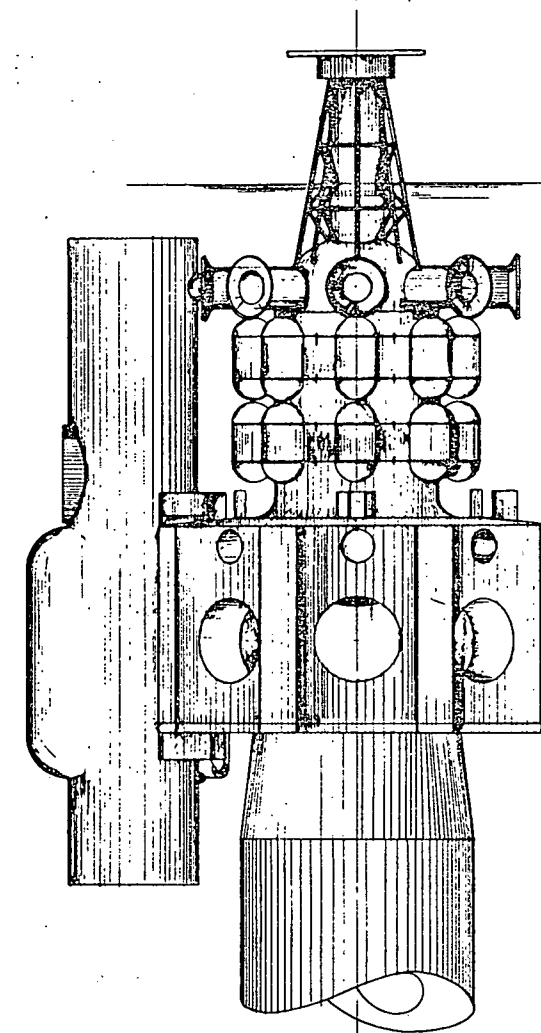
### 4.1.3 Description of Vertical Heat Exchanger Design

General Arrangements of the Vertical Heat Exchanger design are shown on Figures 4.1-3 and 4.1-4. The design using the vertical heat exchangers is similar in many aspects to that using the horizontal heat exchangers. This



Note: All dimensions in meters.

SECTION @ CENTERLINE  
1:500



OUTBOARD PROFILE  
single module shown attached

**PRINCIPAL CHARACTERISTICS**  
**CORE:** Height overall—126.0 m (413.6 ft.)  
 Max width—58.0 m (190.2 ft.)  
**MODULE:** Height overall—120.0 m (393.6 ft.)  
 Width overall—36.0 m (118.1 ft.)

Fig. 4.1-3

DATE	APPROVED	BY
LOCKHEED MISSILES AND SPACE COMPANY INC. SUNNYVALE, CALIF.		
OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SPAR- 400 MWe (Net)		
ARRANGEMENTS VERTICAL HEAT EXCHANGERS INBOARD & OUTBOARD PROFILES		
EARL AND WRIGHT • CONSULTING ENGINEERS ONE MARKET PLAZA • SPAR STREET TOWER • SAN FRANCISCO, CALIFORNIA 94103		
DRAWING NO.	DESIGNED BY	DATE
770932-1	R.H.R.	As noted
	M.G.B.	MAY 1978

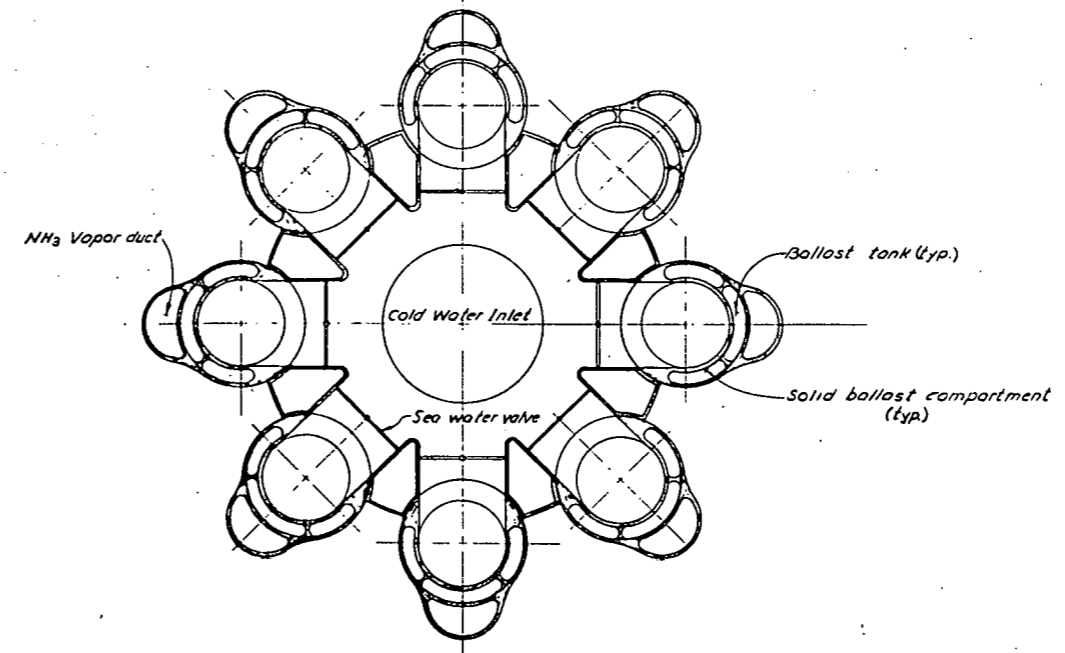
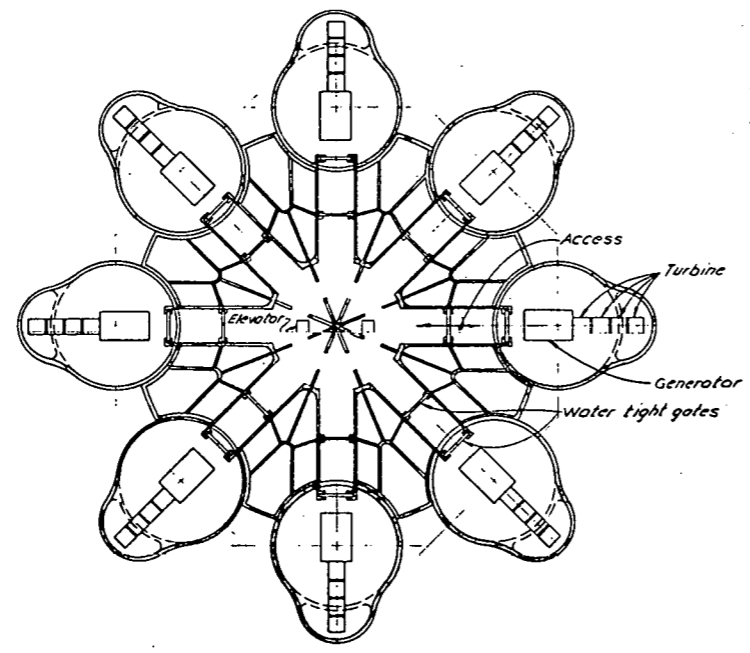
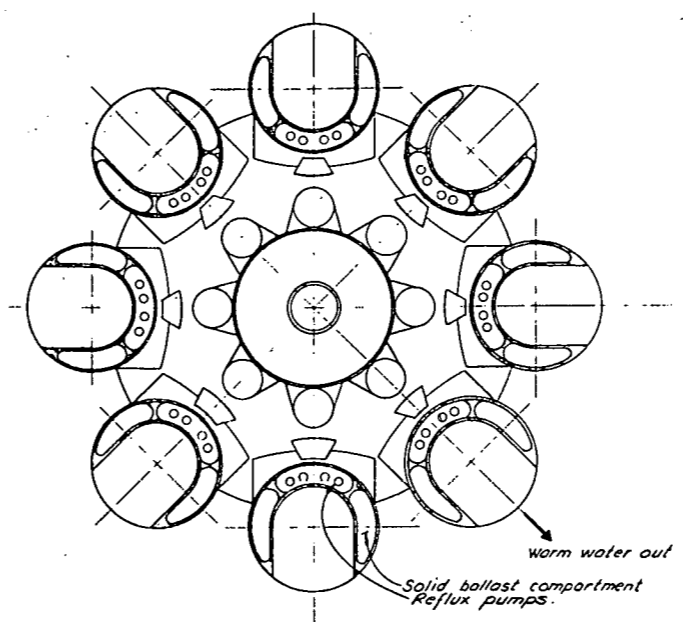
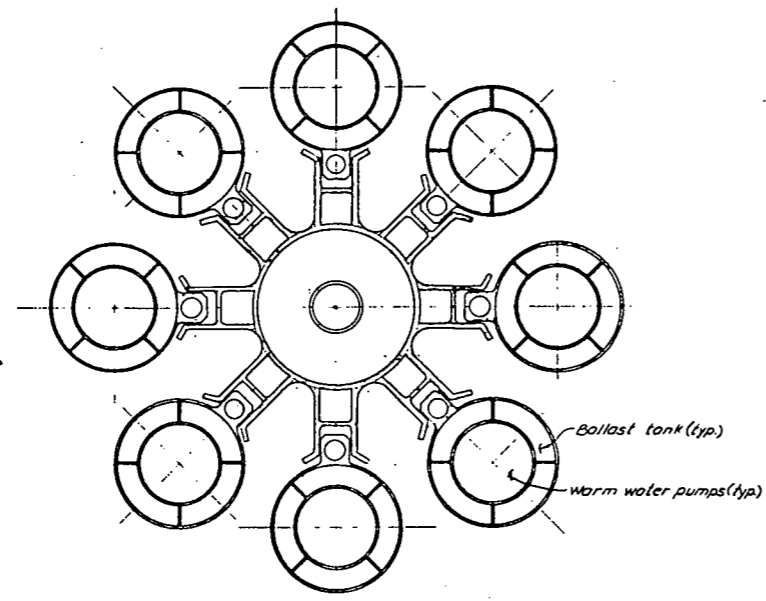


Fig. 4.1-4

NO.	DATE	APPROV.	DESCRIPTION	BY
LOCKHEED MISSILES AND SPACE COMPANY INC. SUNNYVALE, CALIF.				
OTEC PLATFORM CONFIGURATION & INTEGRATION CONCRETE SPAR-400 MWe (NET) ARRANGEMENTS VERTICAL HEAT EXCHANGER PLANS				
SABL AND WRIGHT • CONSULTING ENGINEERS ONE MARKET PLAZA • SPAR STREET TOWER • SAN FRANCISCO, CALIFORNIA 94105				
DRAWING NO.	DRAWN BY: <u>R.K.B.</u> DATE: <u>As noted</u> CHECKED BY: <u>M.G.B.</u> DATE: <u>MARCH 17, 1978</u>			
770932-2	SUBMITTED BY: _____			

section will address only the areas where the two designs differ. For similar features, the descriptions in Section 4.1.3 apply.

### Hull System

The vertical heat exchanger platform differs from the horizontal heat exchanger platform primarily in the shape of the modules. Each module housing the vertical heat exchangers consist of a single vertical cylinder which is mated to the core above and below the cold water intake and at a separate docking connection high on the module.

General characteristics of the central core are:

Over-all height (excluding CWP)	126m (413 ft)
Maximum width (at base)	58m (190 ft)
Operating draft (excluding CWP)	100.9m (331 ft)

General characteristics of each module are:

Over-all height	120m (394 ft)
Diameter	24m ( 79 ft)
Maximum width	36m (118 ft)

### Seawater System

This system is similar to that on the horizontal heat exchanger design, except that the cold water exits downward at a depth of 130 meters, and the ducting is arranged such that sea water passes through the heat exchangers in a vertical direction.

### Platform Modifications for Concrete CWP

A detachable spar platform with a concrete CWP weighing 35,000 t in water was briefly studied. This pipe is similar to the concrete in Section 3.2.2. The spar is similar to the baseline horizontal heat exchanger design, with an increase in core diameter and a corresponding increase in radial distance from the core centerline to the modules. Also the base structure is strengthened to support the heavier CWP. The module is nearly the same as the baseline module.

The concrete core weight is approximately 17,400 t greater than the core weight in the baseline design. The operational mode of the spar in an 8-plant is shown in Fig. 4.1-5.

#### 4.2 SEAWATER SYSTEM

The cold water system on the spar is similar in arrangement to that on the ship (Section 3.2). The central plenum in the core base is circular with eight openings into the power modules. Valves which provide buoyancy during deployment close the outlet during module removal to assure cold water suction. A set of four pumps discharge cold water at 130M depth (Figure 4.1-1).

The spar cold water system losses are summarized in the following table for one module. In addition to the flow losses, a static head loss of 119 psf results from discharging denser water at 130m.

<u>Cold Water System Component</u>	<u>Flow Loss, psf</u>	<u>% of Total</u>
Inlet Screen	1.1	0.2
Cold Water Pipe	73.7	13.0
Diffuser	7.6	1.3
Plenum	25.9	4.6
(1) Valve	5.8	1.0
(1) Vaned 90° Bend	5.8	1.0
(1) Discharge Screen	4.9	0.9
Subtotal, CW System	124.8	22.0
(1) Condenser Tubes	443.3	78.0
Total, CW Flow	568.1	100.0

The spar warm water system components are similar to those found in the ship while their arrangement differs. Four vertically oriented pumps, mounted above the vertical evaporator, have an inlet depth of 10M. Discharge is horizontal at a depth of 55M.

4-13

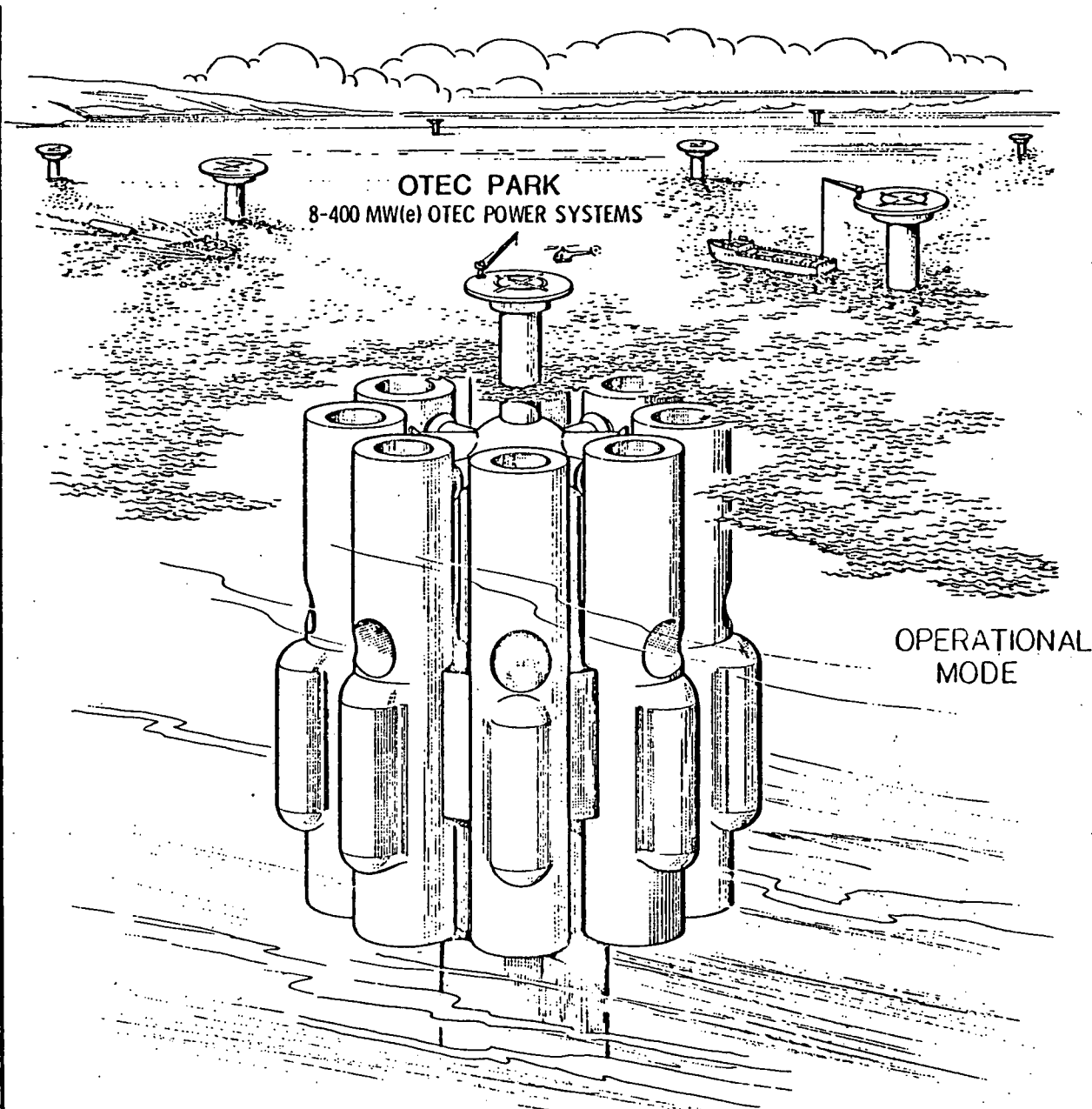
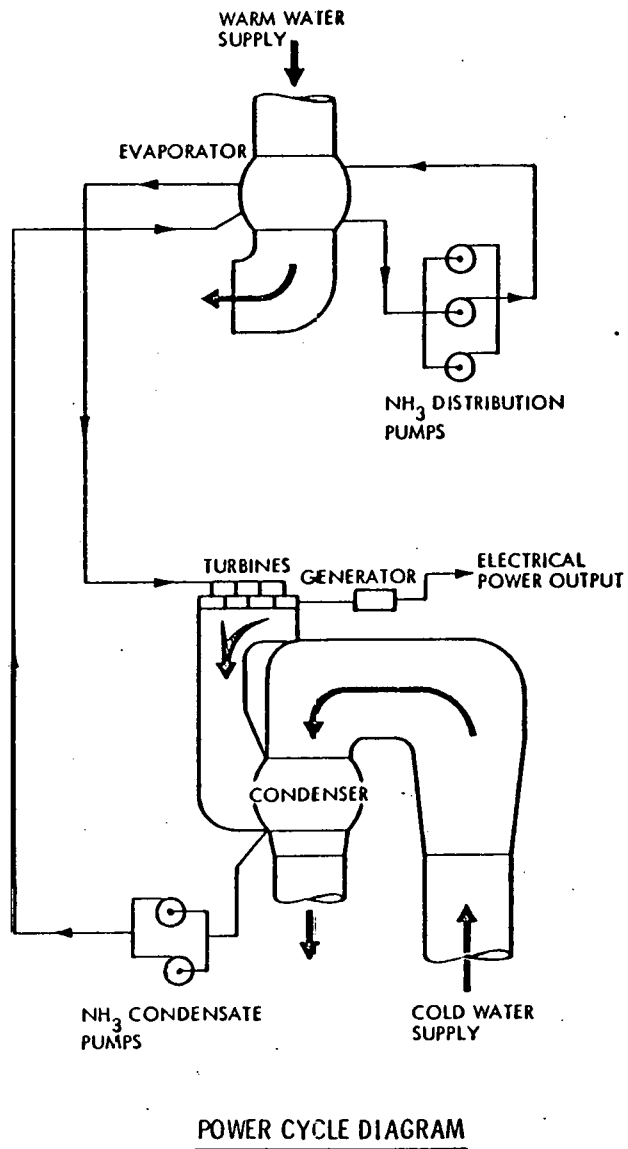


Fig. 4.1-5 OTEC Park - Eight 400-MW(e) OTEC Power Plants

Flow losses in one module of the warm water system are as follows.

<u>Warm Water System Component</u>	<u>Flow Loss, psf</u>	<u>% of Total</u>
Inlet Screen	1.1	0.2
Water Box	-	-
Vaned 90° Bend	5.8	0.9
Discharge Screen	4.9	0.8
Subtotal, WW System	11.8	1.9
Evaporator	624.7	98.1
Total, WW Flow	636.5	100.0

#### 4.3 POSITION CONTROL SYSTEM

Several options are available to position the spar in the candidate sites, including tension moor, multi-point moor, single point moor, dynamic positioning, vectored seawater discharge and hybrid systems. These position keeping concepts are examined in Volume I, Section 2.3.4. In this section costs for a three-point spread moor, and dynamic positioning are compared with a tension moor concept.

The core with modules in place has the following characteristics.

Current Area	10860 m <sup>2</sup>	(117 x 10 <sup>3</sup> ft <sup>2</sup> )
Wind Area	250 m <sup>2</sup>	(2691 ft <sup>2</sup> )
Mean Depth	60 m	(197 ft)
V/V <sub>s</sub>	0.9	
Drag in 100-year storm at New Orleans	878 tonnes	(1.98 x 10 <sup>6</sup> lbs)

A comparison of three point spread moor and dynamic positioning system costs indicates that for Hawaii and New Orleans a mooring system is approximately one third of dynamic positioning. Mooring cost for the spar at New Orleans is \$36.8M. Dynamic positioning is the lower cost system for the Brazil site, \$40M for 40 year service, Figure 4.3-1.

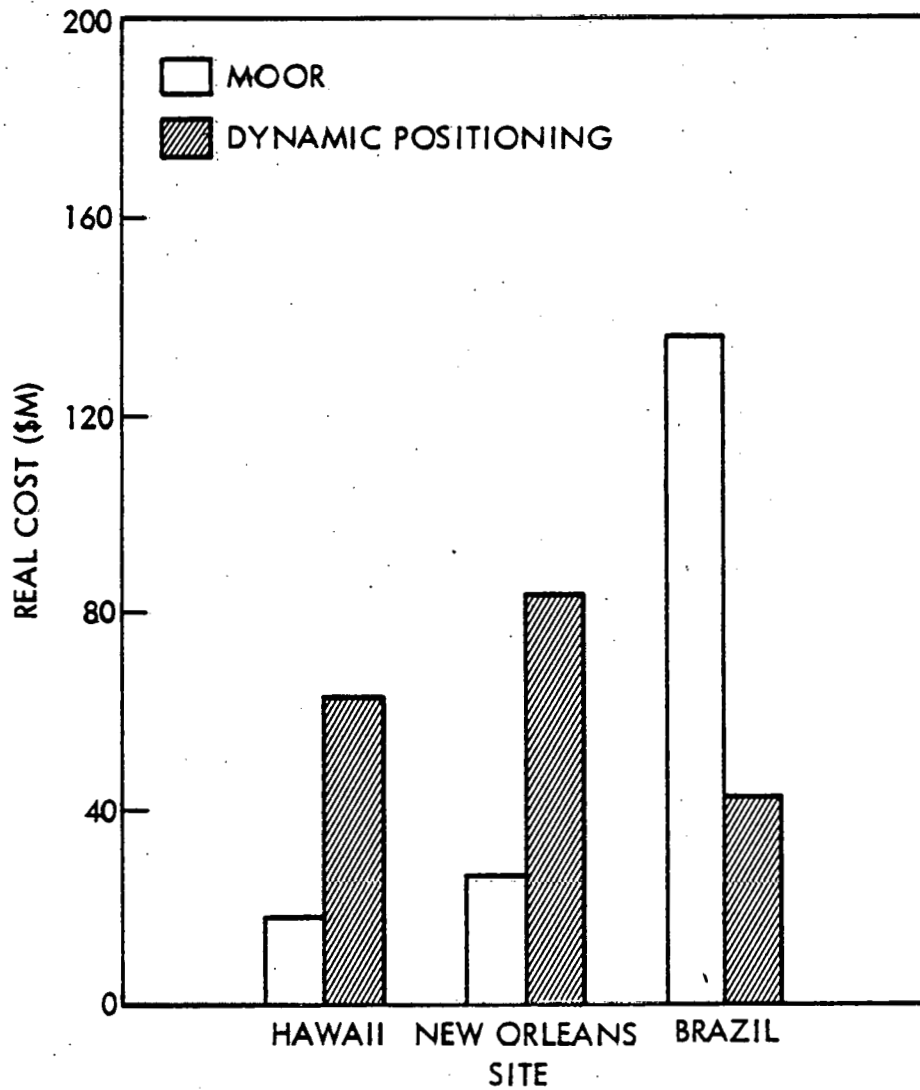


Fig. 4.3-1 Position Keeping System Cost vs. Site, 400 MW(e) Net Spar, 140 Ft O.D. CWP

Another approach to mooring the spar is to provide excess buoyancy at the operating draft and reaction through a tensioned mooring leg, Figure 4.7-2. This approach is found in tensioned leg semi-submersible oil platforms in mid-depth range and in pinned spar-type oil storage structures. The spar platform is suited to this concept because of the low waterplane area and low tons/inch immersion in comparison with the ship. The advantage to be gained is the reduction in mooring line length, with lines attached to the inlet on the bottom of the CWP instead of directly to the core. Further, with lines well separated from the platform there is lower risk of entangling electrical transmission lines and CWP with the mooring system.

An estimated net buoyancy of 6200 Lt including platform and CWP is reacted by tensile load in the soft CWP resulting in stress of 345 PLI which is 655 PLI less than the design limit of 1000 PLI. The tension moor also imposes an additional load in the CWP due to platform drag which must be added to stresses due to other loads (current forces, hydrostatic pressure in the annulus, and platform accelerations). The number of nylon mooring lines of 10 inch diameter and 1500 feet length (unstretched) is 49. This assumes a safety factor of 6 on breaking strength with 6200 Lt static load. If it is assumed that the nylon mooring lines have the same life as the nylon CWP (40 years) then the cost of the lines is \$10.4M. Anchor cost, at \$300/LT and a factor of two on static load is \$3.6M. The cost of the tension moor system is then \$14M. If the nylon lines require replacement every six years, as is assumed in the case of spread moor, then a tension moor cost is \$30.7M, or \$3.9M in excess of a spread moor. Deployment costs are not included in these estimates. Selection of a cost effective mooring system will require additional data on performance history of long term, deep water mooring systems for large surface platforms.

#### 4.4 SUPPORT SYSTEMS

##### Platform Electrical System

The electrical system providing power for platform loads consists of step down transformers, additional switchgear, MCC's, and distribution lines to platform electrical loads. The equipment is housed primarily in the core on levels above the main transformers. This system powers the SW pumps, ammonia pumps, bilge, ballast, and fighting pumps, compressors, blowers, control systems, lighting and other miscellaneous loads (see Figures 4.4-1, 2, 3).

##### Communication and Navigation Systems

Telephone communication will be provided among several stations on the platform. A radio installation will supply communication with other platforms in the energy farm, with support vessels, and with shore bases.

Navigation facilities will probably not be required on each platform. Navigation equipment will be present on support vessels.

##### Storage and Supply Systems

Storage for all necessary commodities is provided on the platform. The large ammonia storage tanks are attached to the core exterior with ammonia lines leading from the core to the modules. Nitrogen storage tanks are inside the core. Lube oil is stored in the core near locations of desired use. Fuel for the emergency generators is stored in tanks adjacent to the diesel-generator sets. A limited amount of critical spare parts are stored in special areas within the core.

Supply for the operating platform is provided through the surface-piercing column. Commodities which can be piped will be transferred from supply vessels to the core through column piping. Items such as spare parts will be lowered through the column via an elevator.

Supply items will arrive at the platform via service vessel or helicopter.

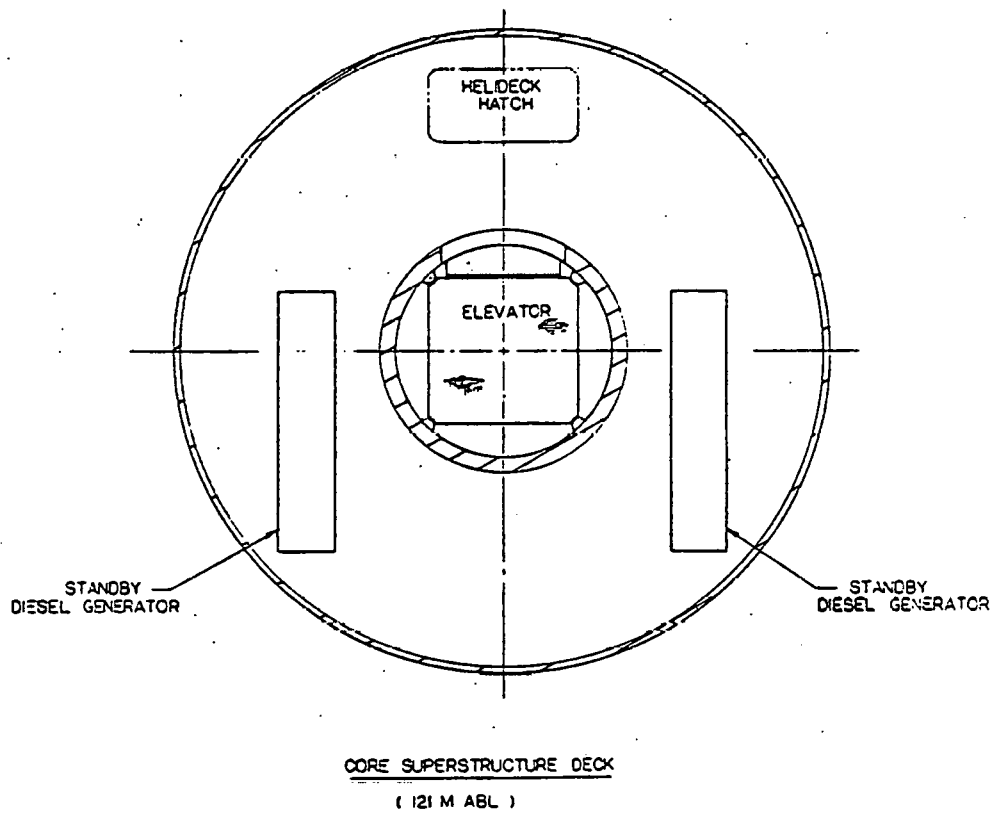


Fig. 4.4-1 Standby Power and Auxiliary Electrical Equipment Arrangement, 400-MW(e) Spar, Core Superstructure Deck

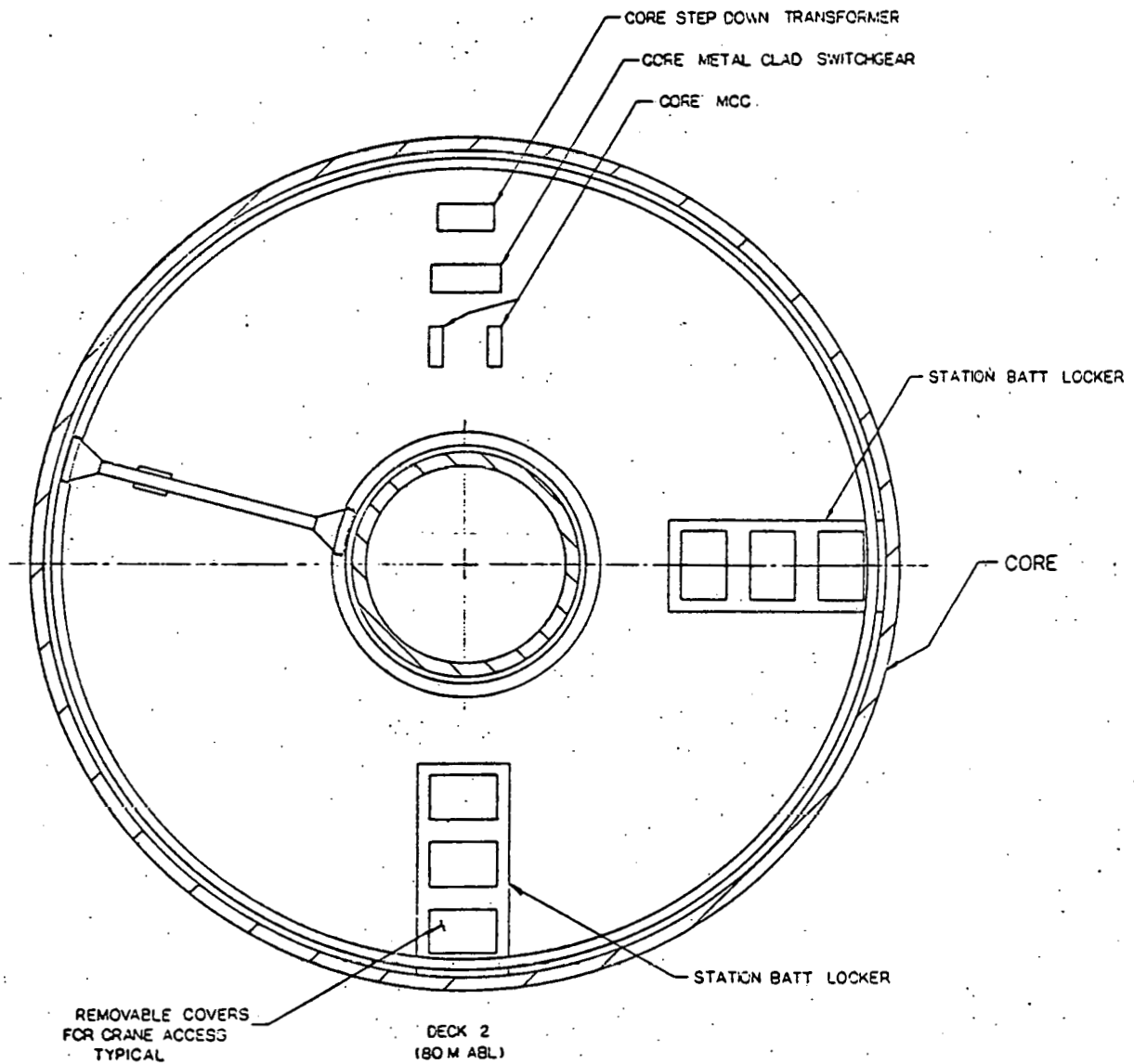


Fig. 4.4-2 Standby Power and Auxiliary Electrical Equipment Arrangement, 400-MW(e) Spar, Deck 2

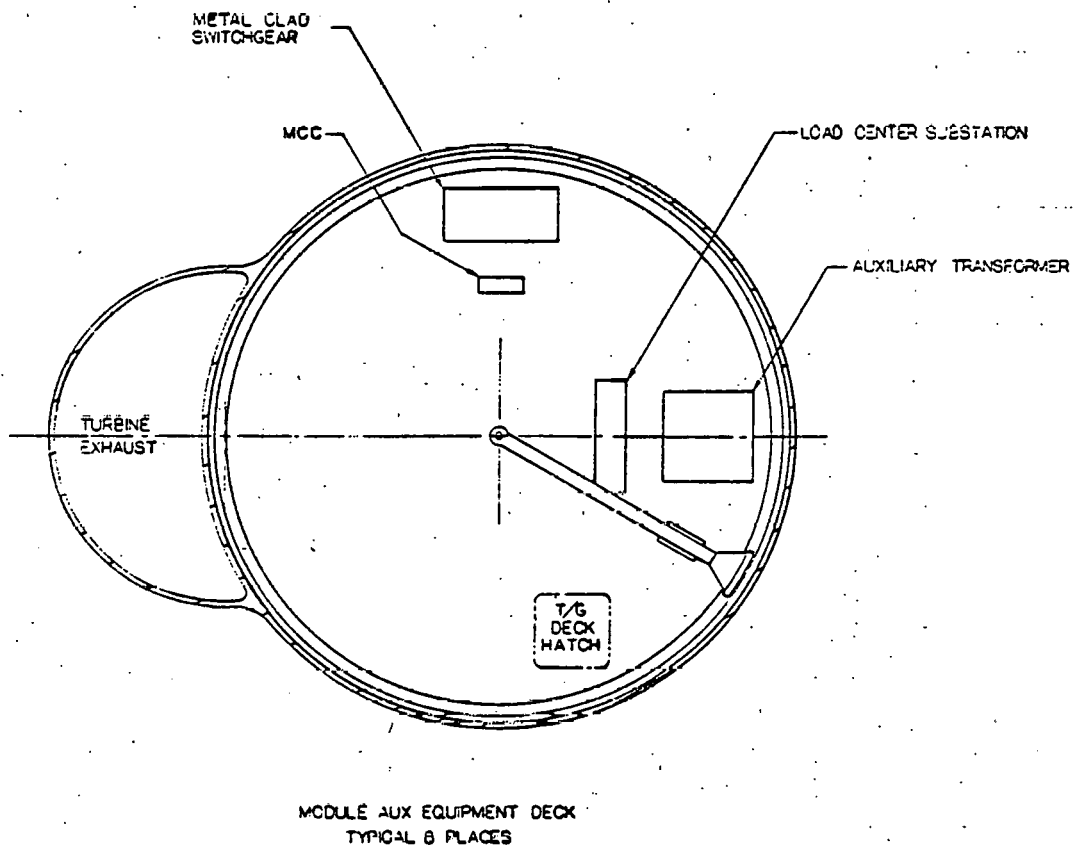


Fig. 4.4-3 Standby Power and Auxiliary Electrical Equipment Arrangement, 400-MW(e) Spar, Module Auxiliary Equipment Deck

### Life Support System

Since the platform will be unmanned except for periodic repair and maintenance crews, the life support system will be minimal. A potable water system and sanitary facilities will be installed, and emergency first aid materials will be available.

### Mechanical Support System

Equipment handling capability is provided by cranes on various decks in the spar, Figures 4.4-4 through 4.4-8. A swivel type bridge crane with 60 T capacity is used to disassembly equipment on the turbine-generator level. A trolley permits equipment transfer between the module and core, when an elevator provides lift capacity to the surface. A rotating bridge crane is used for auxiliary machinery maintenance on the level below the turbine-generator. Also, a trolley and rotating bridge cranes provide for equipment handling in the core decks 1-7. A rail crane, trolley, and whirley crane provide handling capability to and from the superstructure.

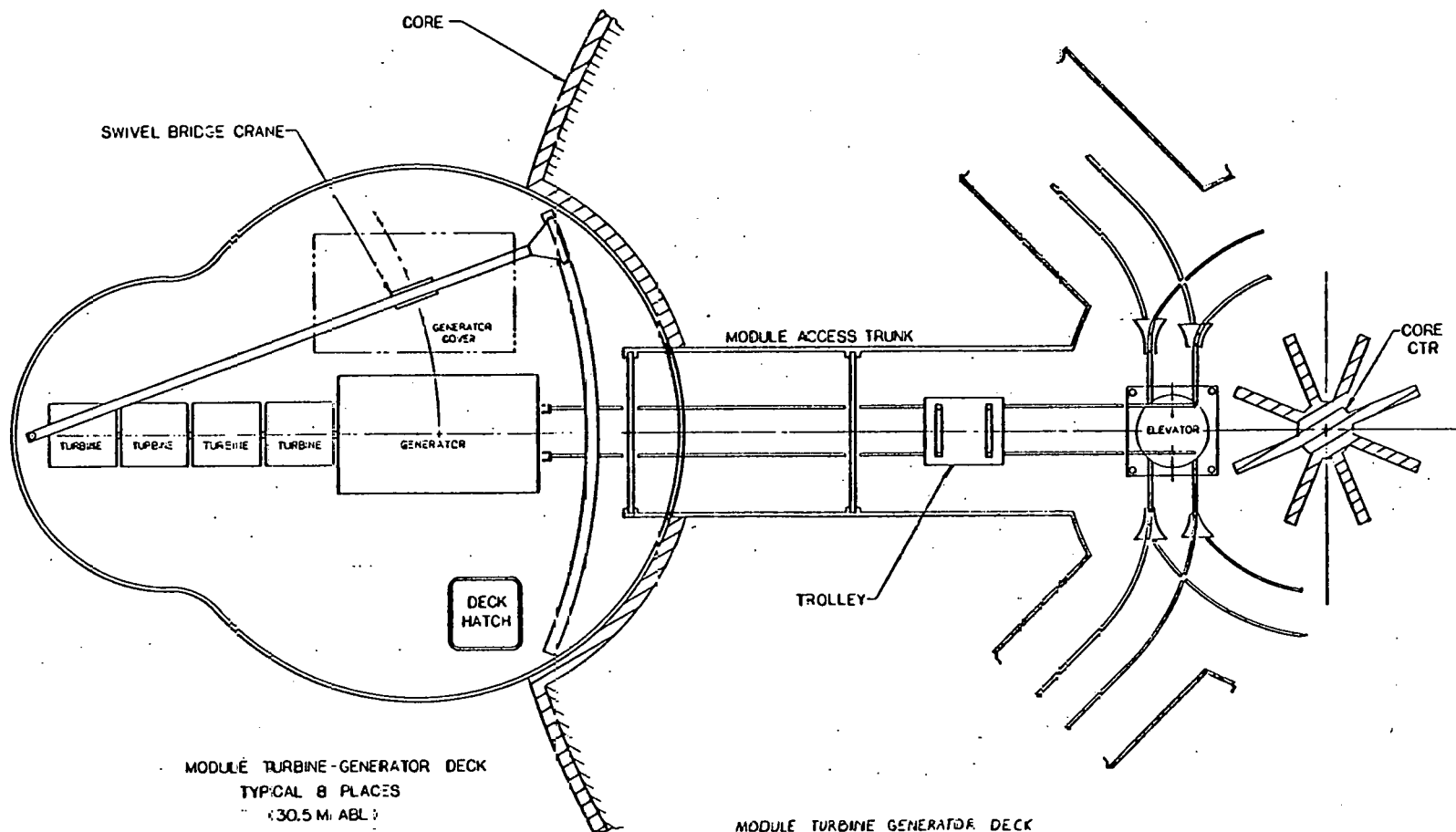
### Environmental Control System

The HVAC system will consist of blowers on the upper level of the core, drawing air through large ducts in the column and distributing it through air conditioning equipment to the core and module spaces. The exhaust air will be ducted back up through the column to be vented at the top of the column. Special chemical monitoring devices will be placed throughout the platform to provide warnings of excessive chemical leakage. Breathing apparatus will be available for emergency operations.

### Data Acquisition and Control System

The DACS will be provided on the platform with direct control or remote read-out on service vessels or ashore. The equipment and control room will be located on the upper level of the core.

4-22



MODULE TURBINE-GENERATOR DECK  
TYPICAL 8 PLACES  
(30.5 M. ABL)

MODULE TURBINE GENERATOR DECK  
HANDLING EQUIPMENT

1. A SWIVEL TYPE BRIDGE CRANE W/ 60T CAPACITY IS USED TO DISASSEMBLE EQUIP ON T'S DECK OR LOAD EQUIP ONTO CORE TROLLEY FOR TRANSFER TO HELIDECK. CRANE ALSO USED TO TRANSFER EQUIP THRU DECK HATCH TO/FROM MODULE AUX MACH'Y DECK.
2. TROLLEY CARRIES EQUIP FROM MODULE TO CORE ELEVATOR. ELEVATOR LIFTS TROLLEY TO NEAR CORE DECK & TROLLEY IS TRANSFERRED TO CORE ACCESS TRUNK ELEVATOR AND THEN TO HELIDECK.

Fig. 4.4-4 Handling Equipment Arrangement, 400-MW(e) Spar, Module Turbine-Generator Deck

MODULE AUXILIARY EQUIPMENT HANDLING

1. ROTATING BRIDGE CRANE - 30 T CAPACITY IS USED FOR AUX MACHY MAINT AND TO TRANSFER EQUIP AREA UNDER T-G DECK HATCH. T-G BRIDGE CRANE LIFTS EQUIP THRU DECK HATCH FOR TRANSPORT TO HELIDECK.

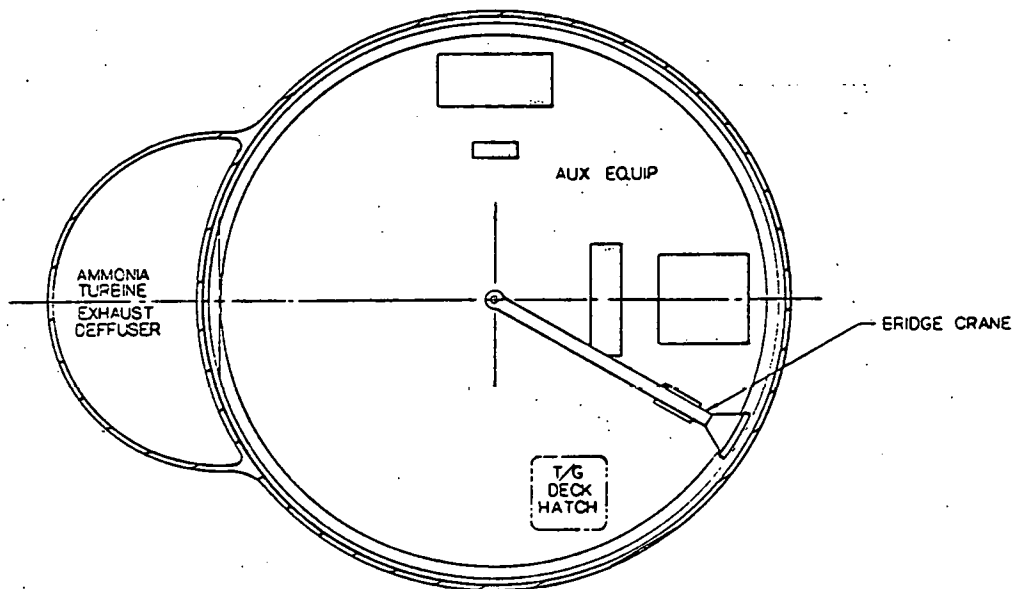
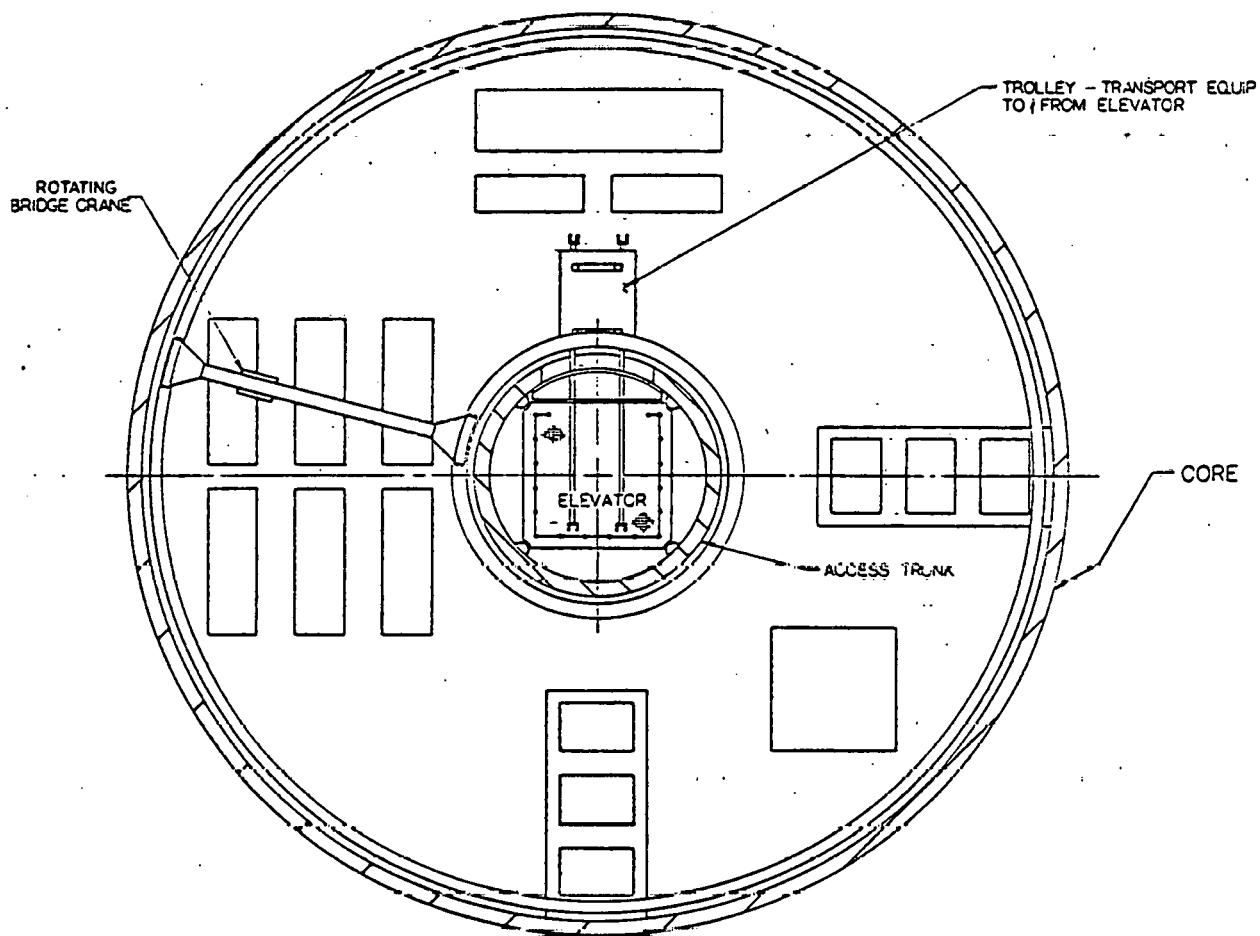


Fig. 4.4-5 Handling Equipment Arrangement, 400-MW(e) Spar, Module Auxiliary Equipment Deck

CORE DECK HANDLING EQUIPMENT

1. TROLLEY CARRIES EQUIP TO & FROM ACCESS TRUNK TO CORE DECK. A ROTATING BRIDGE CRANE OF 60 T CAPACITY UPTS EQUIP TO & FROM TROLLEY TO POSITION ON CORE DECK.
2. A WATERTIGHT, HYDRAULICALLY ACTUATED DOOR (NOT SHOWN) REMAINS CLOSED WHEN CORE DECK UNMANNED.

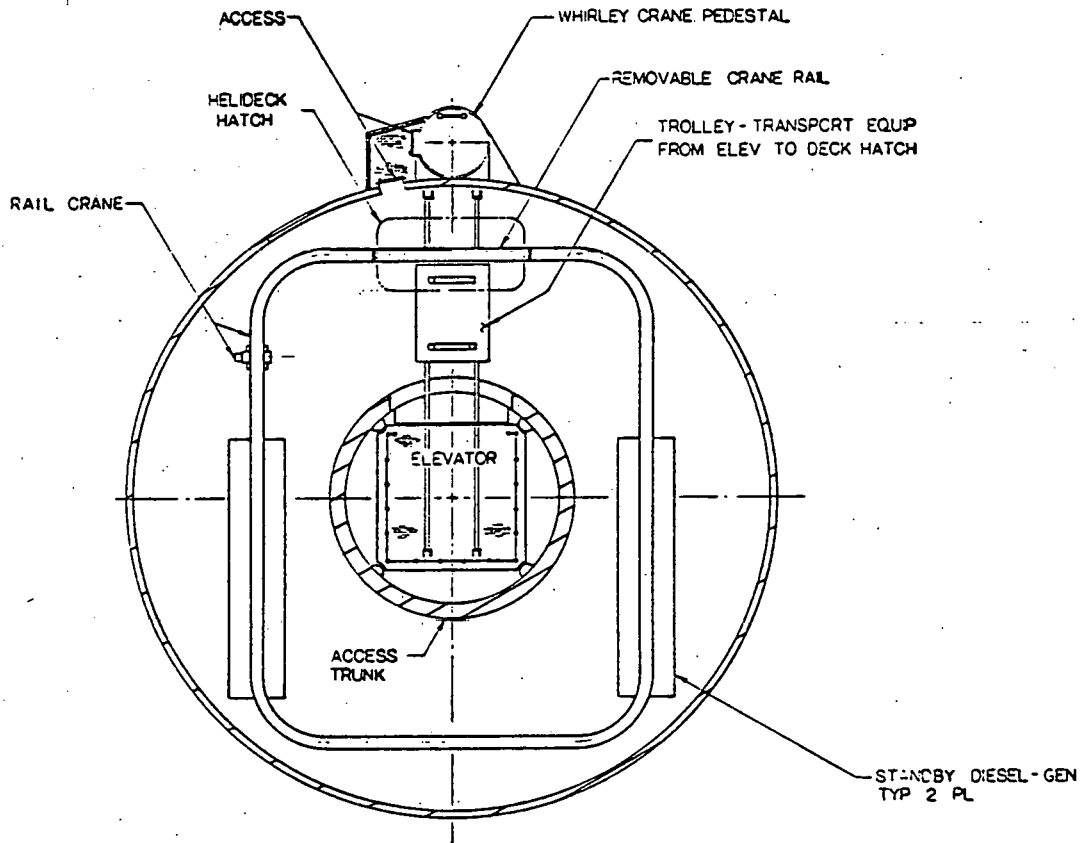


CORE DECK HANDLING EQUIPMENT  
TYPICAL DECKS 1-7

Fig. 4.4-6 Handling Equipment Arrangement, 400-MW(e) Spar,  
Core Deck Handling Equipment

SUPERSTRUC DECK HANDLING EQUIPMENT

1. EQUIP FROM BELOW IS CARRIED BY THE ACCESS TRUNK ELEV TO THE SUPERSTRUC DECK. HEAVY EQUIP THAT MUST BE CRANE LIFTED IS PLACED ON TROLLEY & ROLLED UNDER HELIDECK HATCH. CRANE RAIL IS REMOVED & EQUIP IS LIFTED THRU HATCH BY HELI-DECK CRANE.
2. A 3-TON POWERED RAIL CRANE IS USED FOR MAINT ON DIESEL-GEN.



CORE SUPERSTRUCTURE DECK  
(121M ABL)

Fig. 4.4-7 Handling Equipment Arrangement, 400-MW(e) Spar, Core Superstructure Deck

HELIDECK CRANE

- 1 A 40 T VARIABLE RADIUS CRANE IS MOUNTED ON THE EDGE OF THE HELIDECK FOR OFF LOADING WORK BOATS & BRINGING EQUIP TO THE HELIDECK.
- 2 WHEN NOT IN USE THE CRANE BOOM IS LOWERED AND SECURED TO THE EDGE OF THE HELIDECK FOR HELICOPTER CLEARANCE.

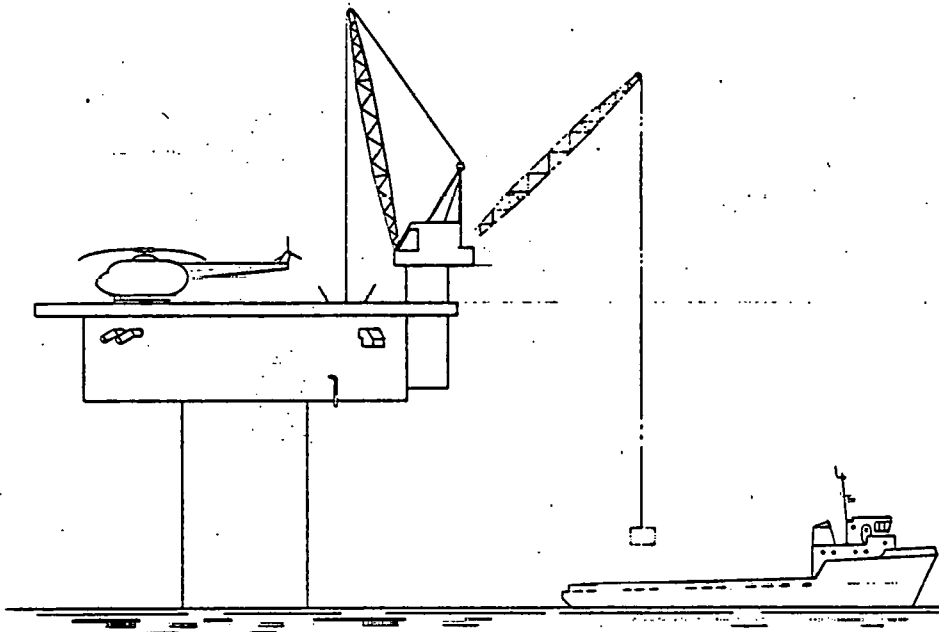


Fig. 4.4-8 Handling Equipment Arrangement, 400-MW(e) Spar, Helideck Crane

### Ancillary Systems

The Firefighting System will consist of fire pumps, piping and fire water hoses at stations located throughout the platform, a central CO<sub>2</sub> system, and small hand-operated CO<sub>2</sub> canisters at several locations.

The Compressed Air System located within the core, includes high and low pressure air compressors, an air dryer, distribution piping and equipment attachment stations.

The Hydraulic Pressure System consists of hydraulic pumps and accumulators, located in the core, supplying pressure through piping to the various hydraulic equipment.

Workshops and Scientific Work Spaces are located within the core structure.

### Special Purpose Systems

The power plant Start-up System consists of a power cable extending from a service vessel to the top of the column, connecting to the platform cable which carries start-up power down to the power plant.

The Bilge and Ballast Systems contain pumps and piping in both the core and modules to empty the bilges and fill or empty the water ballast tanks.

## 4.5 STRUCTURAL ARRANGEMENTS

The structural system for the spar core is represented by the sketch shown in Figure 4.5-1. It consists of a hollow core that provides the necessary buoyancy for the platform to float, a system of structural framing below this core (much like the strongback for lifting heavy weight by a crane) a system of stiffened hangers below the strongback, and the foundation structure below the hangers for the support of the cold water pipe and the power modules.

The spar platform consists of eight modules attached to the core. The structural arrangements are shown in Figures 4.5-2 through 4.5-4.

### Module Design

The construction and floatout stages of the module production appear to govern the design, although dynamic forces in its final vertical position during operation also need to be examined. The continuity of the shell is important as are the weight and floating capacity. Design iteration among space requirements, weight of structure and statical loading criteria has concluded that the cylindrical shell is a logical solution. Openings have to be surrounded with ringbeams for structural continuity in stress transfer. The structural concept also emphasizes the simplicity of connection of the module to the core. The vertical heat exchanger module takes a simple cylindrical shell form. The horizontal heat exchanger module, on the other hand, consists of mainly a strong ringbeam system. In both modules, buoyancy chambers are made independent structures, which are in the form of thin shell torus or cylinders. The loss of one of the buoyancy structures should not affect flotation capacity nor cause damage to the main structure. Turbo-generator compartments are designed to resist external water pressure. An access shaft with depressurization space and gates have been provided for each module.

### Core Design

The shape of the lower part of the core is dictated by the construction procedure.

The foundation ring is self-buoyant and contains temporary buoyancy cells. To avoid obstruction of the cold water flow path, columns are built on the outer periphery of the ring structure, which provide connection between the foundation ring and the core. The columns will transfer loads to shear walls situated between the access shafts. Those shear walls enter the lower core dome and in turn transfer forces onto the main hull. The shell thickness of the main hull (core) is derived from the water pressure and core radius. The safety requirements are met with a thick single wall as well as with thin

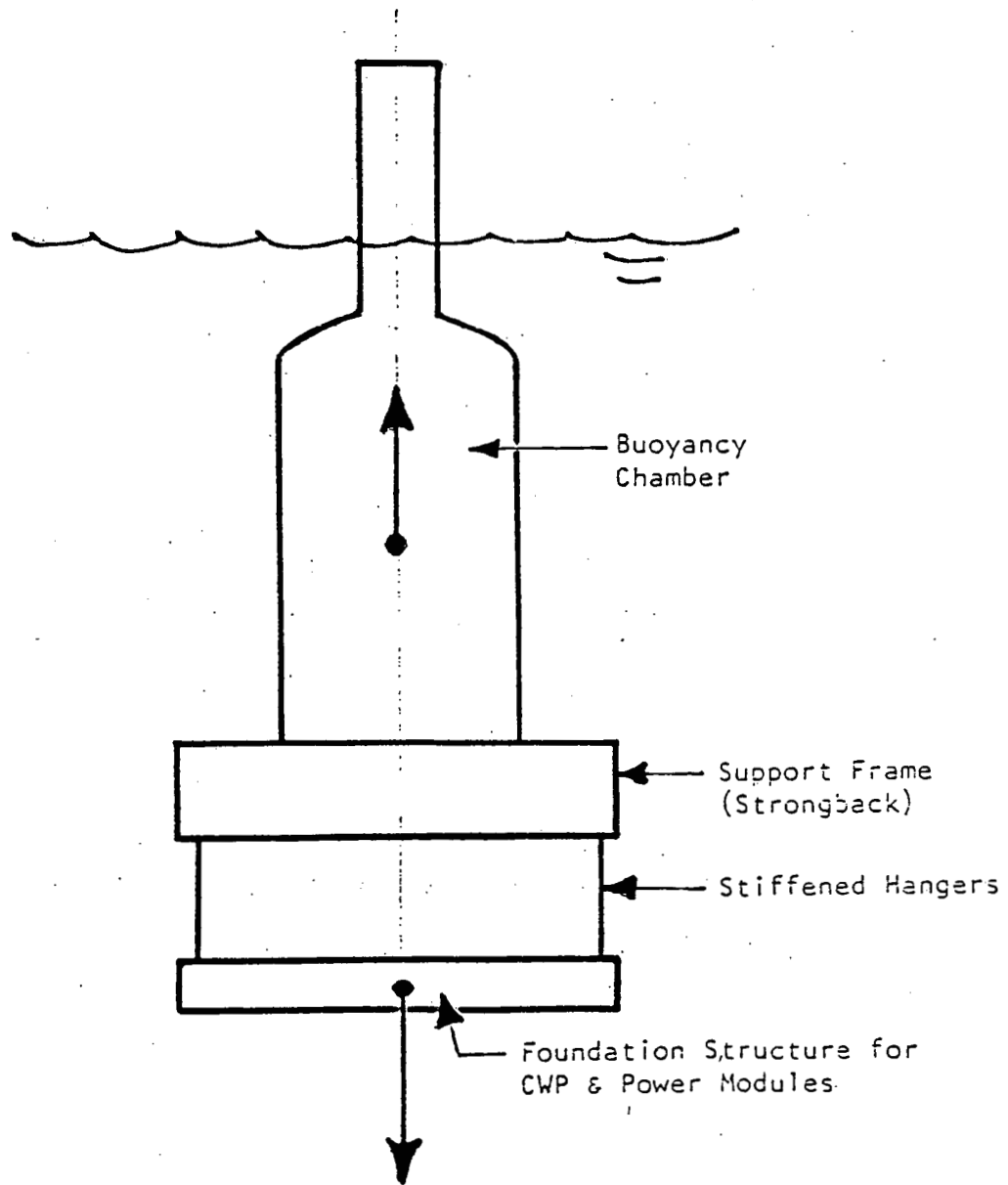


Fig. 4.5-1 Spar Platform Structural System

double walls in the core design. Within the core structure, there are several floor slabs which are supported by elevator shaft, columns and outer shell.

A thick top dome shell is provided at the top of the core structure to protect against accidental punching of form. The elevator shaft to the surface has little collision resistance and, therefore, is protected by a buoy fence, see Figure 4.1-1.

The design and analysis of the concrete shell for the 400 MW(e) spar are based on the following criteria and assumptions.

### Material

Materials are linearly elastic, and have the following properties.

Concrete:  $f'_c = 5,000$  psi  
 $W^* = 130$  lbs/ft<sup>3</sup> =  $2.08$  T/m<sup>3</sup>  
 $E = 33 (W)^{1.5}$  5000 =  $3,500,000$  psi

Tendon:  $f'_s = 270,000$  psi  
 $E_s = 27,000,000$  psi  
 \* Lightweight concrete unit weight includes 110 pcf for concrete, 5 pcf for steel reinforcement, and 15 lbs, long-term water absorption.

Rebars:  $F_y = 60,000$  psi  
 $E_s = 29,000,000$  psi

### Allowable Stresses

Compression:  $f = 0.45 f'_c = 2,250$  psi =  $160$  kg/cm<sup>2</sup>

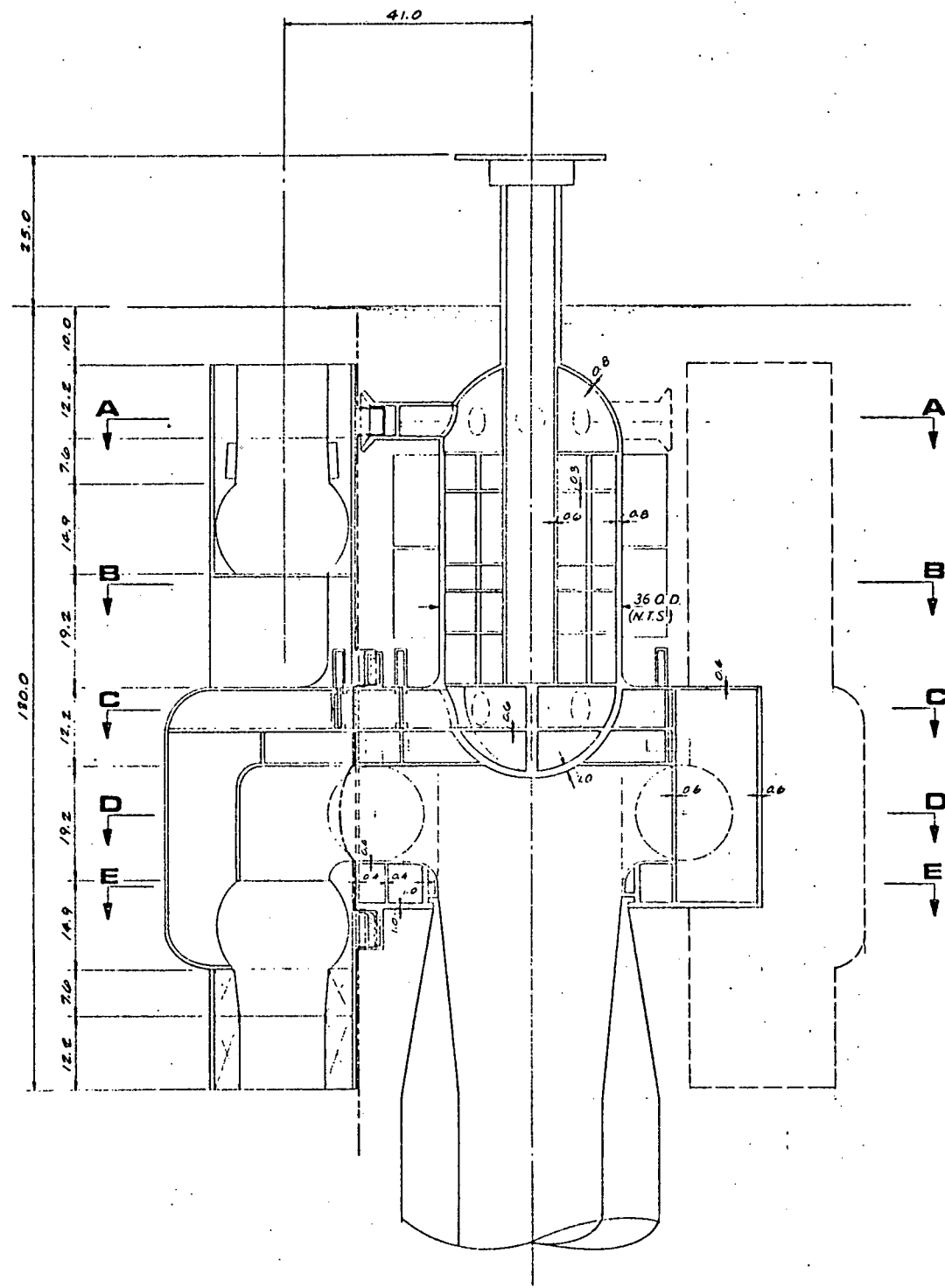
Shear:  $v = 27$  kg/cm<sup>2</sup> =  $378$  psi

### Loading Criteria

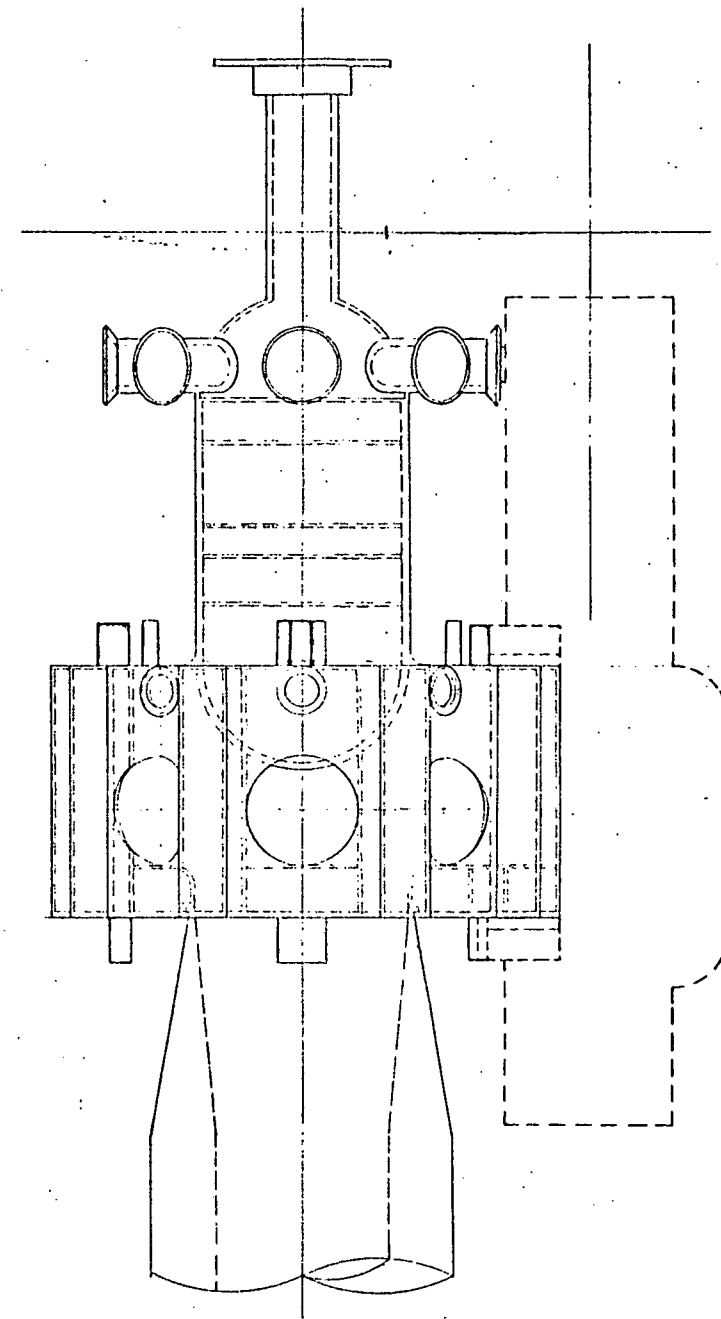
Hydrostatic pressure head:  $p = \lambda \times H$  (H = Draft)  
 Density saltwater:  $\lambda = 1.024$  T/m<sup>3</sup>  
 Floor slab loading:  $q = 1$  T/m<sup>2</sup>  
 Buoyancy of heat exchanger: 2500 T each  
 Cold water pipe: 3000 T  
 Concrete weight: See Materials

### Safety Requirements

Same as for ship design.



SECTION F



ELEVATION

Fig. 4.5-2

SCALE 1:800  
DIMENSIONS IN METERS

NO	REVISION	DATE
----	----------	------



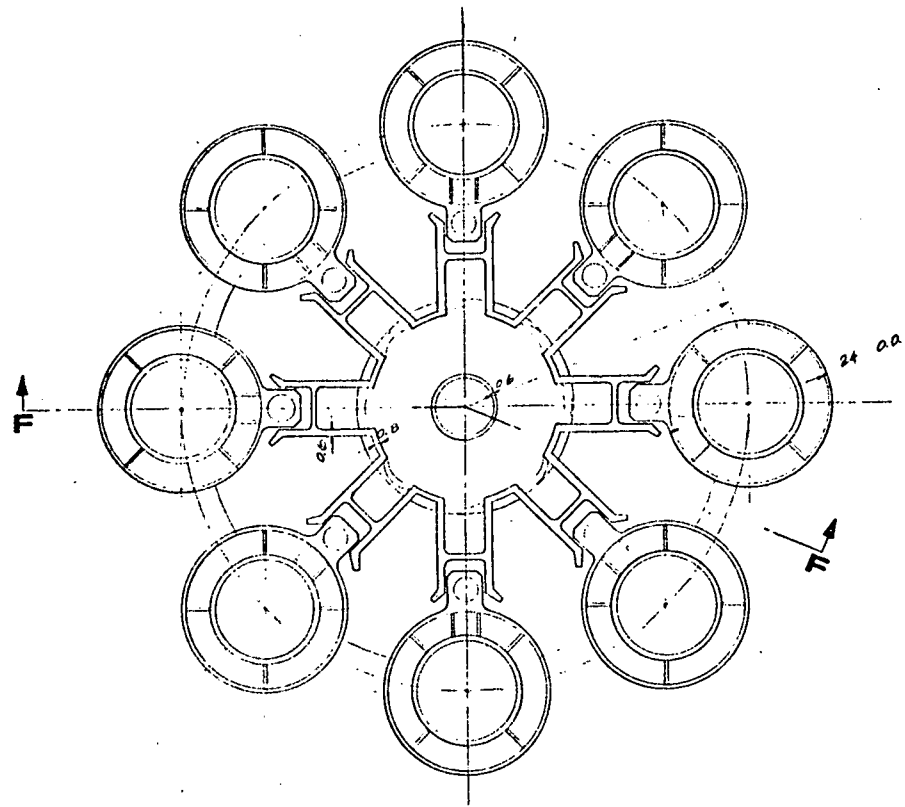
STRUCTURAL ENGINEERING  
315 Bay St., San Francisco, Ca 94133 Tel. (415) 982-1050

Issued For	Date	By

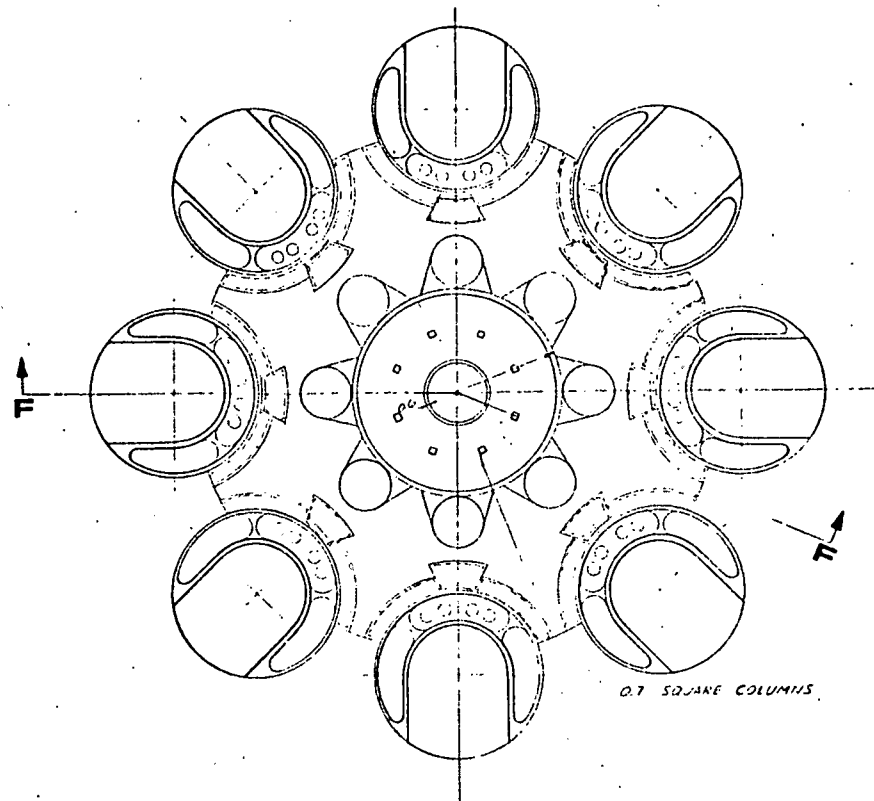
SHEET TITLE **CONCRETE STRUCTURAL ARRANGEMENT**  
**400 MWe NET O.T.E.C. SPAR**  
PROJECT: **O.T.E.C. PLATFORM CONFIGURATION & INTEGRATION**  
**LOCKHEED MISSILES AND SPACE CO. SUNNYVALE, CA.**

SHEET NO:

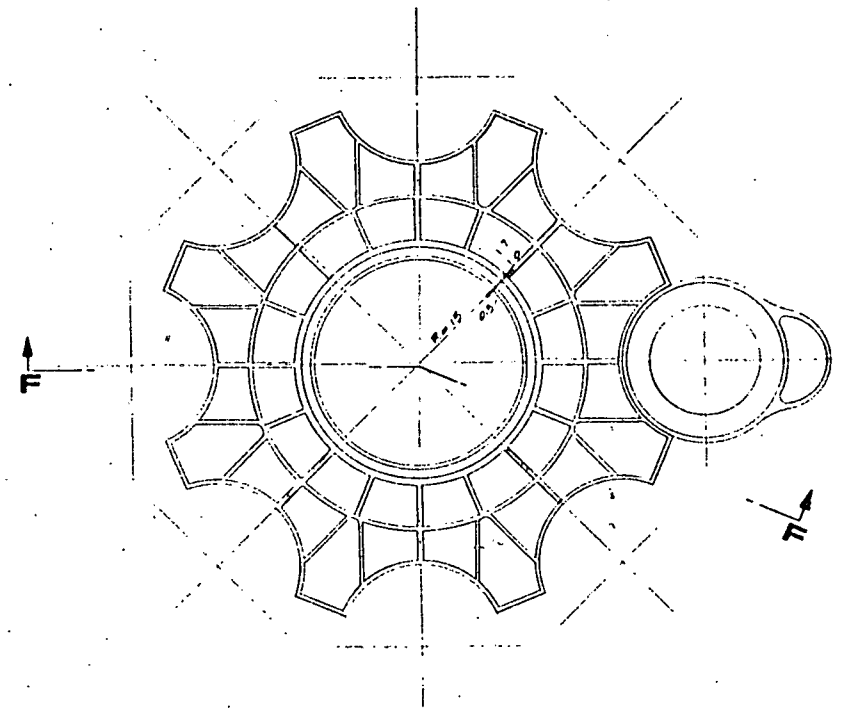
**2-3**



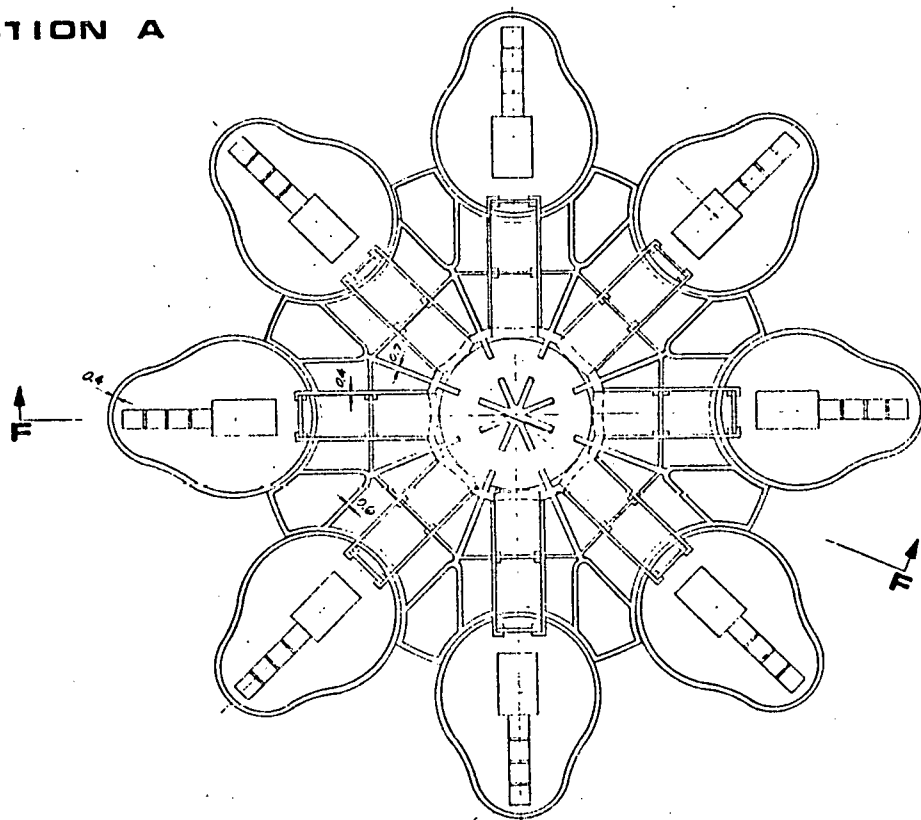
SECTION A



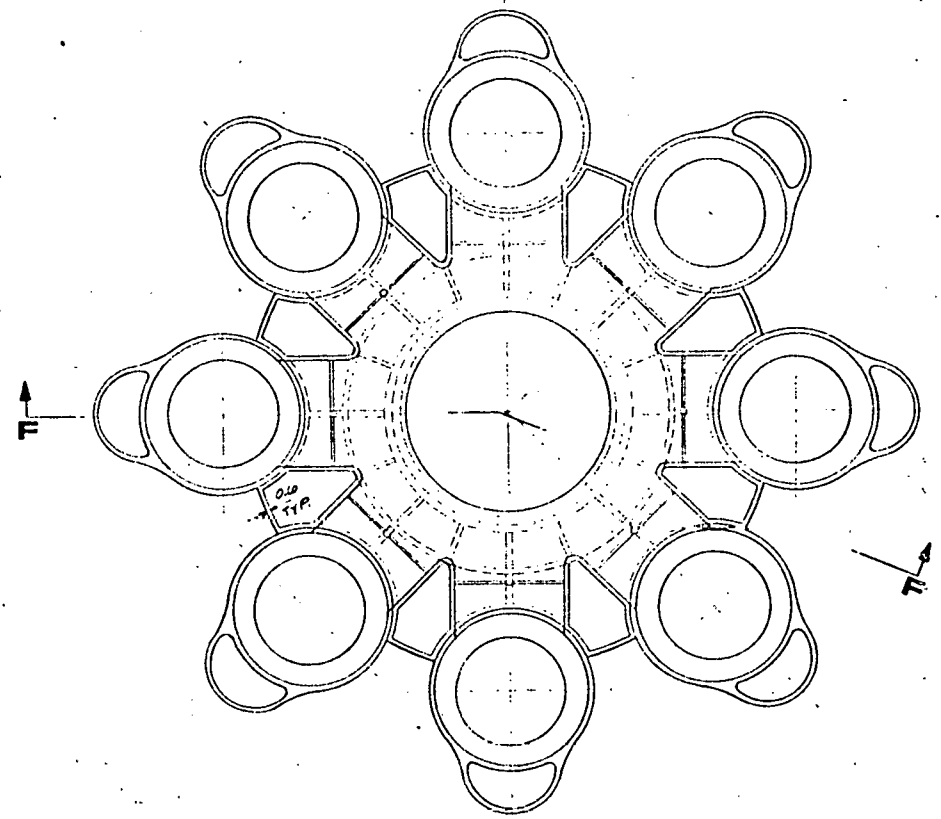
SECTION B



SECTION E



SECTION C



SECTION D

SCALE 1:500  
DIMENSIONS IN METERS

Fig. 4.5-3

NO	REVISION	DATE



STRUCTURAL ENGINEERING  
315 Bay St., San Francisco, Ca 94133 Tel: 415/982-1050

Issued For	Date	By

SHEET TITLE: **HORIZONTAL SECTIONS**  
**400 MWe NET O.T.E.C. SPAR**  
PROJECT: **O.T.E.C. PLATFORM CONFIGURATION & INTEGRATION**  
**LOCKHEED MISSILES AND SPACE CO. SUNNYVALE, CA.**

SHEET NO

2-4



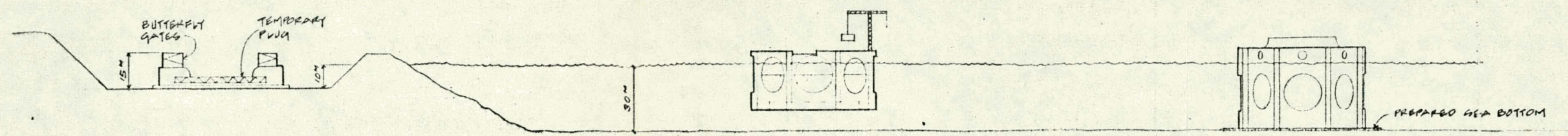
## 4.6 CONSTRUCTION

The construction of the spar platform is performed in the vertical (upright) position. The absence of buoyancy capability in the lower portion of the core makes a problem for floatout from a shallow graving basin. To create the required buoyancy, all openings to the cold water plenum are closed, converting the plenum into a temporary buoyancy chamber. The spar is constructed in the following sequence.

### Fig 4.6-1, 4.6-2

- STEP 1. 1-4 Construct cold water plenum structure to slightly above design floatout draft of 10 M (33 ft). Plug the openings temporarily to enable this lower portion of the spar to the floated out from the graving basin to the deep wet dock.
- STEP 2. 5-6 Continue construction upward in deep wet dock until it reaches a level which is slightly above the water surface when the structure is sunk to the bottom.
- STEP 3. 7. Flood cold water plenum to lower structure to prepared bed on the bottom of wet dock.
- STEP 4. 8. Continue construction upward until completion using slip-form method as far as possible. It will be necessary to hollow out solid structural sections in order to reduce weight for floatout purposes. The hollow sections will be concreted after the platform has arrived on site.
- STEP 5. 9-10 Attach buoyancy tanks around cold water plenum, blow plenum and buoyancy tanks to float platform for tow-out to site. Fill voids in structure with concrete. Flood plenum and buoyancy tanks to lower spar to natural floating position.
- STEP 6. Dismantle and remove temporary plugs and buoyancy tanks.

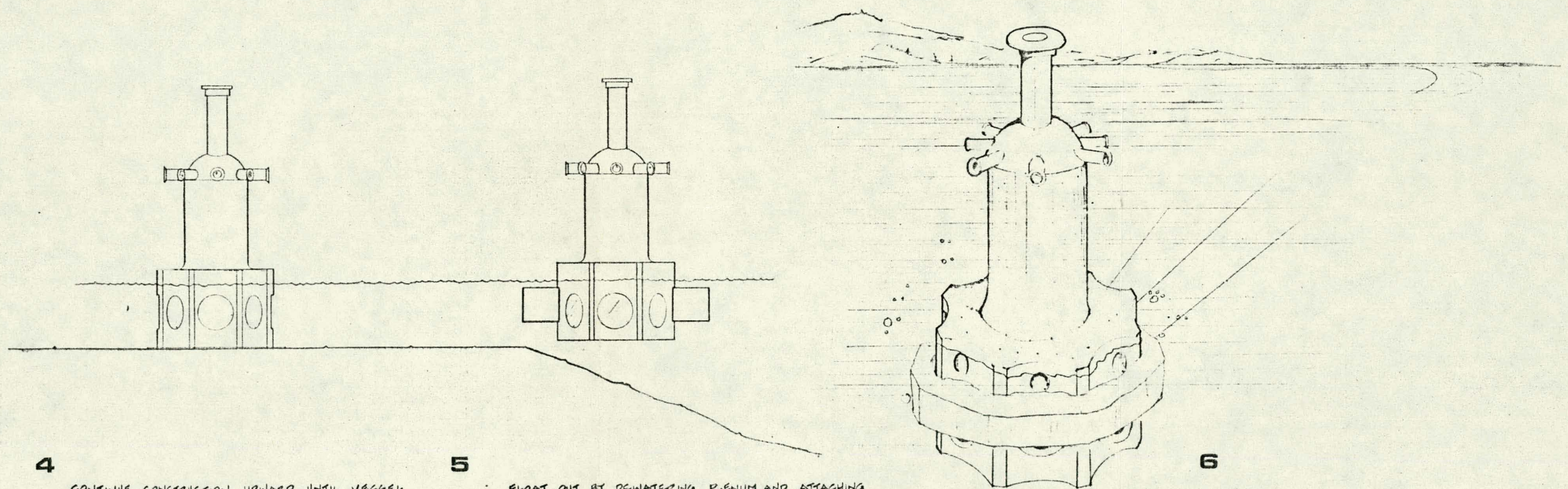
# OTEC HULL - PROPOSED CONSTRUCTION SEQUENCE OF SPAR PLATFORM USING GRAVING BASIN METHOD



**1**  
 PREPARE GRAVING BASIN WITH TON OUT DRAFT OF 10 M. CONSTRUCT LOWER PORTION OF CORE TO ABOUT 10M. MAKE IT INTO A TEMPORARY BUOYANCY CHAMBER BY CLOSING ALL SIDE OPENINGS INTO GRIDDED BUTTERFLY GATES AND CENTER WELL WITH TEMPORARY PLUGS. PROVIDE SUMP TO DEWATER TEMPORARY BUOYANCY CHAMBER AS NECESSARY

**2**  
 OPEN EMBANKMENT TO LET IN WATER. TOW BOTTOM CORE PORTION TO DEEPER 30M SHELTERED WATER TO CONTINUE CONSTRUCTION

**3**  
 WHEN CONSTRUCTION REACHES APPROXIMATELY 35M, THEN LOWER THE STRUCTURE TO PREPARED SEA BOTTOM



**4**  
 CONTINUE CONSTRUCTION UPWARD UNTIL VESSEL IS COMPLETED. MAKE VESSEL AS LIGHT AS POSSIBLE TO FACILITATE FLOAT-OUT OPERATION. THICK CONCRETE SECTIONS MAY BE CONSTRUCTED WITH HOLLOW-OUT CORES WHICH ARE GRAITED WATER, WHEN VESSEL IS IN DEEPER WATER.

**5**  
 FLOAT OUT BY DEWATERING PLENUM AND ATTACHING BUOYANCY TANKS

**6**

Fig. 4.6-1

NO	REVISION	DATE
----	----------	------

**TYIN** INTERNATIONAL  
 STRUCTURAL ENGINEERING  
 315 Bay St., San Francisco, Ca 94133 Tel (415) 982-1050

Issued For	Date	By

SHEET TITLE: **400 MWe NET O.T.E.C. SPAR**  
 PROJECT: **O.T.E.C. PLATFORM CONFIGURATION & INTEGRATION**  
**LOCKHEED MISSILES AND SPACE CO. SUNNYVALE, CA.**

SHEET NO  
**2-6**

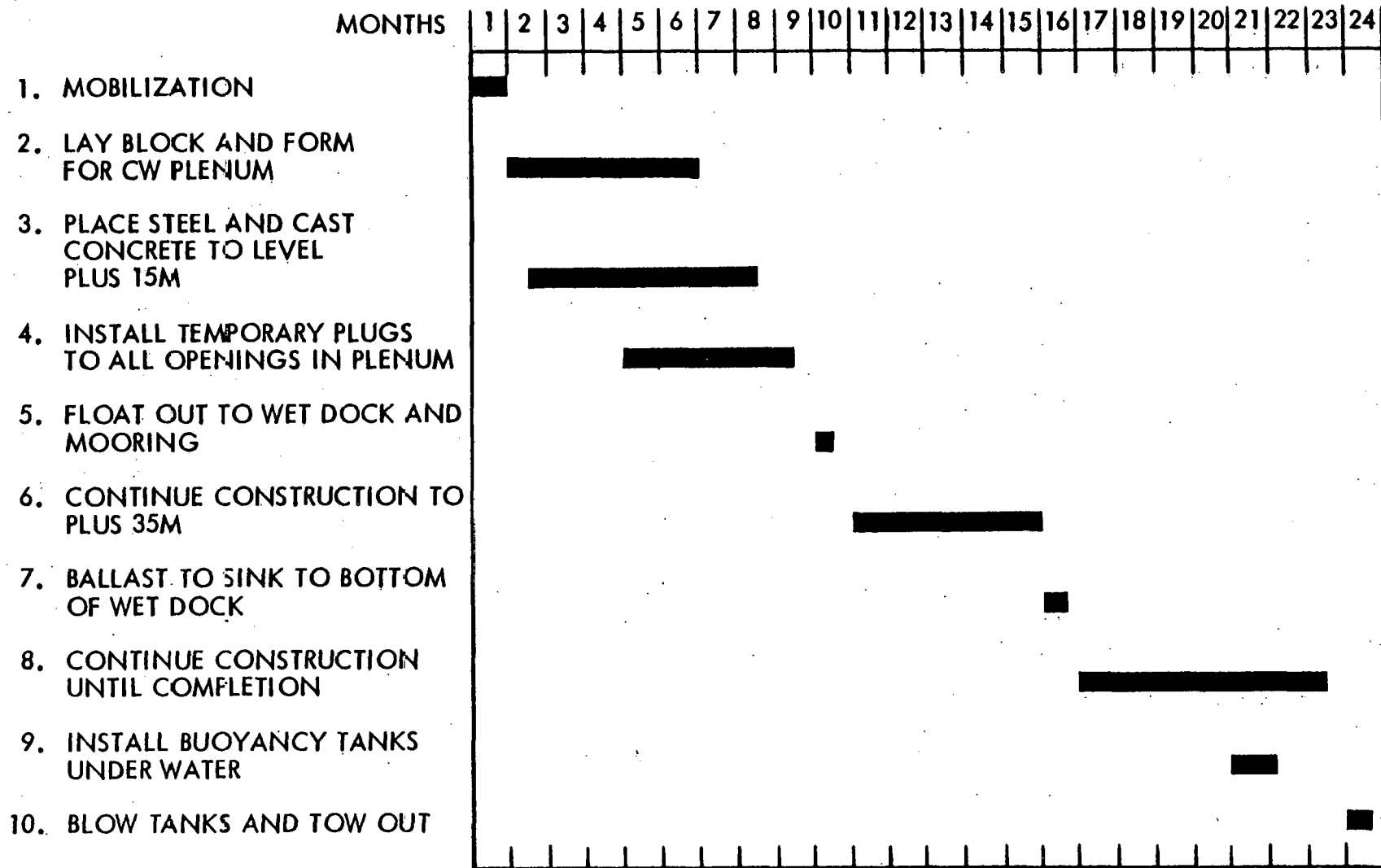


Fig. 4.6-2 Construction Schedule for Structural Concrete – Spar Hull

Table 4.6-1

HULL CONSTRUCTION COSTS FOR SPAR - FIRST UNIT COSTS

Item	Price/cu. yd.	Price/m <sup>3</sup>	M <sup>3</sup>	\$1,000
Shell PIP	1,090	1,425	61,507	87,647
Shell PC	750	981	-	-
Walls	750	981	4,355	4,272
Deck	750	981	1,526	1,497
Columns Stability C	1,090	1,425	596	849
<b>TOTAL</b>	<b>(1061 Ave.)</b>	<b>(1387 Ave.)</b>	<b>67,984</b>	<b>94,265</b>

## 4.7 DEPLOYMENT

### 4.7.1 Core Deployment

The core will be deployed from the final assembly site at a draft of 30 meters (98 feet). At the operational site, all temporary buoyancy spaces will be flooded and all auxiliary buoyancy will be removed. The draft of the core section at this time will be approximately 22 meters less than the operating draft. The center of buoyancy will be about 3 meters above the center of gravity, indicating positive floating stability.

At this point, the rubber-nylon cold water inlet pipe will be either lowered from a pre-installed, stored position in the base, or else brought on location separately and lowered on cables to its position beneath the core. In either case, the CWP seal will be at the base of the core, and the vertical support will extend to the top of the cold water plenum. With the cold water pipe in place, the draft of the core will be about 19 meters less than the operating draft.

Ballast tanks in the base of the central pressure vessel provide assistance in bringing the core down to operating draft. The mooring system is then attached. The tanks are deballasted, and the vertical mooring line forces hold the platform at the operating draft. The vertical force on the mooring lines of 6200 mt positive net buoyancy provides safety in the event of partial flooding during operation.

### 4.7.2 Module Deployment

The module containing horizontal heat exchangers is discussed in this section. Similar deployment procedures apply for the vertical heat exchanger module.

The module will be towed out from the dry-dock to the installation site on its side, with the heat exchanger axes horizontal. Portions of the sea water system will be sealed off as buoyancy chambers to allow passage over the

dry-dock sill.

Buoyancy during the tow will be provided by evacuated ballast tanks and auxiliary buoyancy added at the ends of the module, giving a towing draft of about 15.5 meters (50.9 feet). The auxiliary buoyancy is located such that the module will be stable in this towing position, and is of sufficient magnitude to assure survival of the module in case of damage. A minimum of two 8,000 horsepower tugboats is recommended for the tow.

Upon arrival at the operational site, the following procedure is followed, Figure 4.7-1.

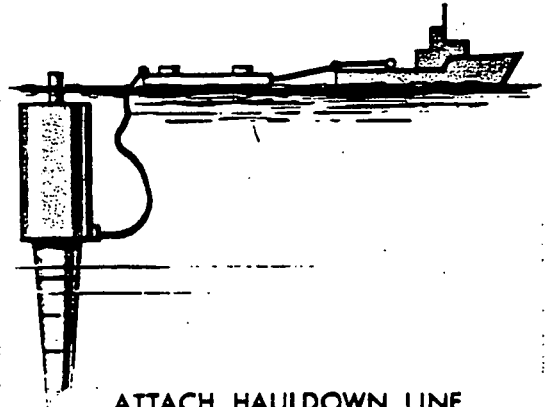
1. Lines are passed from pulling locations on the core to corresponding positions on the module.
2. Auxiliary buoyancy is removed from the cold water end of the module and the module is ballasted to a vertical position below the surface, with only the top auxiliary buoyancy extending through the surface.
3. The top of the module is controlled with lines to tugs, while the bottom is drawn in by cable to the bottom of the core.
4. The module cold water connection is seated on the core base structure, and the module is ballasted to provide bearing force on the seat.
5. The top of the module is drawn in with the upper cable. The module is secured with a positive hydraulically operated fastening system located above the core base structure.
6. Ballast is adjusted to provide nearly neutral buoyancy of the module without auxiliary buoyancy.
7. Auxiliary buoyancy at the upper end of the module is removed, and the module is ready for operation.

#### 4.7.3 CWP and Mooring Deployment

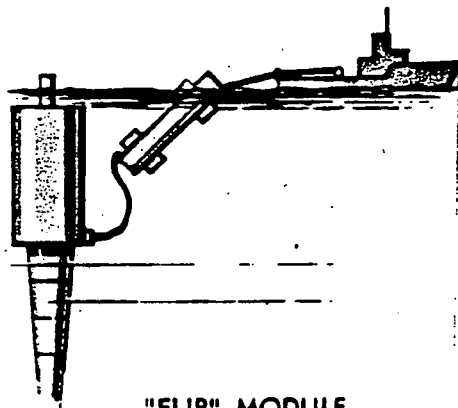
The flexible, nylon fabric CWP and combined mooring are deployed by the



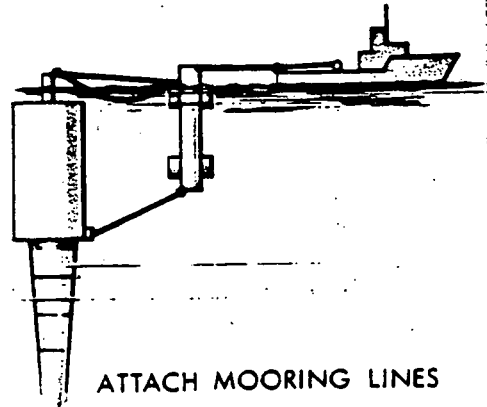
MODULE UNDER TOW



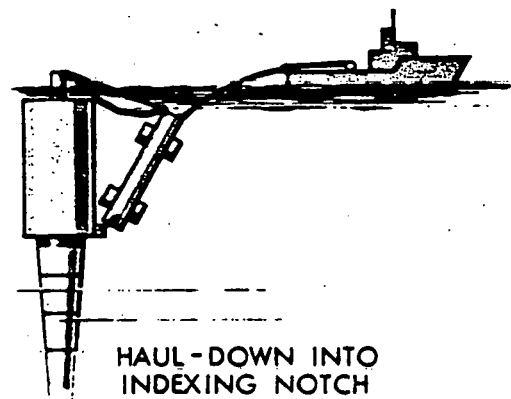
ATTACH HAULDOWN LINE



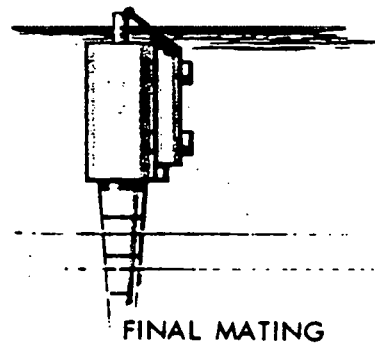
"FLIP" MODULE



ATTACH MOORING LINES



HAUL-DOWN INTO INDEXING NOTCH



FINAL MATING

Fig. 4.7-1 Module Deployment

following sequence, Figures 4.7-2(a), 4.7-2(b), and 4.7-2(c).

Step 1. The CWP and inlet screen, manufactured and assembled at a shoreside facility, are placed on barges for transit to site. The dimensions of CWP in its deflated configuration and the inlet screen are large, requiring three ocean-going barges lashed together.

Step 2. When the CWP arrives on site, prerigged inhaul lines from the core are transferred by a crane barge and connected to the CWP flange. The inhaul lines connected to the flange pass through the bottom of the cold water plenum in the core and out cold water discharge ports to deck winches on the crane barge.

Step 3. After the inhaul lines are attached, the flange is lifted from its barge and lowered into a position below the core for inhaul. The inhaul lines connected to winches on the crane barge are tensioned and haul in the flange to the core base. The lines from the crane barge used to lower the flange from its barge are disconnected by acoustic command to hydraulic line releases on the flange and retrieved. When the flange is lowered the CWP is paid out by releasing its securing lines to the barges. Additional tag lines are attached to the CWP from tuggers on the crane barge to help support its weight. A guideline attached near the CWP flange and connected to a tug helps guide the flange into the core base against any possible current. Underwater operations are observed by RCV television cameras. When the flange is hauled into the core, pins on the flange engage hydraulic wellhead connectors that clamp around mating grooves on the pin and secure the CWP to the core. The wellhead connectors are hydraulically actuated, self-locking sub-sea connectors used in the offshore oil industry to connect the BOP to the wellhead. Hydraulic pressure is used to lock or unlock the connector. A shallow taper on the locking segments makes the connector self-locking and eliminates the need for hydraulic pressure to hold the connector in the locked position.

Step 4. After the CWP is attached to the core, the anchor previously towed

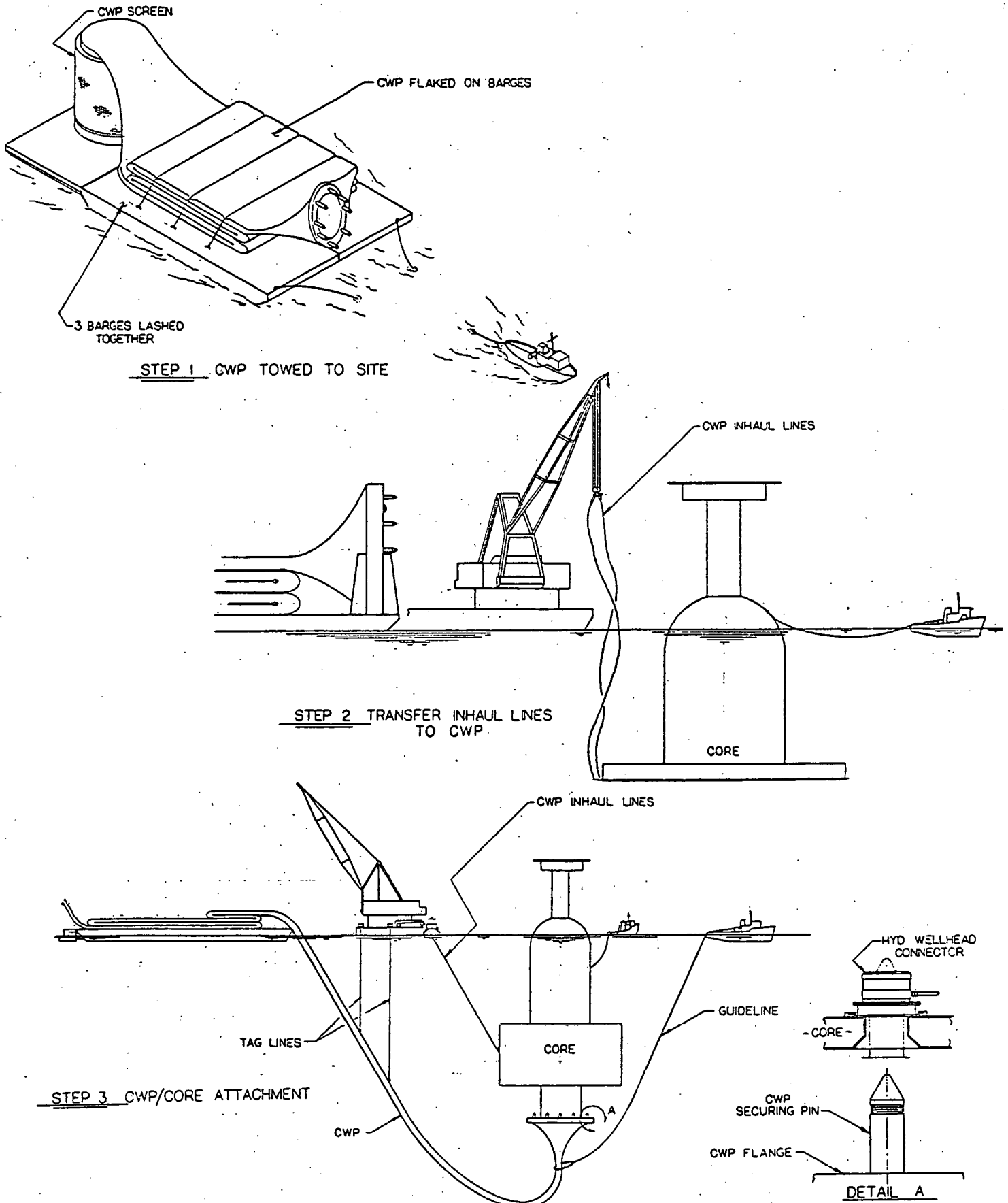


Fig. 4.7-2 Spar Cold Water Pipe and Module Deployment Sequence  
4-42

to the site is positioned between two crane barges. CWP mooring lines, anchor lowering lines, and cement hoses for anchor ballasting are attached to the floating anchor. The anchor is then flooded and lowered by special deck winches on the crane barges. The mooring lines and cement hoses are paid out as the anchor is lowered. The barges maintain station by dynamic positioning.

Step 5. When the anchor is lowered to a depth of 400 M, the free end of the mooring lines are passed to the CWP barges and attached to the bottom of the screen.

Step 6. The screen and its barge are positioned between the crane barges and lifted from its barge. The CWP and screen transport barges are removed and the screen is lowered to just above the surface. Lines from deck winches on the crane barges are then attached to the top of the screen. The screen is lowered by the cranes until these lowering lines take up the weight of the screen. The hoist lines from the cranes are then released. While the screen is supported near the surface, the anchor is lowered to the full extent of the mooring lines until the new lowering lines attached to the screen carry the combined load of the anchor, mooring lines and screen. Lowering lines connected to the anchor are disconnected and retrieved by the crane barges.

Step 7. The CWP, screen, and anchor are now ready to be lowered beneath the core. As the screen is lowered and the CWP begins to move under the core, the crane barges progress toward the core until the screen is lowered completely and the barges straddle both sides of the core. During lowering, the core is dynamically positioned relative to the crane barges by tugs.

Step 8. Before the anchor is ballasted with cement, the CWP is pressurized and checked for proper inflation and integrity. After checkout, cement is pumped down to the anchor from the crane barges. As the anchor increases in weight, the mooring lines stretch and pull down the core until the anchor lands on the bottom and the core is at its operating draft. Additional

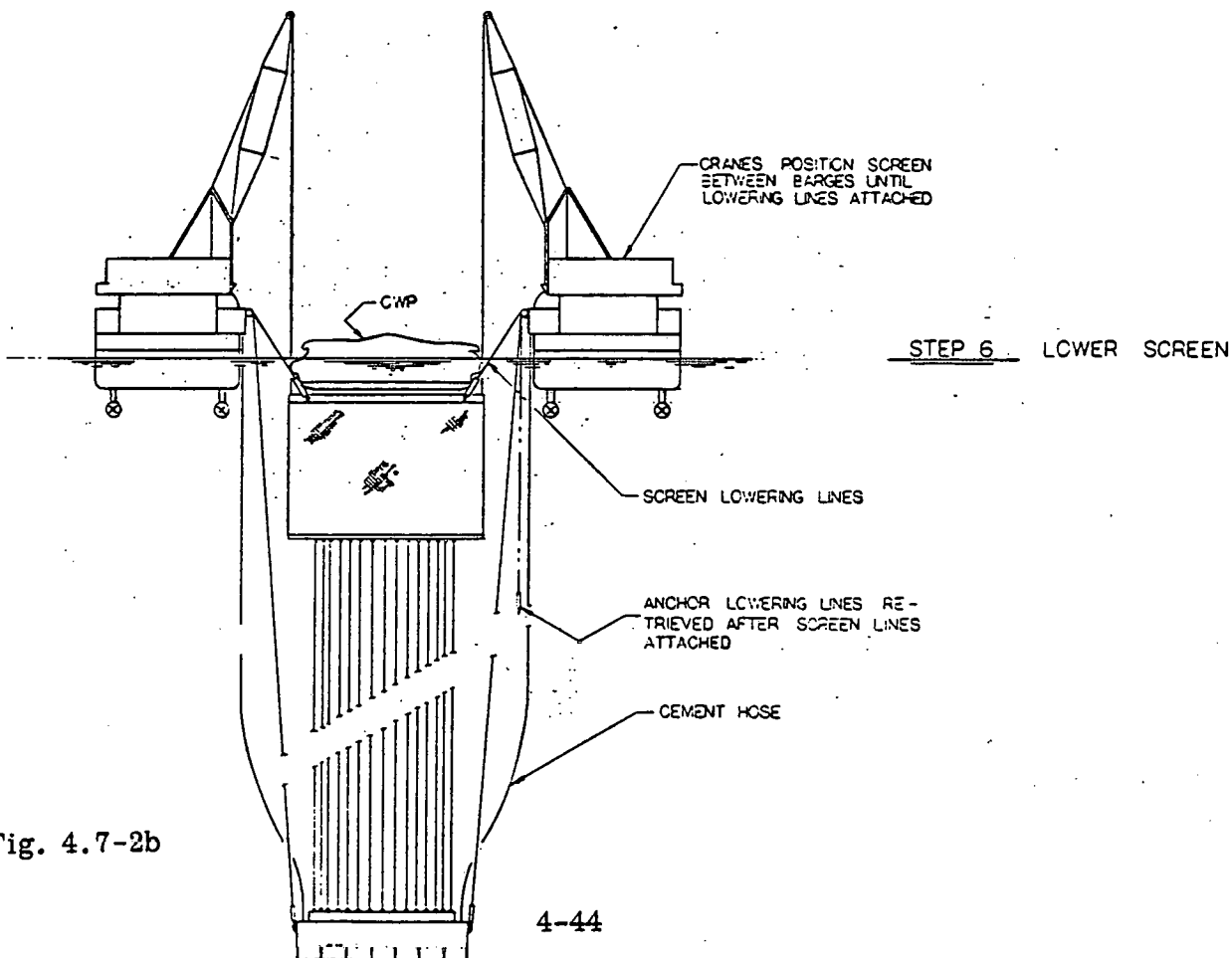
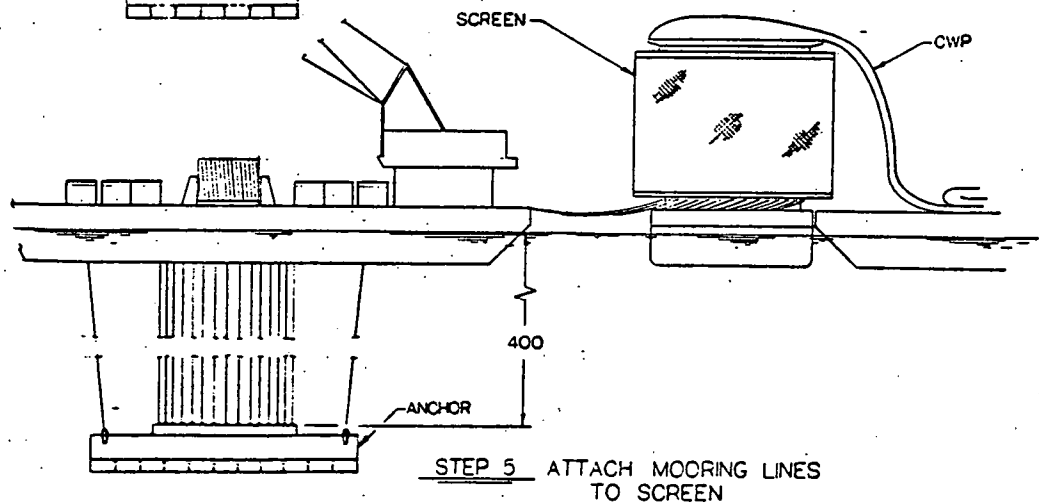
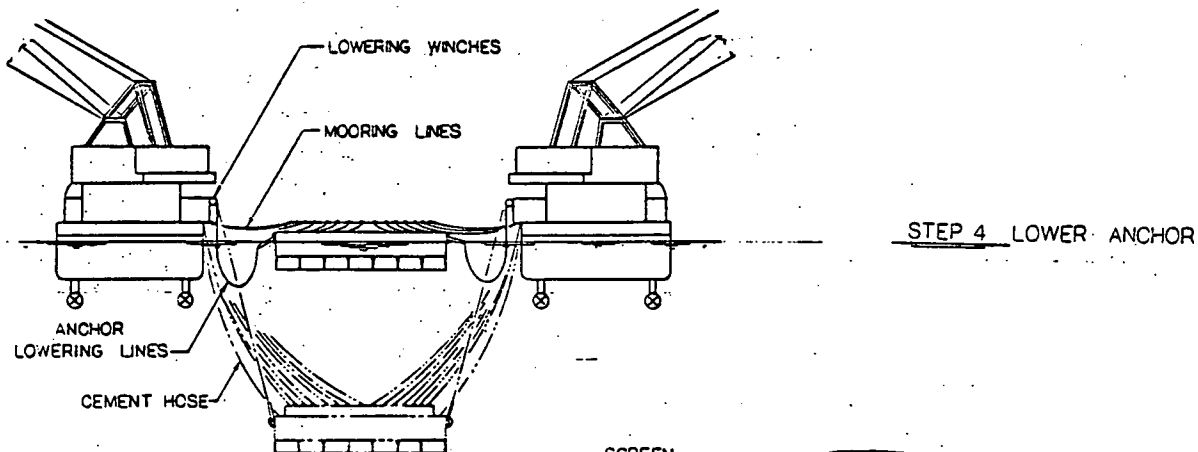
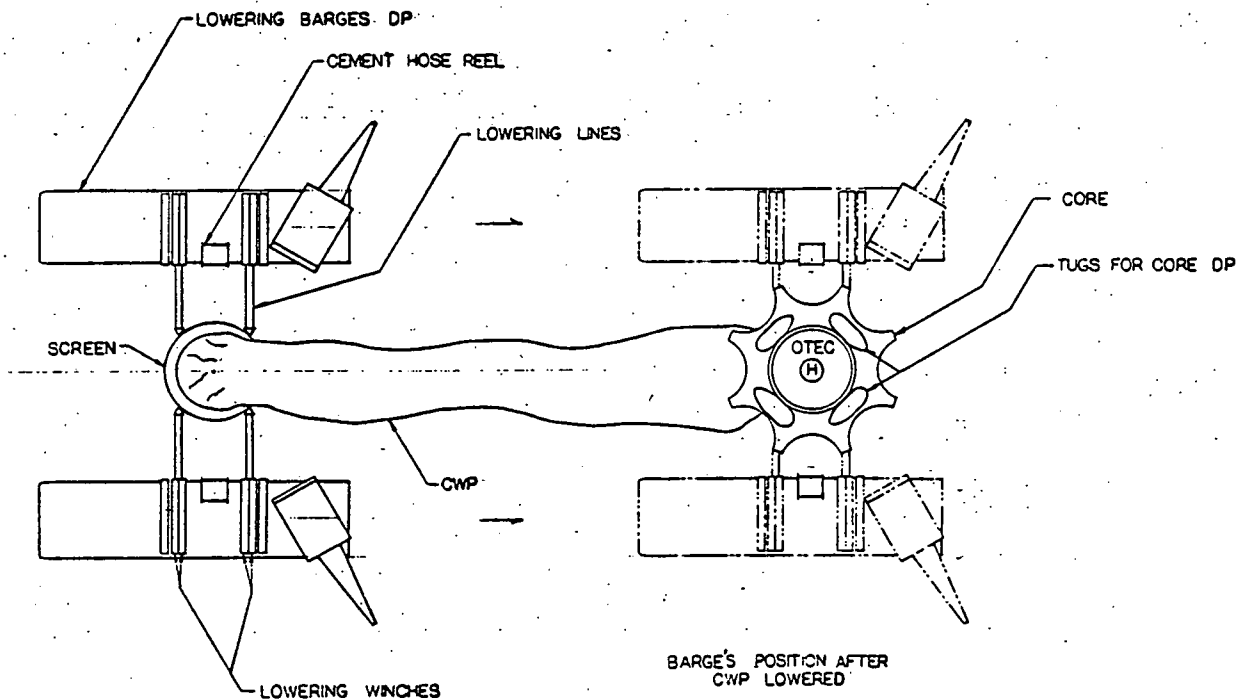


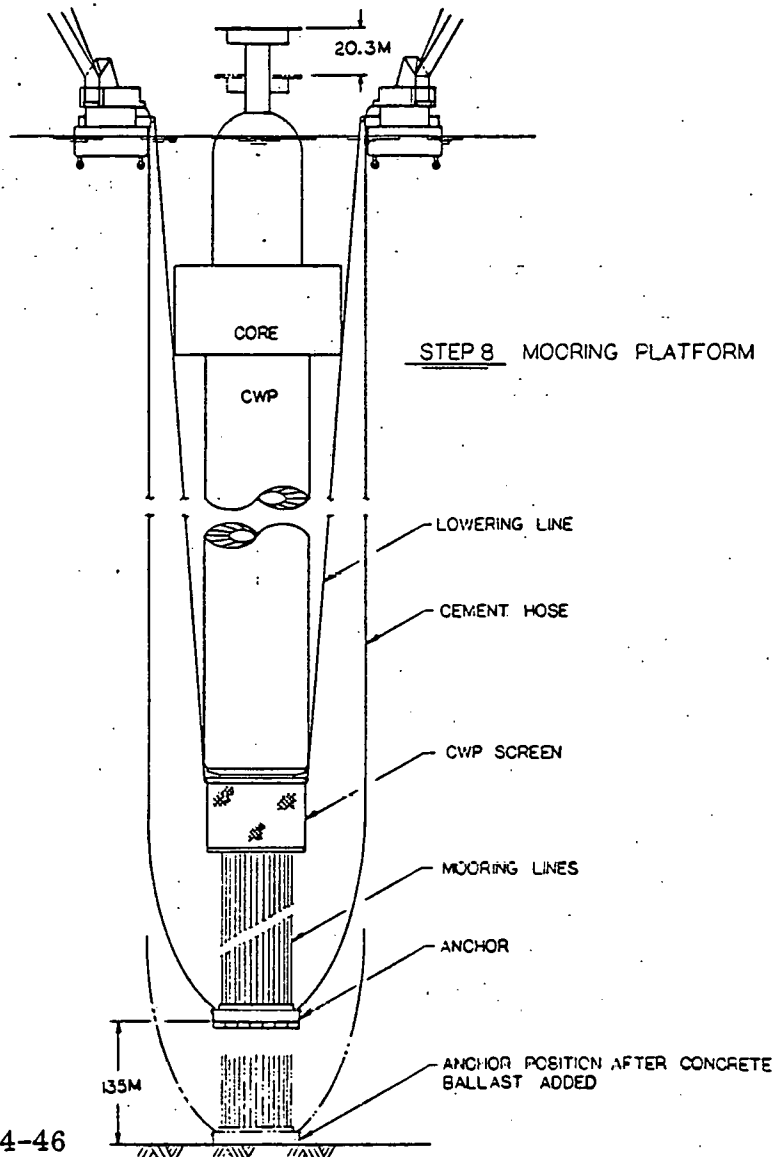
Fig. 4.7-2b

ballasting in the core either positively or negatively may be necessary to achieve proper draft. When the anchor is completely ballasted, the cement hoses and screen lowering lines are released and returned to the barges. The core is now ready for installation of modules.

The equipment (crane, barges and tugs) required for the deployment of the flexible CWP and combined mooring and the time schedule for the operation are presented in Table 4.7-1. A total span of 27 days is required for this task.



**STEP 7** LOWERING CWP/ANCHOR  
PLAN VIEW



**STEP 8** MOORING PLATFORM

Fig. 4.7-2c

TABLE 4.7-1

## TIME TO DEPLOY CWP &amp; MOOR SPAR

Operation (Fig. 4.7-1(a)-(c))	Crane Barges	Tugs		Function	Days
		Function	#		
2. Transfer Inhaul Lines to CWP	1	Core DP	4	Preliminary	1
		CWP Barge	<u>2</u>	Transfer Lines	1
			6		
3. CWP/Core Attachment	1	CWP Barge	6	Preliminary	2
				Attach	1
4. Lower Anchor	2	Core DP	4	Rig-up	4
		CWP Barge	2	Lower	1
		Tow Anchor	<u>2</u>		
			8		
5. Attach Mooring Lines to Screen	2	Core DP	4	Rig-up	4
		CWP Barge	<u>2</u>		
			6		
6. Lower Screen	2	CWP Barge	6	Position	1
				Attach Hoist	1
				Lift/Lower Screen	1
				Attach Screen L.L.	2
				Lower Anchor	1
7. Lower CWP/Anchor	2	Core DP	4	Preliminary	1
				Lower	1
8. Moor Platform	2	Core DP	4	Inflate CWP	2
				Ballast	2
				Retrieve Lines	1
Total Number of Days .....					27

#### 4.8 SUPPORT FACILITIES

Major support facilities for the OTEC 400 MWe (net Spar platform include the following.

- Facilities for module deployment and removal
- Facilities for platform supply
- Facilities for personnel maintenance and transportation

An arrangement of these facilities is presented in Figure 4.8-1.

##### Facilities for Module Deployment and Removal

The drydock required for major module maintenance will be the module construction dry-dock or a similar facility. It will be located as close as possible to the operating site, with necessary cranes, shops, transportation, etc., to properly service the modules.

A minimum of two 8,000 horsepower tugboats will be required for towing the module to location, and an additional two 2,000 horsepower tug/supply boats should be available at the operating site for line handling and supply and personnel services.

A barge with equipment for remote control of the module ballast system and a revolving crane will be necessary for attaching and detaching the module. Support facilities for diving operations would also be housed on the barge.

The auxiliary buoyancy needed for the top of each module would consist of an inflated rubber-nylon cylinder, controlled by air lines from the barge.

##### Facilities for Platform Supply

A service vessel, either semi-submersible or conventional hull design, will

provide supply services for the platform. Generators on the vessel will supply start-up power for the platform power system. Ammonia and nitrogen storage will be re-charged through lines from the supply vessel. Fuel oil, lube oil and other required items will be supplied by the vessel. Spare parts will be stowed on the service vessel.

Small supply items will be carried to the platform by helicopter.

#### Facilities for Personnel Maintenance and Transportation

Operating and maintenance personnel will be housed either on a platform or vessel centrally located in the OTEC farm, or at a nearby shore installation. The choice will depend upon farm location and availability of shore-based facilities. Personnel transportation will be primarily by helicopter from the central base to each platform.

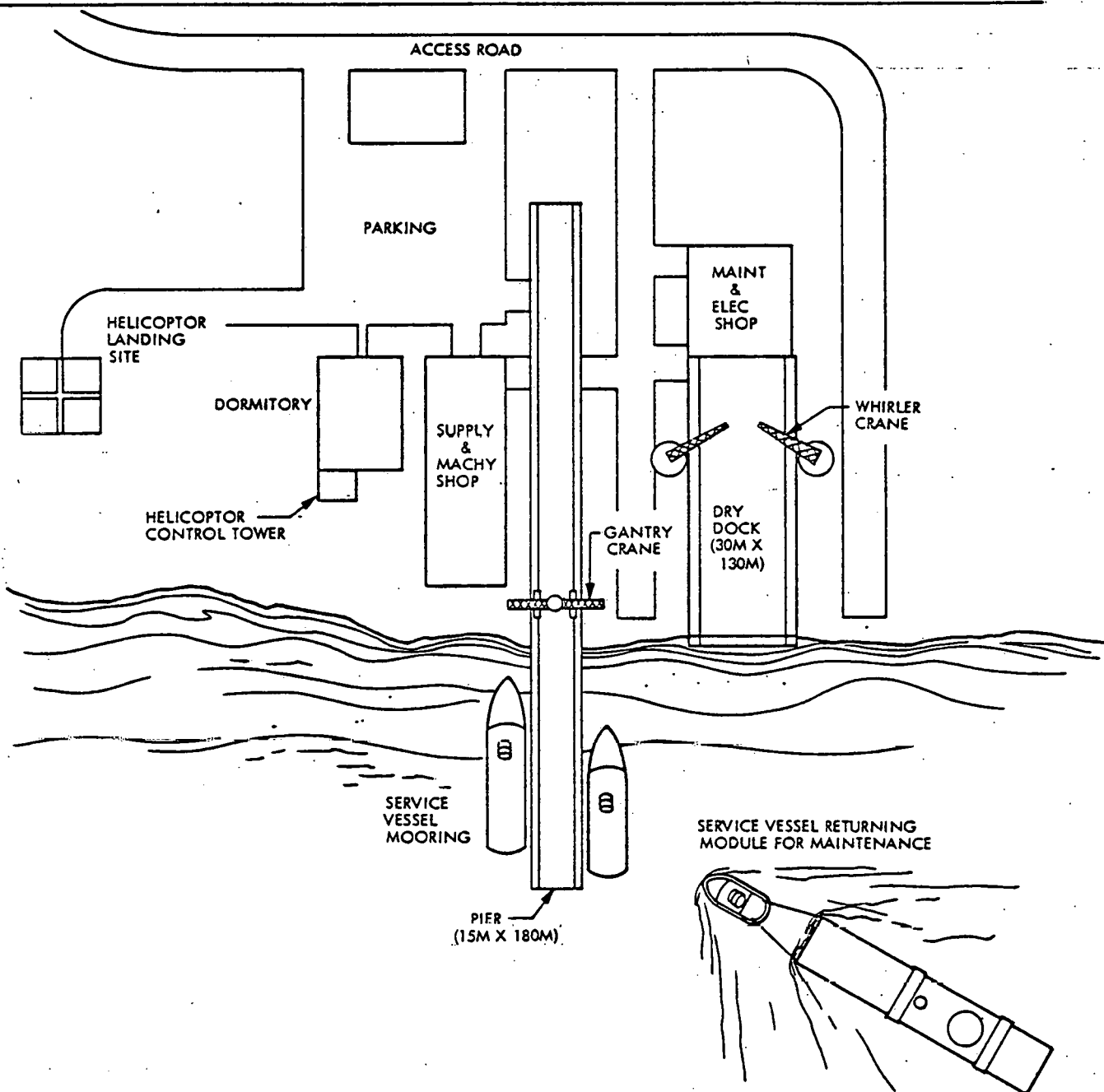


Fig. 4.8-1 Shore Facilities

#### 4.9 MAINTENANCE

Routine periodic maintenance of all core equipment and module turbines and generators will be accomplished by crews transported to the platform by helicopter or service vessel. Space is provided near each piece of equipment for overhaul and other maintenance functions. Hoisting facilities will be installed where lifting of large items is necessary.

Major repair or replacement of components of the seawater system will require that the module be towed ashore and placed in dry dock, Figure 4.9-1. The sea water pumps may then be extracted through the ends of the cylinders, and the heat exchangers can be retubed directly through the short ducts. If the maintenance program requires removal of an entire heat exchanger, rather than retubing in place, larger openings can be provided in the structure to accommodate the removal.

Removal of the modules will require the following procedure.

1. Attach auxiliary surface-piercing buoyancy above the warm water intake duct.
2. Adjust the module ballast to provide approximately neutral buoyancy of the module. This can be monitored with load-sensing devices on the core/module connections.
3. Attach tugboat lines to top of warm water inlet duct and to top of warm water exit duct.
4. Release module hold-on devices and pull module with upper tug line.
5. Reduce module ballast so that base of module rises out of ledge and module separates from core.

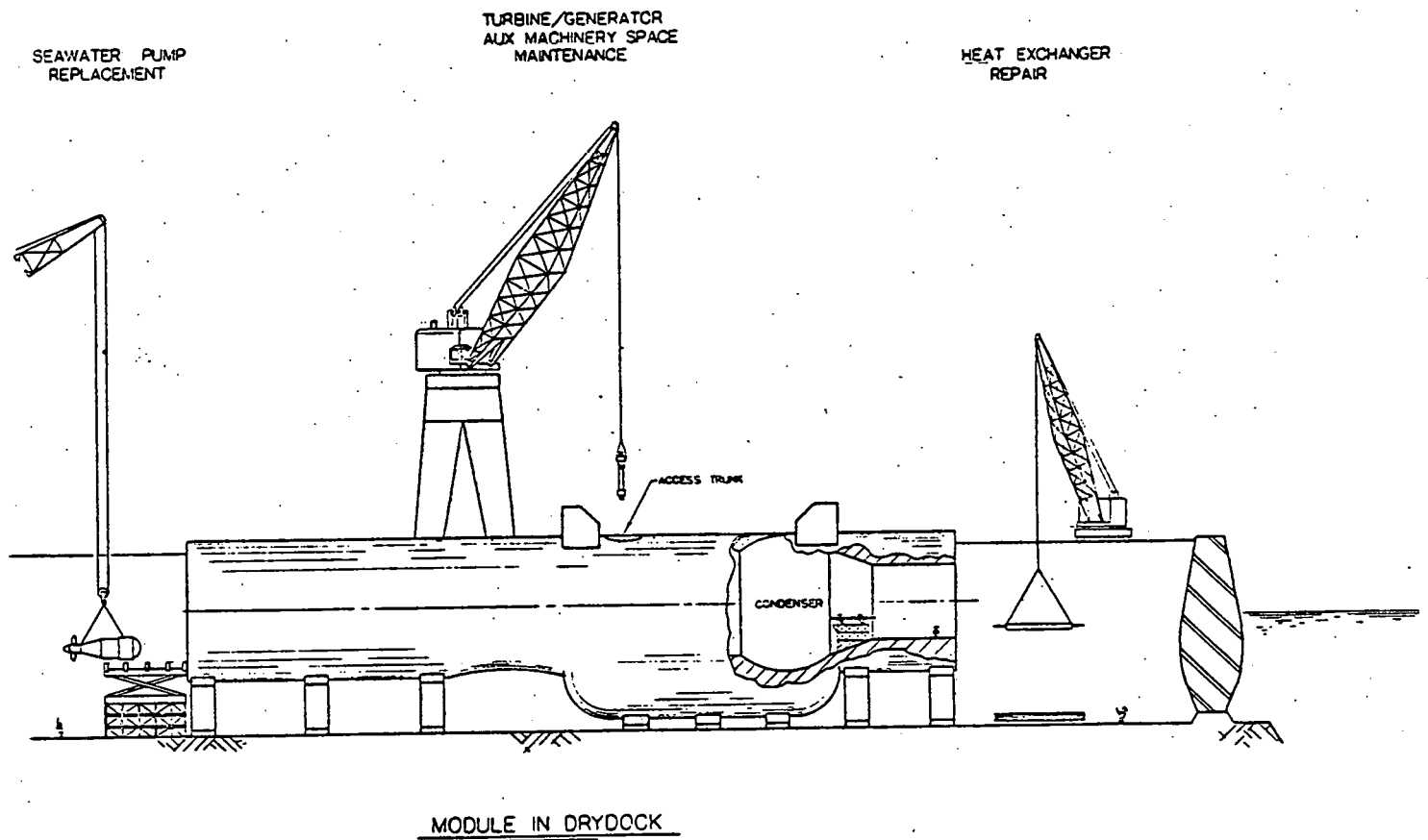


Fig. 4.9-1 Module Maintenance and Repair Scheme, 400-MW(e) Spar

6. Pull module free of core with lower line.
7. Pump out all ballast tanks, allowing module to rise to the surface on its side.
8. Attach auxiliary buoyancy to warm water exit duct or inflate rubber nylon extension pipe annulus with air.
9. Tow module to dry-dock.

Replacement of the module after maintenance is accomplished by following the module deployment procedure.

#### 4.10 CONTINGENCIES

The manner of dealing with several potential hazardous situations has been studied to assure that adequate contingency capabilities exist with the spar platform. Figure 4.10-1 illustrates some of these contingency features as described below.

##### Loss of Cold Water Pipe

Material failure of the rubber/nylon cold water intake pipe could result in total separation and loss of pipe, or a hole of such a size that an acceptable operating temperature differential cannot be maintained. In this case the power system would be shut down and secured. Emergency diesel generators would start automatically to handle essential loads. In the case of total separation of pipe and spar, the spar would rise 12 meters, remain stable and drift. Tugs would be dispatched to control the movement of the platform. The electrical riser cable would be automatically released to avoid damage to the riser as the spar moved beyond the allowable watch circle.

Maker buoys attached to the screen would automatically deploy to aid in locating the pipe, screen and anchor during subsequent recovery operations.

##### Ship Collision

A ship with less than 10 meters (33 ft) of draft could be driven by storm conditions and loss of control (power or rudder) over the ring of power module inlets and into the main vertical column. If the column sustained enough damage below the waterline that the column floods 3170 LT of buoyancy would be lost, reducing the positive buoyancy by less than one half of normal. There would be a small change in draft and stability, with the mooring controlling the position of the spar.

Collision with a ship of over 10 meters (33 ft) of draft could damage one or two power modules at the warm water intake and possibly rupture the upper buoyancy chambers. Assuming that two neighboring modules are damaged with one quadrant of each unit flooded, a loss of 1204 LT would result in a heel of approximately 4.25 degrees. If an evaporator were to be flooded a loss of buoyancy of the order of 3248 LT would be experienced. In this condition the spar would be stable with a heel of 11.5 degrees.

If the double failure of the mating seal between spar and power module and the isolation door seal were to occur flooding of the machinery spaces would result, and 3298 LT of buoyancy would be lost. This is essentially the same condition as a flooded heat exchanger with a heel of approximately 11.5 degrees.

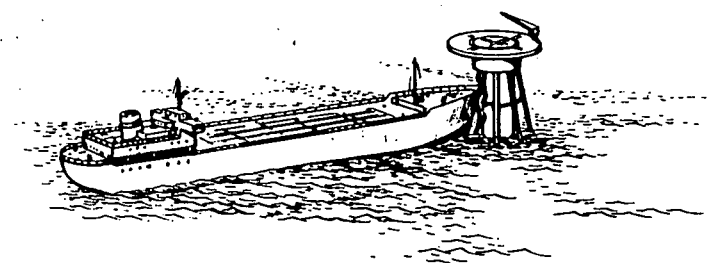
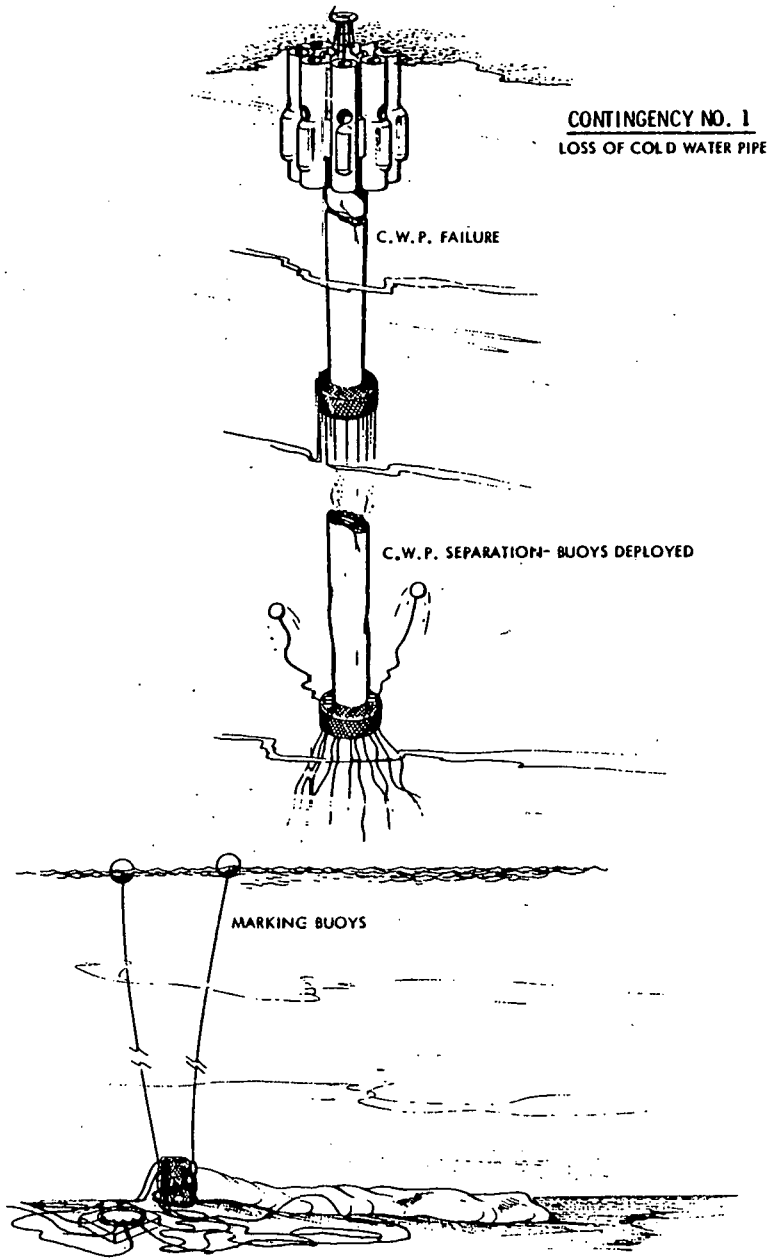
#### Hurricane

Since the spar platform is primarily below the wave zone, hurricane waves will have little effect on motions of the unit. Since wind area is slight, wind heeling should not be a serious problem. Therefore, apart from causing possible local damage at the column top, a hurricane should pose little threat to the platform.

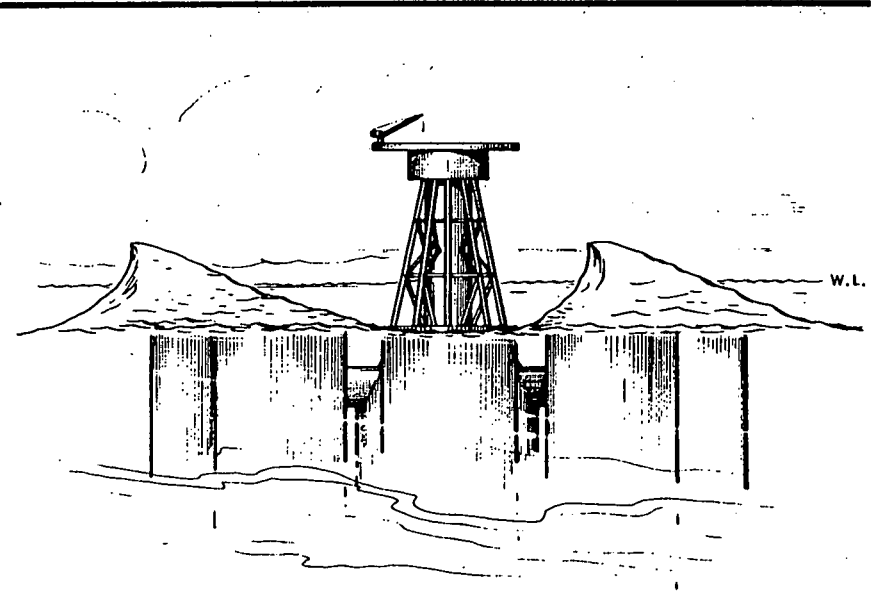
It is likely, however, that a storm of hurricane proportions will modify the ocean thermal layers to such an extent that the power plant output may be significantly reduced. In this case, it may be necessary to shut down the power generation system until the resource temperature differential stabilizes. Platform diesel-generator sets would provide all required support power and standby capability.

#### Loss of Power Module

Since the power modules are ballasted to be neutrally buoyant the loss of a module would not upset the stability or attitude of the spar. The loss of a



**CONTINGENCY NO. 2**  
VESSEL/SPAR COLLISION



**CONTINGENCY NO. 3**  
100 YEAR STORM

Fig. 4.10-1 Contingency Configurations, 400-MW(e) Spar

power module after a completed installation is extremely remote in view of the hydraulic locking mechanism engaged at two locations. The loads on the power module relative to the core are small because of the deep location of these components.

#### Damage (flooding)

The core structure is nearly impervious to damage. The main pressure vessel is protected by a ring of ammonia storage bottles on the side, and by sloping truss-work on top. This truss-work also serves as shock absorber and deflector for any vessel threatening to hit the column.

In the operating position, the modules are only slightly vulnerable to flooding. The damage condition investigated was the flooding of the ammonia side of the evaporator. However, this condition was studied and the platform is able to withstand the flooding. When one evaporator is flooded with 3,300 metric tons of water, the platform sinkage is six meters and the tilt angle is 11.5 degrees. The platform has adequate stability in this position. Following such damage to a module, the modules weight would be reduced by removing either liquid or solid ballast to return the module to a neutrally buoyant condition. The module would then be disconnected, following the procedure described in Section 4.9, and towed ashore for repair.

In the towing position, the module could be subjected to collision with a surface vessel. If this occurred, it is unlikely that the concrete structure would allow flooding of any buoyant compartment. However, if such a compartment were flooded during tow, the reserve buoyancy of the module would be sufficient to prevent loss of the module. If the module assumed a vertical attitude, it could be returned to a side-floating position by removal of solid ballast or attachment of auxiliary buoyancy. It could then be towed ashore for repair.

#### 4.11. COSTS AND SCHEDULES

This section discusses the cost and schedule of building and operating eight OTEC power plants of the spar configuration. The structure and content of the section is similar to that of 3.11, the equivalent section for ship-type platforms. The estimates presented here include similar allowances for contingency and fees, and do not include construction financing charges. Table 4.11-1 summarizes spar platform costs at the second level and significant items at the third level of the WBS with more detailed cost breakdowns provided in Appendix B. Table 4.11-1 is similar to Table 3.11-1 and the cause of the different costs presented for the first platform and for follow-on units is as discussed in section 3.11 in connection with ship-type platforms. Namely, facilities, tooling and equipment, and design costs are charged entirely to the first unit, and engineering, systems integration and project management-related expenditure is assumed to be higher for the first unit.

The platform system accounts for an even higher proportion of total cost for spar-type units than was the case for ship-type platforms. The largest single cost element within the platform system is the seawater system, followed closely by the platform hull, each accounting for roughly a third of platform system cost for the follow-on units. Mooring system and auxiliary systems costs each account for roughly a tenth of the total for WBS element 1.0. Cold water pipe system costs are similar in composition to those for ship-type platforms, but they are somewhat lower. As a result, CWP costs account for only a sixth of total platform cost. The procedure followed in estimating the cost of WBS elements 5.0, 6.0, 10.0 and 11.0 is as discussed in section 3.11. As also discussed in that section, WBS element 7.0 has been split into two subelements to segregate non-recurring capital costs from annual operating costs. Deployment costs were estimated for the procedure described in section 4.7. They are somewhat lower than was the case for ship-type

platforms, mainly as a result of the simpler mooring system concept adopted. The cost of the facilities required for spar-type platform construction is expected to be somewhat higher than was the case for ship-type units. The cost of the deepwater pier necessitated by the construction sequence envisaged more than outweighs the reduction in cost brought about by the smaller construction basin required for spar-type units. It should be noted that the limitations of the facility cost estimates for ship-type platforms discussed in section 3.11 apply here. The total cost of the first spar-type platform is estimated at slightly over 610 million dollars, or roughly 1500 \$/Kw, follow-on platforms would cost approximately 320 million dollars each, or 800 \$/Kw, approximately 15% more than was the case for ship-type plants. Should a learning curve with a slope of .95 be assumed, average costs would be reduced by roughly 10%, and the cost of the eight unit by 15%.

The construction schedule Figure 4.11-1, for an OTEC park of eight spar platforms is based on the individual plant construction schedule discussed in section 4.6. Since the estimated construction time for the power module is one year, the central platform core is the pacing item. As platform construction takes place at two physically different sites, it is possible to compress the schedule significantly by beginning construction of a plant in the construction basin while its immediate predecessor is being finished at the deep water pier. As a result, the total time required to build the eight plants is 122 months, about a year more than is required to build an eight-plant park of ship-type units.

Table 4.11-1

SPAR-TYPE 400 MW(e) COMMERCIAL PLANT COST SUMMARY  
(NEW ORLEANS SITE)

WBS SYSTEM	COST \$M	
	1ST UNIT	2ND THROUGH 8TH UNITS
1.0 PLATFORM SYSTEM	262.4	228.6
1.1 Platform Integration and Engineering	10.0	5.0
1.2 Hull and Structure	79.5	69.5
1.3 Position Control System	32.7	30.7
1.4 Platform Service Systems	35.6	33.6
1.5 Outfit and Furnishings	0.5	0.5
1.6 Assembly Support Services	12.8	0
1.7 Seawater System	91.3	89.3
1.8 Biological and Corrosion Control System	0	0
2.0 COLD WATER PIPE SYSTEM	62.4	51.6
5.0 SYSTEMS ENGINEERING AND INTEGRATION	5.0	2.5
6.0 SYSTEM TEST AND EVALUATION	10.0	5.0
7.0-A OPERATIONAL SUPPORT	25.0	0
8.0 DEPLOYMENT	15.7	12.7
9.0 INDUSTRIAL FACILITIES	200.0	0
10.0 ENVIRONMENTAL, LEGAL, LICENSING, REGULATION AND INSURANCE	7.5	5.0
11.0 PROJECT MANAGEMENT	22.5	15.0
TOTAL CAPITAL COST	610.5	320.4
\$/KW(e)*	1,526.0	801.0
7.0-B ANNUAL OPERATIONAL COST OF EIGHT- PLANT PARK	24.2	24.2

\* BASED ON NOMINAL PLANT RATING OF 400 MW(e) NET

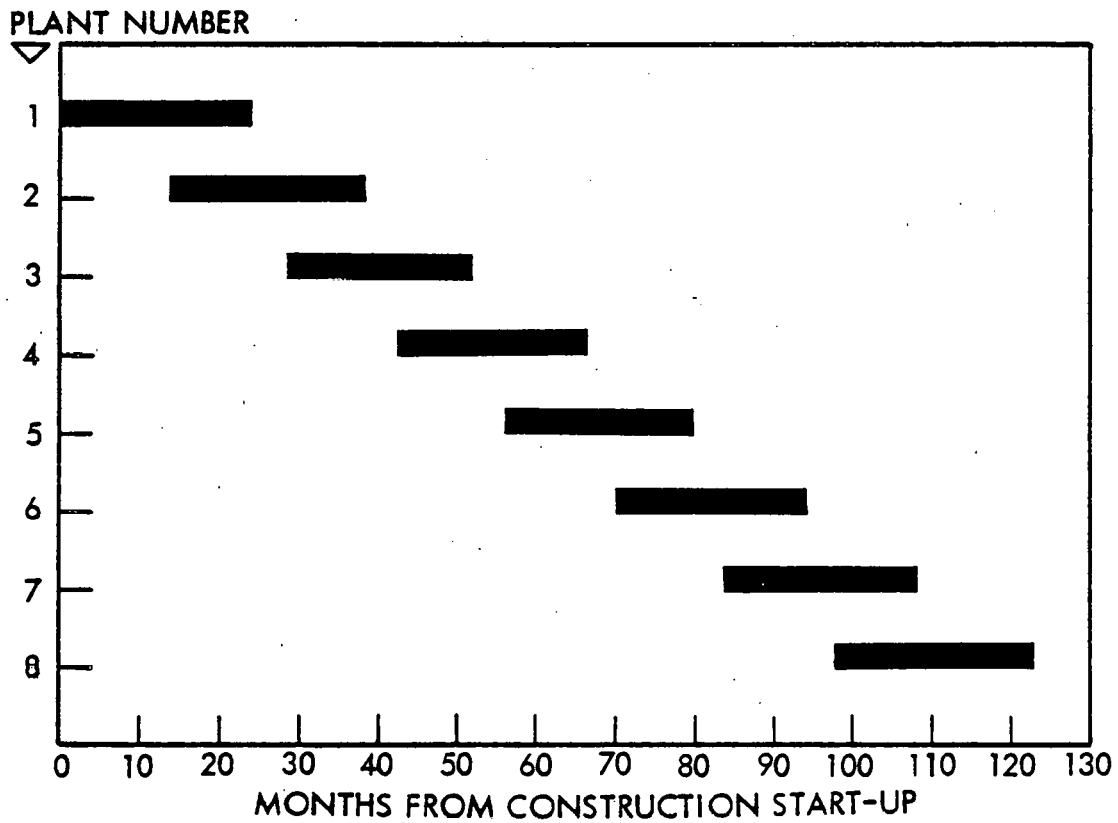


Fig. 4.11-1 OTEC Park Construction Schedule for Eight Plants of Spar Type

4-61

SECTION 5  
DISCUSSION OF RESULTS

The two OTEC platform types for which conceptual designs have been performed (ship and spar) have a variety of attributes some of which are site dependent. This section discusses the general characteristics of these two conceptual designs and comments on these attributes.

5.1 NEW ORLEANS

The baseline site for the conceptual designs was New Orleans. Therefore all the designs and characteristics are appropriate to this site as defined in the environmental data package. Forthcoming reductions in the extreme sea definition for the New Orleans site should have only limited impact on the results as presented in this report. Refinement of the definition of ocean currents may be expected to have a small and erratic effect on the costs for cold water pipes and position keeping system. The following discussion is based on the original New Orleans environmental definition.

The physical characteristics of the ship and the spar are similar, with the ship having a 41 percent smaller operating displacement than the spar for a design output of 400 MW(e) net.

	<u>SHIP</u>	<u>SPAR</u>
Length	210m (689 ft)	158m (518 ft)
Beam	73m (240 ft)	158m (518 ft)
Draft	28m (92 ft)	114m (374 ft)
Displacement, Operating	257,953 tonnes (253,867 L.T.)	438,000 tonnes (431,102 L.T.)

The similarity in size between the current 400 MW(e) net concepts and the previous designs for 100 MW(e) net (VOLUME 1) allows the results of analyses

of previous configurations to be used to represent the conceptual designs for determination of motions and design loads. For 100 MW(e) net the following were the computed platform significant amplitudes of motion for significant wave heights of 58.1 ft.

	<u>SHIP</u>		<u>SPAR</u>
	Head	Beam	
Surge (ft)	14.7	15.3	8.7
Heave (ft)	20.1	32.2	8.2
Pitch (degrees)	6.2	14.7	2.5

These results indicate that the motions of the ship are 70 to 250 percent greater than the spar in these extreme conditions, if the ship can be headed into the weather. If the position control system does not allow weather-vaning, the ship motions are 600 percent greater than the spar when exposed to a beam sea.

The costs of the 2nd to 8th units of these conceptual designs are nearly the same (within 15 percent) based on rated output of 400 MW(e) net.

<u>SHIP</u>	<u>SPAR</u>
690 \$/kW	801 \$/kW

The elements of these costs are compared on Figure 5-1.

Analysis of the power requirements for sea water and ammonia pumping for these designs indicates a parasitic power ratio of 1.35 (ship) and 1.34 (spar) for a 40 °F design temperature differential for 50 MW(e) net power modules.

<u>MEGAWATTS</u>	<u>SHIP</u>	<u>SPAR</u>
Cold Water Pumping Power	8.774	7.375
Warm Water Pumping Power	7.379	6.832
Ammonia Pumping Power	<u>1.362</u>	<u>2.758</u>
Total MW(e)	17.515	16.965
<u>Gross</u>	1.350	1.339
Net		

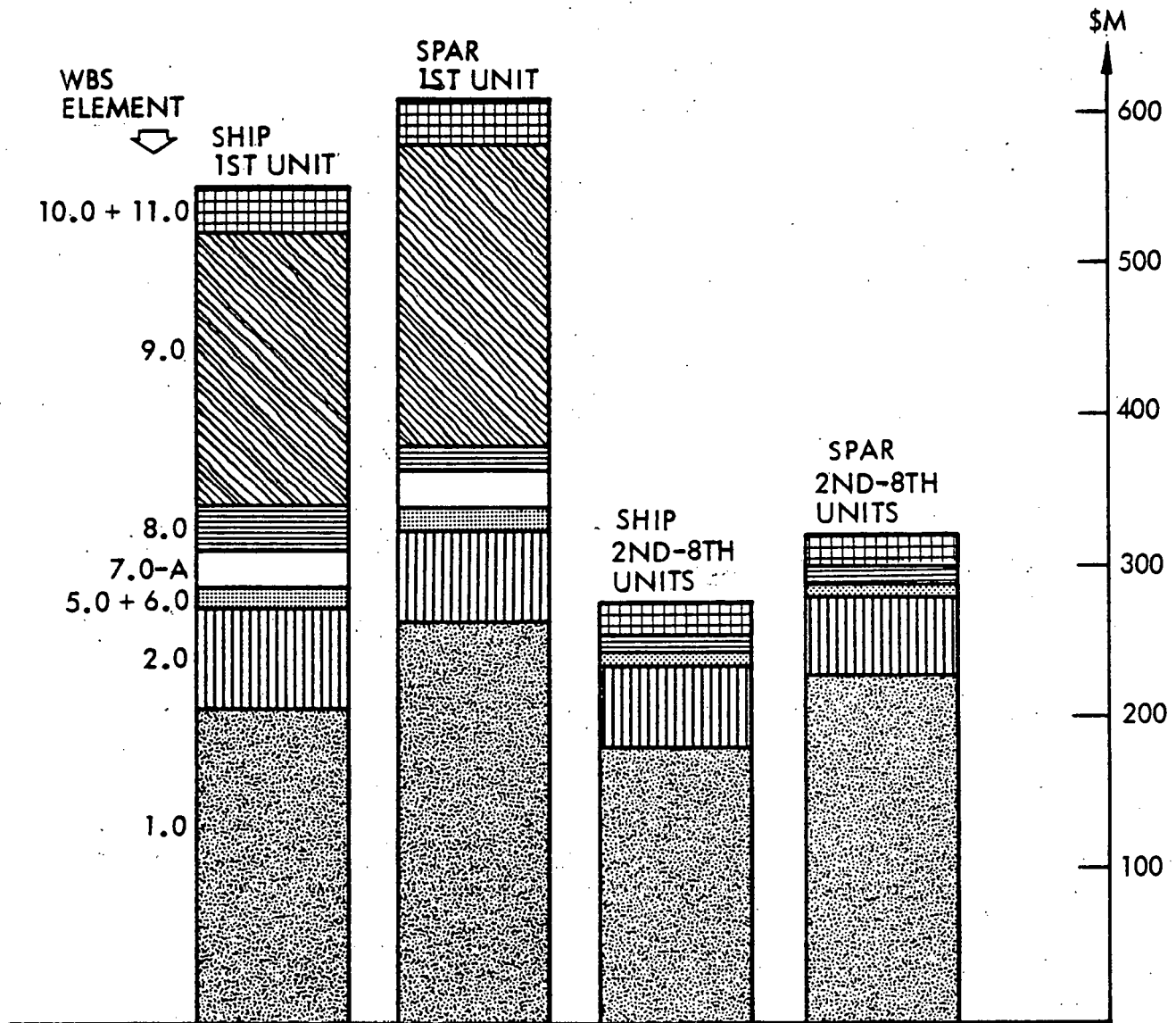


Fig. 5-1 Comparison of Platform Costs For  
400 MW<sub>e</sub> Net Commercial OTEC Plant At New Orleans

If the gross power were 65 MW(e) (1.3 x 50) per module, the net output would be the following for a 40 °F temperature differential.

<u>SHIP</u>	<u>SPAR</u>
48.14 MW(e)	48.50 MW(e)

Since the power system used in this design is rated for a nominal 50 MW(e) (Net) per module for a surface platform, the net output per power module on these two platforms is the following at the design temperature differential (40 °F).

<u>SHIP</u>	<u>SPAR</u>
50.00 MW(e)	50.42 MW(e)

The average annual net output of the modules on these platforms at New Orleans accounting for monthly variation in temperature differential and corresponding power system performance, is the following.

<u>SHIP</u>	<u>SPAR</u>
45.46 MW(e) average	45.82 MW(e) average

The sensitivities to site of cost and performance of the two platforms are presented in the following section.

## 5.2 SITE SENSITIVITY

Three major platform-related factors are affected by the selection of the operational site for the commercial plant. These are the motions of the platform, the costs of the platform, and the average annual output of the power system. A summary of these factors for the two platform configurations for the sites of New Orleans, Hawaii, and Brazil are presented in Table 5-1. The depth of the cold water intake is 1000m (3281 ft).

TABLE 5-1

## SENSITIVITY TO OPERATIONAL SITE

(Intake depth of cold water pipe is 1000M (3281 ft))

SITE	Platform	
	SHIP	SPAR
<u>Platform Motions in Extreme Seas</u>		
	<u>Significant Amplitude of Pitch angle - degrees</u>	
New Orlean ( $H_5=58.1$ ft)	6.2 (Head)	2.5
Hawaii ( $H_5=35.9$ ft)	2.6 (Head)	1.0
Brazil ( $H_5=29$ ft)	1.8 (Head)	0.7
<u>Capital Costs *(for each 2nd to 8th Units)</u>		
	<u>Millions of Dollars(1978)</u>	
New Orleans (Moored)	275.9 (Head)	320.4
Hawaii (Moored)	261.2 (Head)	306.7
Brazil (Dyn. Pos.)	327.2 (Head)	330.7
<u>Annual Average Output of Plant ( t Design=40<sup>o</sup>F)</u>		
<u>(Assuming 65x8=520 MW<sub>e</sub> (gross))</u>		
	<u>MW<sub>e</sub> (Net) average</u>	
New Orleans	363.7	366.6
Hawaii	378.3	381.4
Brazil	440.0	448.0
<u>Capital Cost per Annual Average Output *,</u>		
	<u>\$/kW<sub>e</sub> average</u>	
New Orleans	759	873
Hawaii	690	802
Brazil	736	738

\*Excluding costs of power and energy transfer systems.

The motions of two platforms estimated for extreme (survival) conditions for the three sites indicated that the ship headed into the sea undergoes 2.5 times the pitch motion of the spar. The pitch motion is greatest (6.2 degrees for the ship and 2.5 degrees for the spar) at New Orleans and least for the Brazil site.

Capital costs for commercial OTEC plants with nominal 400 MW(e) net output, excluding power and energy transfer systems, primarily reflect the change in cost for the position control system for each site. The ship cost varies 26 percent among the sites, while the spar costs vary by 7 percent.

The annual average output of the plants based upon assumed gross design output of the power system of 520 MWe (=65x8) ranged from a low of 364 MW(e) for the ship at New Orleans to 448 MW(e) for the spar at Brazil. The power system for this case is based on a design temperature differential of 40 degrees F. The spar is about 1 percent more efficient than the ship concept because of lower parasitic power requirements in the sea water system.

The ratio of capital cost per annual average output for the commercial plants varies 16 percent among the three sites for the ship and 18 percent for the spar.

SECTION 6.  
SUMMARY OF CONCLUSIONS

The following conclusions have been developed in course of this conceptual design study.

1. A concrete cold water pipe equipped with flexible joints is the lowest cost to construct and is very insensitive to design sea conditions. Deployment costs for this pipe are 75 percent of construction costs. Its large weight has an impact on buoyancy requirements on the platform.
2. An inflated rubber/fabric cold water pipe is apparently slightly more cost effective than the concrete pipe if long life can be attained. Platform impact and deployment costs are minimal with this type of pipe.
3. Hulls for OTEC platforms can be optimized by utilizing the inherent buoyancy obtained by immersion of components of the power system, chiefly the heat exchangers and the ammonia storage tanks.
4. The sea water pumps are a major cost item of the platform.
5. A conceptual design of a ship-type platform for a 400 MWe (net) OTEC commercial plant has an estimated capital cost per nominal net output of 690 \$/KW for a New Orleans site.
6. A spar-type platform with detachable power modules has an estimated cost of 801 \$/KW nominal for the New Orleans site.
7. The sensitivity of these conceptual designs to three sites (New Orleans, Hawaii, Brazil) shows a large (3.5:1) variation among the sites for both platforms for motions in extreme seas, and 26 percent variation in capital cost for the ship and 7 percent variation for the spar among the sites.

8. It is recommended that a demonstration unit for an OTEC plant have an output of about 25 MWe to meet the needs of both small and large system users. Demonstration of full scale components (pumps, thrusters, anchors, etc.) is recommended. Demonstration of the energy transfer system (electrical transmission or chemical conversion and shipment) must be included. Operations personnel should represent potential OTEC users.

APPENDIX A  
COLD WATER PIPE CONCEPTUAL DESIGN

## APPENDIX A

### COLD WATER PIPE CONCEPTUAL DESIGN

The analysis for cold water pipes of 54 feet inside diameter showed that of the materials investigated prestressed concrete with flexibly joined sections was the lowest cost concept. However, the resultant payload requirement on the platform, particularly on the non-floating concepts, was reflected in a high cost penalty. Recognizing the objective to significantly reduce acquisition cost for the ocean systems, this conceptual design considers alternatives to the materials previously investigated as well as approaches to reducing the weight of concrete pipe.

Pipe characteristics investigated conceptually were diameter, length, thickness, material, joints, deployment, and platform attachment. These are each discussed in the paragraphs below. The following are the significant results of these analyses for a 400 MW<sub>e</sub> net commercial plant.

1. The optimum inside diameter is in the range of 21 to 24 m (70 to 80 ft) for concrete pipe.
2. Optimum pipe length is 808 meters (2650 ft) for a concrete pipe on the spar in New Orleans. Inlet depth is 900 m (2950 ft).
3. Pipe thickness, strongly dependent on material, lies in the range of 0.5 cm ( $\frac{1}{2}$  inch) for rubber-nylon to 0.3 m (1 foot) or more for jointed concrete.

4. Among the rigid materials investigated (concrete, GRP, aluminum), the reinforced concrete pipe with flexible joints is the lowest cost pipe material.
5. The rubber-nylon concept is an attractive alternative to concrete from the standpoint of lowweight and cost if the material life in seawater is equal to that of concrete. If not, then the costs to deploy a replacement rubber-nylon pipe(s) in the forty years of plant operation would make this concept non-cost competitive with concrete.
6. Flexible joints have been devised for rigid pipe sections which provide for ease of deployment as well as fail-safe continuous operation in storms. The latter by limiting pipe bending stresses through pre-determined levels of rotational fixity. Connections for pipe sections of other materials not requiring this latter characteristic would be less costly.
7. Deployment of the pipe for any of the rigid concepts consists of sequentially lowering, by a jacking system, each pipe section through a temporary opening and cofferdam. This approach applied to the spar would be carried out in deep water on the base structure prior to slip forming of the core, the latter fitted with temporary buoyancy tanks to support the CWP.
8. Deployment of the soft, rubber-nylon pipe would consist of lowering the pipe and attaching to the platform from below either the ship or spar.
9. Attachment to the platform in the case of the rigid pipe concept requires a bearing to minimize platform-induced pipe bending stress in a hurricane. This approach may not be required for the rubber-nylon pipe where the pipe wall is assumed to stretch under bending applied at the pipe-platform interface, thereby relieving tensile stress.

A comparison of these advantages and disadvantages of several pipe materials and deployment schemes is presented in Table A-1.

TABLE A-1 COMPARISON OF CWP CONCEPTS

<u>CHARACTERISTIC</u>	<u>CONCEPT</u>	<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
Material	Concrete	<ul style="list-style-type: none"> <li>• Low Cost</li> <li>• No Maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Large Payload</li> <li>• Major Deployment</li> <li>• Flexible Joints Required</li> </ul>
	Aluminum	<ul style="list-style-type: none"> <li>• Low Payload</li> </ul>	<ul style="list-style-type: none"> <li>• Deployment</li> <li>• High Cost</li> <li>• Manufacturing Beyond SOA</li> </ul>
	GRP	<ul style="list-style-type: none"> <li>• Low Maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• High Cost</li> <li>• Manufacturing Beyond SOA</li> </ul>
	Rubber-Nylon	<ul style="list-style-type: none"> <li>• Low Payload</li> <li>• Potential Low Cost</li> <li>• Low Deployment Cost</li> </ul>	<ul style="list-style-type: none"> <li>• Unknown Life in Seawater</li> <li>• Manufacturing Beyond SOA</li> </ul>
Deployment	Center-Well	<ul style="list-style-type: none"> <li>• Pipe Control</li> <li>• Low Risk</li> </ul>	<ul style="list-style-type: none"> <li>• Primarily for Ship</li> <li>• High Cost</li> </ul>
	Submerged Attachment	<ul style="list-style-type: none"> <li>• Low Cost</li> <li>• Applicable to Any Platform Type</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to Light Weight Pipes</li> </ul>

The pipe used in the conceptual design drawings is the rubber-nylon pipe. The design calculations also have been made for a jointed concrete pipe. The costs for the rubber-nylon pipe have been used in the cost estimations.

#### Cold Water Pipe Length

The influence of cold water pipe length on cost associated with incremental power increases was investigated with the objective of identifying an optimum pipe length for a specific site and platform. The study is based on data obtained in preconceptual design, while the influence on results of more recent conceptual design data is indicated.

Temperature profiles for New Orleans provide at depths of 2000, 2640, 3280, and 4000 feet monthly average temperature differences, such as shown in Table A-2. The energy and power produced for each of four different baseline design temperature differences (32, 36, 40, and 44°F) are obtained based on off-design performance predictions for an optimized flow design (Figure A-1). An evaluation criterion factor equal to the sum of cost of heat exchangers, turbine-generators, seawater pumps, platform and cold water pipe incremental costs normalized by net power output, indicated the relative cost effectiveness of variation in cold water pipe length. A low criterion value, indicating low cost to produce power, is desired. Net power includes a parasitic power increment required by the additional head loss associated with the longer pipes.

$$\text{Eval. Criterion} = \frac{C_{HE} + C_{TG} + C_{SWP} + C_P + C_{WP}}{\text{NET POWER}}$$

The power system costs for a 25 MW(e) module based on a baseline design  $\Delta t$  of 40°F are given in Table A-3. Cost of heat exchanger and turbine generator are assumed independent of CWP length while SW pump costs decrease with increasing design  $\Delta T$ .

The platform cost increment, which decreases with  $\Delta T$ , is in the range of 20 to 80 dollars per cubic foot (706 to 2826 \$/m<sup>3</sup>) of heat exchanger pair incremental unit volume. This was derived from the ratio of 25 MW(e) net module concrete cost to heat exchanger pair volume. (Note, the 50 MW(e) vertical

Table A-2

MONTHLY AVERAGE TEMPERATURE DIFFERENCES AND  
NET POWER - NEW ORLEANS, 1,980-FT DEPTH (600 M)

Month	$\Delta T_{AV}^*$	Hrs	44°		40°		36°		32°	
			MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh
J	29	744	7.2	5356.	9.6	7142.	13.2	9820.	18.9	14061
F	25.2	672	4.4	2956.	5.8	3897	8	5376	11.6	7795.
M	25.8	744	4.8	3571.	6.4	4761	8.8	6547	12.8	9523
A	27.8	720	6.3	4536	8.4	6048	11.5	8280	16.7	12024
M	31.1	744	9.2	6844.	12.3	9151.	16.7	12424.	23	17112
J	37.1	720	15.9	11448	20.6	14832	26.8	19296	34.1	24562
J	40.7	744	20.6	15326	26	19344	32.5	24180	39.2	29164.
A	39.8	744	19.4	14433.	24.6	18302.	31.1	23138.	38	28272
S	38.2	720	17.3	12456	22.3	16056	28.6	20592	35.8	25776
O	33.8	744	12	8928	16	11904	21.3	15847	28.3	21055.
N	31.3	720	9.4	6768	12.6	9072	17	12240	23.4	16848
D	30.8	744	8.9	6621	11.9	8853.	16.2	12052	22.4	16665.
	32.5			99247.		129364.		169795.		222349.

MONTHLY AVERAGE TEMPERATURE DIFFERENCES AND  
NET POWER - NEW ORLEANS, 3,281-FT DEPTH (1,000 M)

Month	$\Delta T_{AV}^*$	Hrs	44°		40°		36°		32°	
			MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh	MW <sub>AV</sub>	MWh
J	32.8	744	10.9	8109	14.6	10862.	19.6	14582	26.4	196416
F	27.6	672	6	4032	8	5376	11	7392	16	10752
M	28	744	6.3	4687	8.4	6249.	11.5	8556	16.7	12424
A	32.4	720	10.5	7560	14	10080	18.9	15608	25.7	18504
M	25	744	13.4	9969	17.7	13168	23.3	17335.	30.5	22692
J	40.5	720	20.3	14616	25.7	18504	32.2	23184	38.9	28008
J	43.8	744	24.6	18302.	30.5	22692	36.6	27230.	42.2	31386.
A	43.4	744	24.2	18004	30	22320	36.2	26932	41.9	31173
S	41.8	720	22	15840	27.6	19872	34.1	24552	40.4	29088
O	38	744	17	12648	22	16368	28.2	20980	35.5	26412
N	35.6	720	14.1	10152	18.5	13320	24.3	17496	31.6	22752
D	34.9	744	13.2	98208	17.5	13020	23.2	17260.	30.4	22617
	36.15			135742.		171832		219110		275462

\* Based on preliminary environmental data( 8/77).

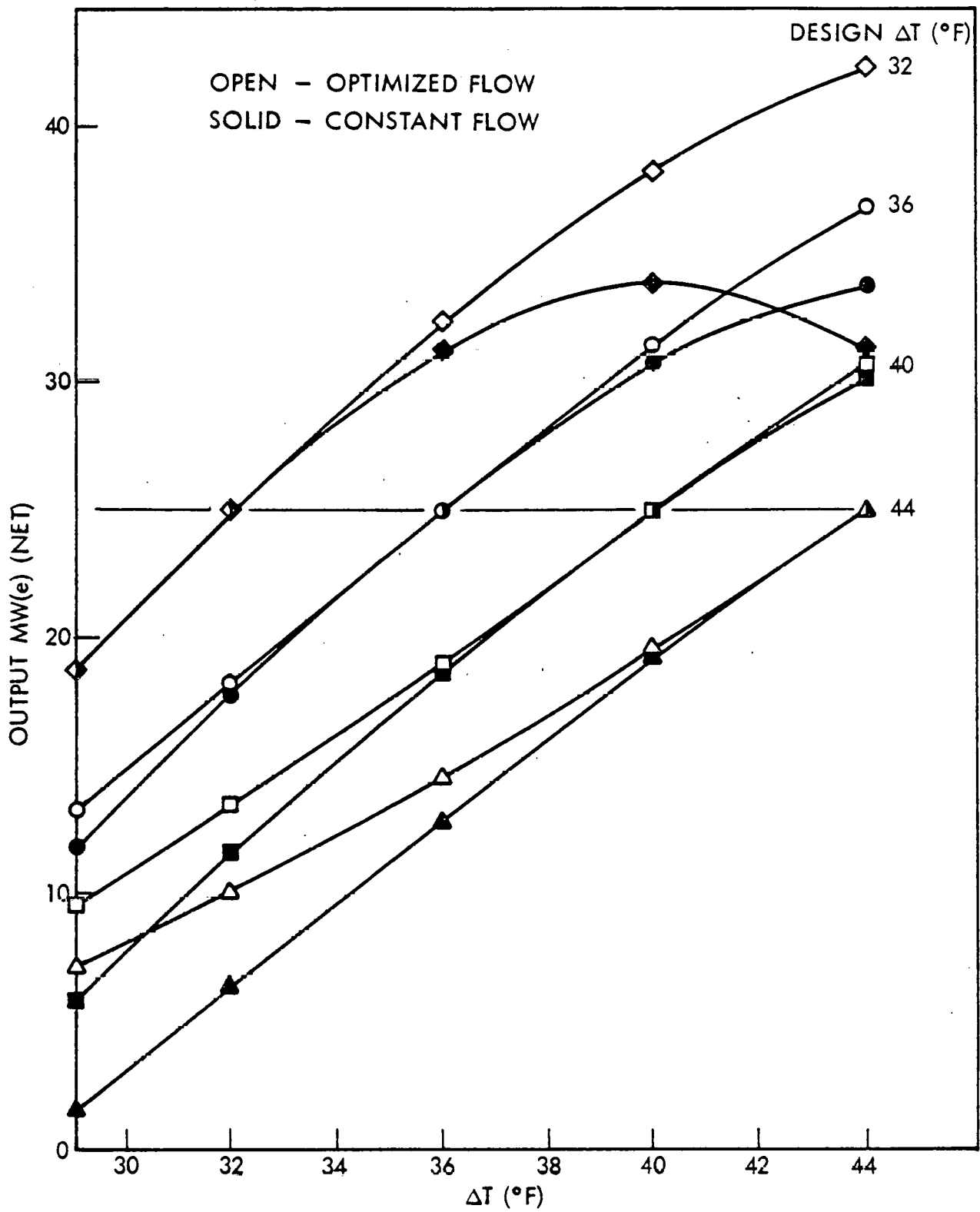


Fig. A-1 Off-Design Performance of 25-MW(e) (Net) Module, Radial Turbine

Table A-3

EVALUATION CRITERION FOR COLD WATER PIPE FOR VARIATION IN  
 DEPTH OF COLD WATER INTAKE AND DESIGN CONDITIONS FOR POWER SYSTEM  
 -25 MW<sub>e</sub> NET POWER MODULE AT NEW ORLEANS ON SPAR WITH CONCRETE PIPE

Length of Pipe (ft)	Design ΔT (°F)	Costs (\$)				MWh Per Year	Evaluation Criterion (\$/MWh/yr)	Platform Penalty (cu ft)	At \$20 Per Ft <sup>3</sup> (\$)	Total (\$)	Evaluation Criterion (\$/MWh/yr)	CWP Penalty	Total (\$)	Pumping Power MW(hr/yr)	Net Power	Evaluation Criterion (\$/MWh/yr)
		Heat Exchanger	Turbino-Generator	Seawater Pumps	Subtotal											
2,000	32	12,859,492	4,110,800	5,692,348	22,662,540	222,849.6	101.7	81,750	1,635,000	24,297,640	109.0	0	24,297,640	0	222,849.6	109.0
	36	10,051,534	3,452,995	5,318,313	18,822,842	169,795.2	110.9	32,100	642,000	19,464,842	114.6	0	19,464,842	0	169,795.2	119.6
	40	8,191,365	2,855,691	4,526,410	15,572,466	129,364.8	120.4	0	0	15,572,466	120.4	0	15,572,466	0	129,364.8	120.4
	44	6,912,853	2,380,117	4,157,635	13,450,605	99,247.2	135.5	-25,520	-510,400	12,940,205	130.4	0	12,940,205	0	99,247.2	130.4
2,640	32	12,859,492	4,184,354	5,692,348	22,736,194	255,379.0	89.03	81,750	1,635,000	24,371,194	95.43	700,000	25,071,194	3,942	251,437.0	99.71
	36	10,051,534	3,609,032	5,318,313	18,978,879	199,796.0	94.99	32,100	642,000	19,620,879	98.20	700,000	20,320,879	3,942	195,854.0	103.76
	40	8,191,365	3,059,065	4,526,410	15,775,840	154,469.0	102.13	0	0	15,775,840	102.13	700,000	16,475,840	3,942	150,527.0	109.45
	44	6,912,853	2,527,359	4,157,635	13,597,847	119,520.0	113.77	-25,520	-510,400	13,087,447	109.5	700,000	13,787,447	3,942	115,578.0	119.29
3,280	32	12,859,492	4,257,908	5,692,348	22,809,748	275,462.4	82.8	81,750	1,635,000	24,440,748	88.7	1,600,000	26,044,748	9,461	256,001.4	97.91
	36	10,051,534	3,765,068	5,318,313	19,134,915	219,110.4	87.3	32,100	642,000	19,776,915	90.3	1,600,000	21,376,915	9,461	209,649.4	101.01
	40	8,191,365	3,262,438	4,526,410	16,979,213	171,832.8	93.5	0	0	15,979,213	93.5	1,600,000	17,579,213	9,461	162,371.8	107.65
	44	6,912,853	2,674,600	4,157,635	13,745,088	133,742.4	102.77	-25,520	-510,400	13,234,158	98.6	1,600,000	14,834,158	9,461	124,281.4	119.36
4,000	32	12,859,492	4,340,656	5,692,348	22,892,496	304,452.0	75.19	81,750	1,635,000	24,527,496	80.58	3,600,000	28,127,496	15,856	288,596.0	97.46
	36	10,051,534	3,940,609	5,318,313	19,310,456	246,784.0	78.25	32,100	642,000	19,952,456	80.85	3,600,000	23,552,456	15,856	230,928.8	101.99
	40	8,191,365	3,491,233	4,826,410	16,211,008	195,492.0	82.92	0	0	16,211,008	82.92	3,600,000	19,811,008	15,856	179,636.0	110.28
	44	6,912,853	2,840,247	4,157,635	13,913,735	153,657.0	90.53	-25,520	-510,400	13,403,335	87.21	3,600,000	17,003,335	15,856	137,801.6	123.37

A-7

HE module (Figure 4.1-1) concrete cost per cubic foot of heat exchanger is  $\$5.4/\text{ft}^3$ , while the entire spar concrete cost is  $\$3.4/\text{ft}^3$ . These costs for conceptual platform design are substantially lower than the costs of the earlier spar design.) Further, the cost increment associated with increase in CWP length is shown in Figure A-2. The concrete pipe, including deployment, for 400 MW(e) and 3280 foot length has a unit cost of  $\$51 \times 10^6 / (3280 \times 400)$  or  $\$40/\text{MW-FT}$ . For a 25 MW(e) module, with baseline of 2000 foot depth, the increment in CWP cost increases to  $\$3.6\text{M}$  for 3700 foot pipe length.

The resulting evaluation criterion dependence on CWP length, Figure A-3 decreases with increasing pipe length up to 2500 feet. The larger criterion, or higher indicated costs to produce power, are associated with the low cost platform design temperature differential. A minimum is reached in the pipe length range of 2600 to 2700 feet depending on design  $\Delta T$ . The criterion is relatively flat for the low  $\Delta T$  system. The average  $\Delta T$  at depth associated with each pipe length are also shown. The evaluation criteria decreases with decreasing design temperature differences for the power system, Figure A-4. Based on these results the indicated minimum cost system is a cold water pipe 2650 feet in length and a power system designed to a temperature difference of  $35^\circ\text{F}$ .

#### Cold Water Pipe Diameter

The CWP diameter is sized to provide a specified volume of seawater at an optimum flow rate. To identify an optimum diameter for the 400 MW(e) (net) Commercial Plant the CWP and platform costs as determined in conceptual design were employed in a trade-off study of cost of energy versus CWP diameter.

Costs related to the CWP are the pipe cost, proportional to diameter (D), deployment cost ( $D^{2/3}$ ), pumping cost ( $D^{-5}$ ), and spar platform cost associated with CWP. The latter is dependent on the CWP wet weight. To these costs are added the cost of diffuser at the inlet to the cold water plenum and the cost of joints as required to connect the CWP sections. The sum is added to the total OTEC Plant less CWP cost ( $\$1500/\text{KW}$ ).

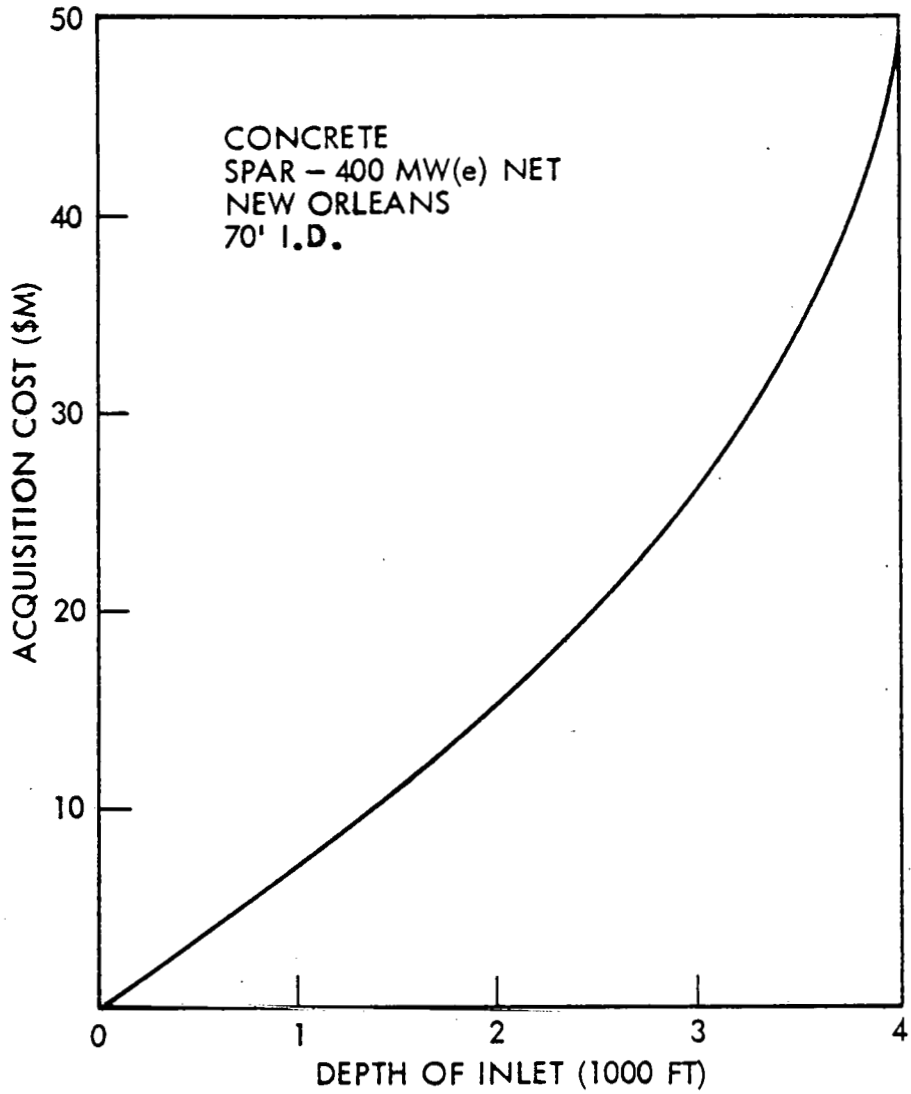


Fig. A-2 Variation of CWP Cost With Length

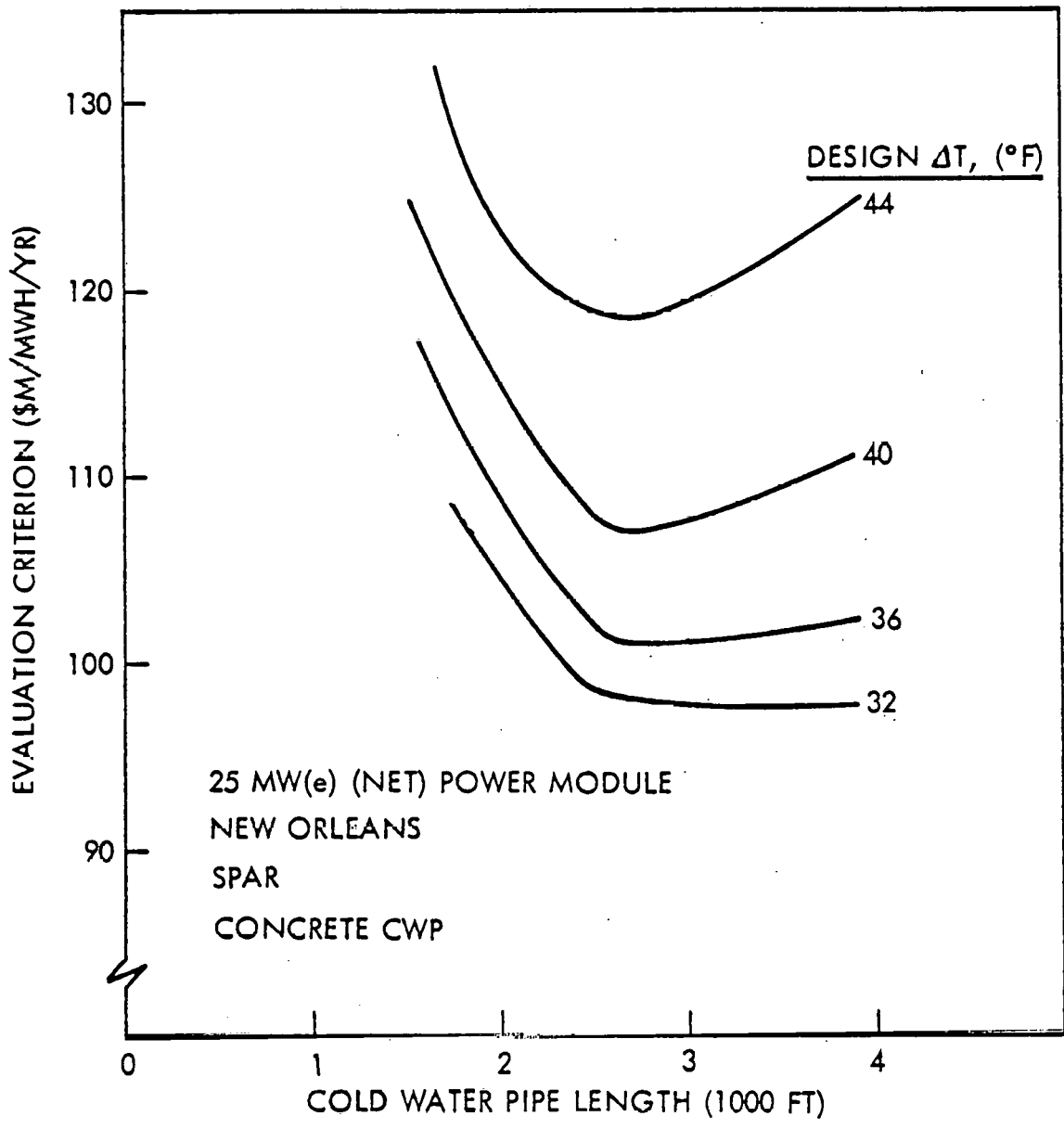


Fig. A-3 Evaluation Criterion vs. Cold Water Pipe Length

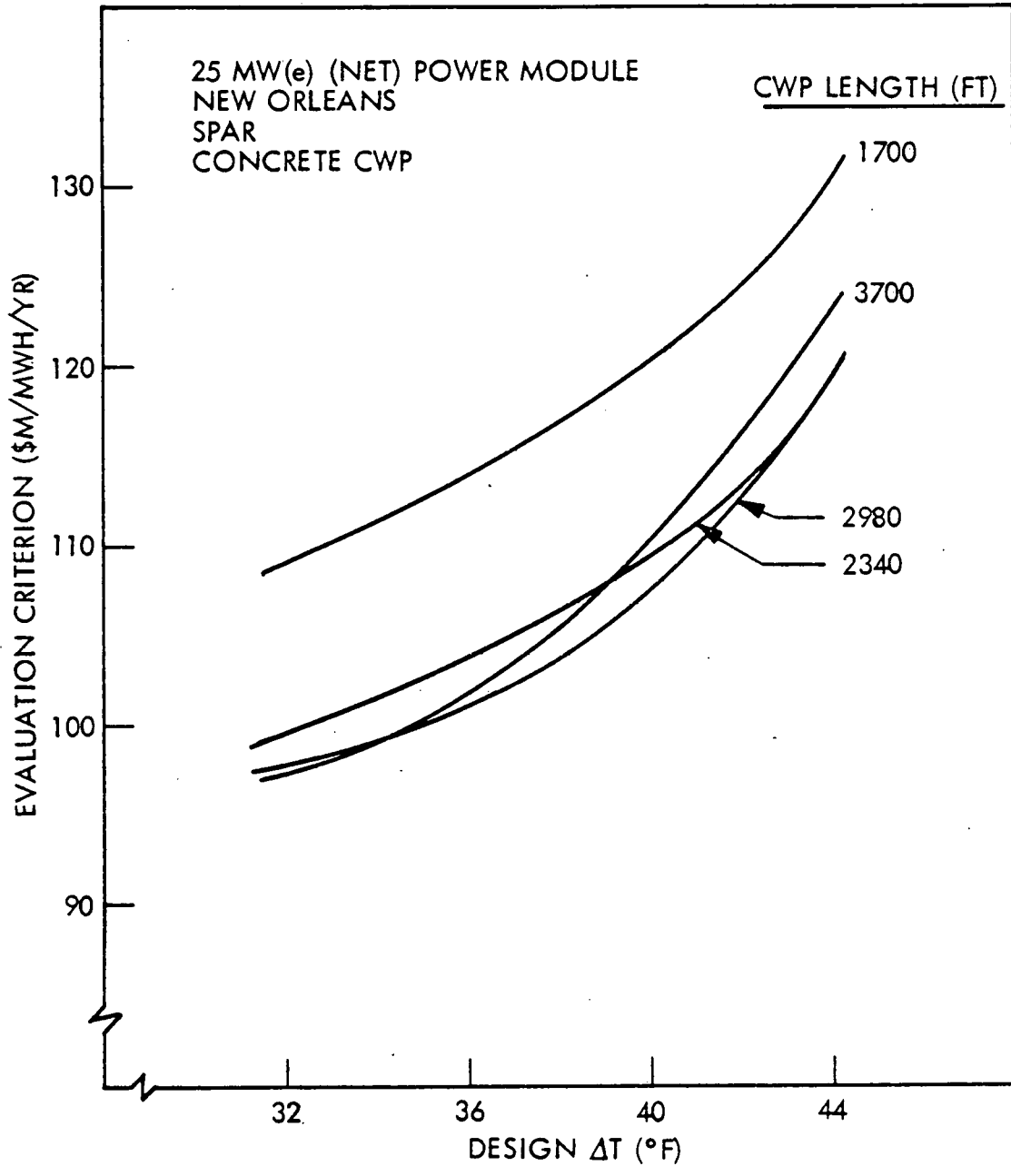


Fig. A-4 Evaluation Criterion vs. Design  $\Delta T$

Results for the spar, Figure A-5, indicate that CWP system costs are relatively insensitive to CWP inside diameter in the range of 20 to 27 meters (70 to 90 ft). Costs increase significantly above 27 meters and below 21 meters. Total plant costs are relatively flat in the range 20 to 30 meters (70 to 100 ft), but increase significantly for diameters less than 20 meters (70 ft). The effect of increasing plenum diameter from 24 meters (80 ft) to 30 meters (100 ft) is shown to reduce plant costs while having negligible influence on CWP system costs. The influence of CWP deployment is also illustrated. Similar results are obtained for the ship.

Based on an earlier study with preconceptual design data the selected baseline design diameter for the concrete CWP was 22 meters (73 ft). The results of this updated study, incorporating conceptual design data, indicate that the differential increase in cost of energy between the minimum cost CWP diameter of 27 meters (90 ft) (1700 \$/KW(e) net) and 22 meters (73 ft) (1735) is 2 percent. Considering that the smallest diameter CWP is desirable from the standpoint of manufacturing, handling, deployment, maintenance, and repair, the 22 meters (73 ft) diameter CWP was selected for baseline design.

#### Cold Water Pipe Thickness

A study was conducted to determine minimum thickness requirement as a function of pipe material, site and platform. Loading conditions include static as well as dynamic loads, the latter derived from a data set generated by Hydranautics, Inc. Materials analyzed included aluminum, GRP, and concrete for ship and spar platforms. Results are presented which illustrate the strength requirements for systematic variation of significant CWP parameters.

#### Static Loads

Included in static loading, the weight of pipe below the section under consideration is

$$S_{AT} = \int_0^S \frac{(\rho_M - \rho_W) (R_O^2 - R_I^2)}{(R_O^2 - R_I^2)} dS$$

where it is assumed that the pipe is a thin-walled shell. The thicknesses derived in this analysis provide area and stiffness requirements for a CWP.

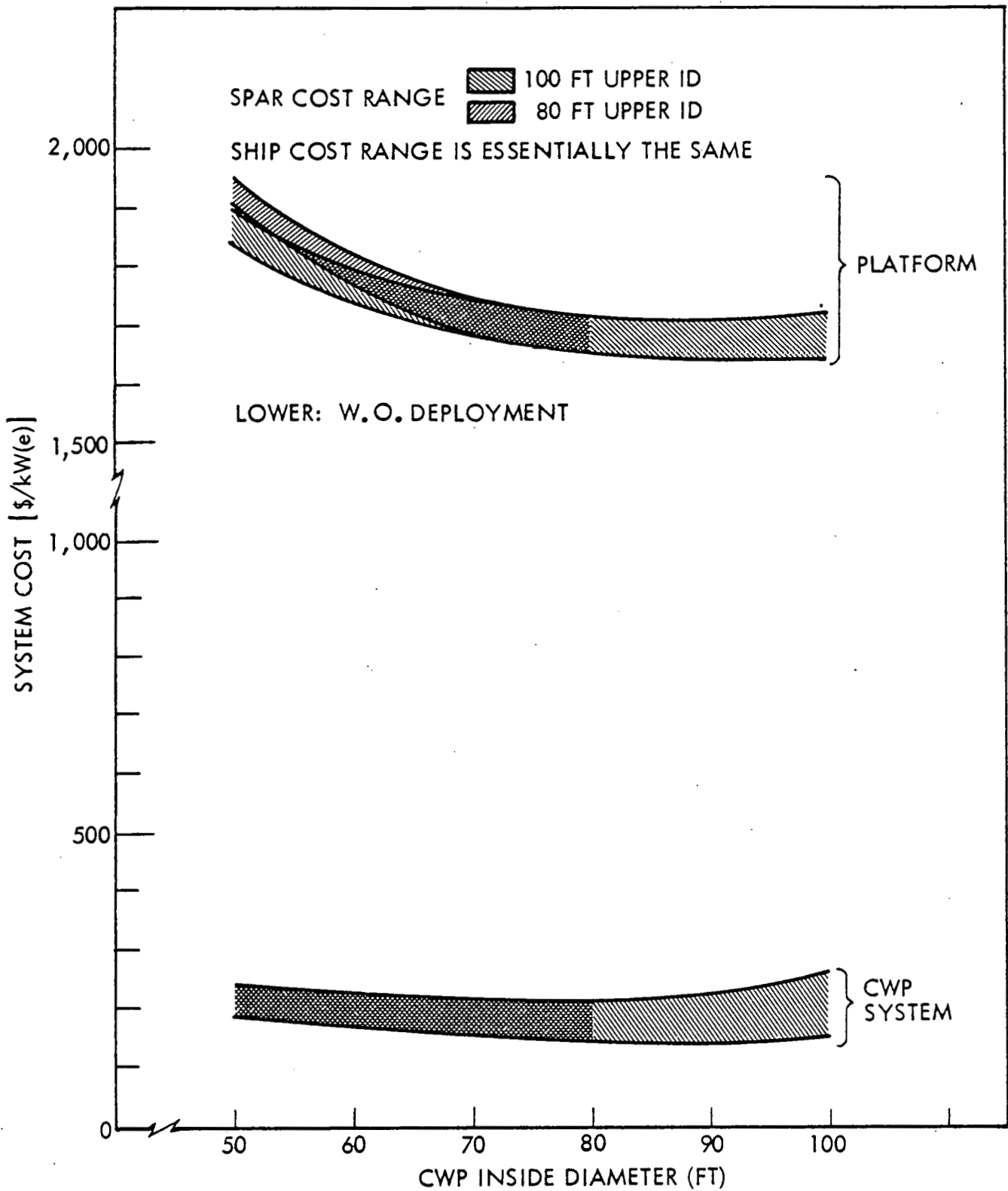


Fig. A-5 OTEC Plant System Cost vs. CWP Diameter

Detailed design based on these requirements may lead to sections other than thin-walled prismatic sections.

The current induced shear and bending stresses are

$$S_{CS} = \frac{F_S}{\pi (R_O^2 - R_I^2)} \qquad S_{CT} = \frac{4M_S FR_O}{\pi (R_O^4 - R_I^4)}$$

where:

- $F_S$  = Current Shear Force at Section S
- $M_S$  = Current Moment at Section S
- $F$  = Form Factor for Shell, = 1.2
- $R_I$  = Inside Diameter
- $R_O$  = Outside Diameter
- $S$  = Distance from Pipe Intake to Section

The shear and moment are obtained for the extreme current profile as described in Section 2.3.4, Volume I.

Hoop stress due to differential pressure across the pipe wall is:

$$S_{HT} = \frac{PR_O}{t}$$

where:

- $P$  = Pressure differential
- $t$  = Wall thickness

The pressure drop inside the pipe is the sum of inlet loss, static head drop over the entire length, pressure drop due to density increasing with depth, and pressure drop due to friction. Then:

$$P_S = 0.25 q_{IN} q + g \int_0^S (\rho - \rho_0) (Z - S_0) dS + 0.02 \frac{S q}{ZR_I}$$

where:

- $Z$  = depth

$$q = \frac{1}{2} \rho \left( \frac{Q}{\pi R_I^2} \right)^2$$

$Q = 49,016$  cfs ( $1400 \text{ m}^3/\text{s}$ ) is the required flow rate for 400 MW(e) cold water.

The density profile is that given for the Caribbean (Reference 1).

### Dynamic Loads

The dynamic loads considered are those induced by the seaway, which are vertical acceleration, shear and bending.

$$S_{ZT} = \frac{z}{z} \int_0^S \frac{(\rho_M - \rho_W) (R_O^2 - R_I^2)}{R_O^2 - R_I^2} dS$$

$$S_{DS} = \frac{F_D}{\pi (R_O^2 - R_I^2)}$$

$$S_{DT} = \frac{4F M_D R_O}{\pi (R_O^4 - R_S^4)}$$

The dynamic loads are derived from the results presented by Hydranautics for the internal spar and ship 100 MW(e) (net) designs of Phase I. A comparison of the 400 MW(e) (net) ship conceptual design with the earlier 100 MW(e) concept shows that the Froude scale factor which is proportional to the cube root of displacement ratio is 1.03 between the two designs and the scale factor which is proportional to ratio of dimensions varies between 0.8 to 1.3. The corresponding factors for the spar are 0.96 and 1.2 to 1.5. Based on the fact that the ratio of Froude scale factors is near unity, the pipe loads for the 100 MW(e) platform are projected to apply directly to the 400 MW(e) plant designs.

The shear force in the CWP is assumed to be a linear function of wave height and pipe stiffness and to vary sinusoidally with axial location on the pipe. Identifying the largest shear force along a concrete pipe on the spar as the "maximum" shear, then the dependence of this response to wave height is shown in Figure A-6 to be non-linear for the thin-walled pipe and approximately linear above  $H_s = 20$  feet for the thick-walled pipe. The functional dependence

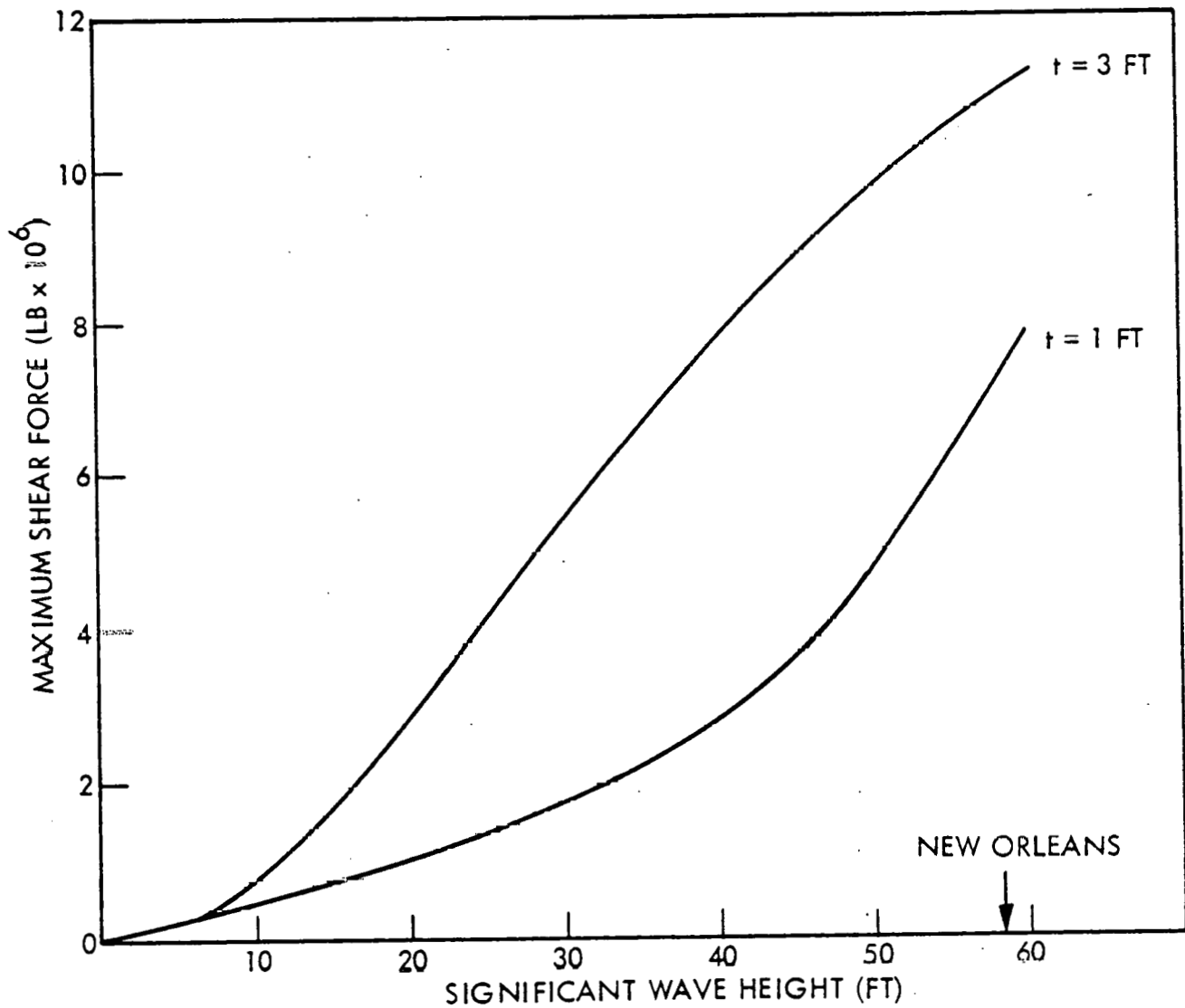


Fig. A-6 Validation of Dynamic Shear Force With Wave Height - Internal Spar With Concrete CWP, 100-MW(e) (Net)

is assumed to be linear and independent of thickness, thereby yielding conservative loads for thinner walled pipes.

The shear distributions for several cases were compared to derive the following approximate functional dependence of shear on axial position (see Figure A-7).

$$F_D = \begin{cases} \frac{8S}{L} F_{MAX}, & S < \frac{L}{8} \\ F_0 + (F_{MAX} - F_0) \cos \left( \frac{2\pi (S - L/8)}{7L/16} \right), & \frac{L}{8} \leq S \leq L \end{cases}$$

where:

- S = Distance from pipe intake to section
- L = Pipe length
- $F_0 \approx F_{MAX}/2$
- $F_{MAX}$  = Maximum shear force on pipe

The maximum shear is shown in Figure A-8 to be linearly dependent on pipe stiffness up to  $60 \times 10^{12}$  lb-ft<sup>2</sup>. The shear decreases with stiffness, increasing beyond this limit. The functional model which approximates this pipe loading is then:

$$\begin{aligned} F_{MAX} &= 6.2 \times 10^{-9} (EI) H_{1/3}, \quad EI \leq 60 \times 10^{12} \\ &= 4.4 \times 10^5 H_{1/3}, \quad EI > 60 \times 10^{12} \end{aligned}$$

The significant value of shear is doubled to estimate the value of extreme response in a seaway.

The bending moment is treated in a manner similar to the modeling of shear force. Linear dependence on wave height is assumed yielding a conservative moment for thinner pipes (Figure A-9). The moment distribution along the pipe, shown in Figure A-10 for several cases of concrete wall thicknesses, is approximated as:

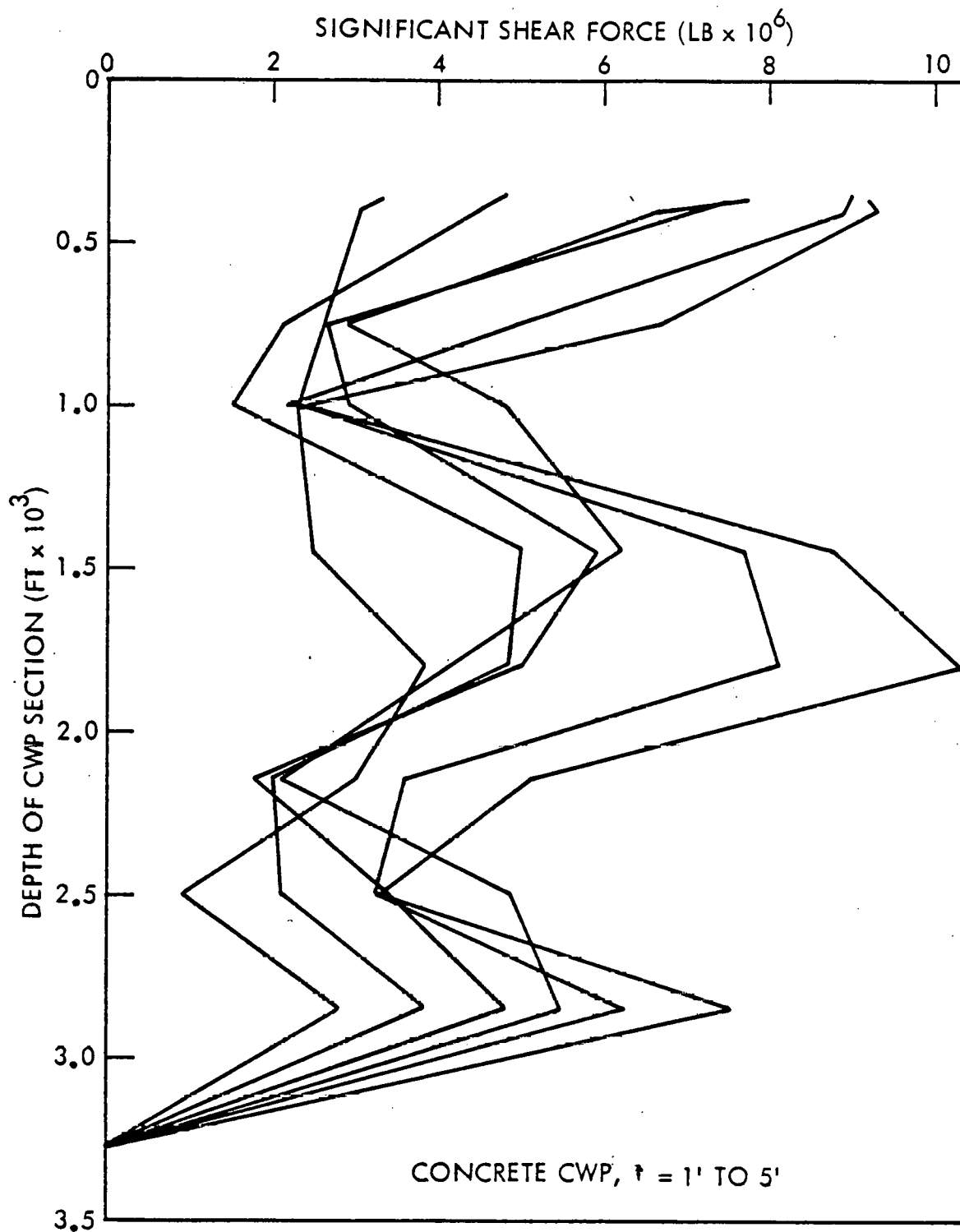


Fig. A-7 Dynamic Shear Force on CWP  $H_{1/3} = 45.8$  Ft Spar (Internal)

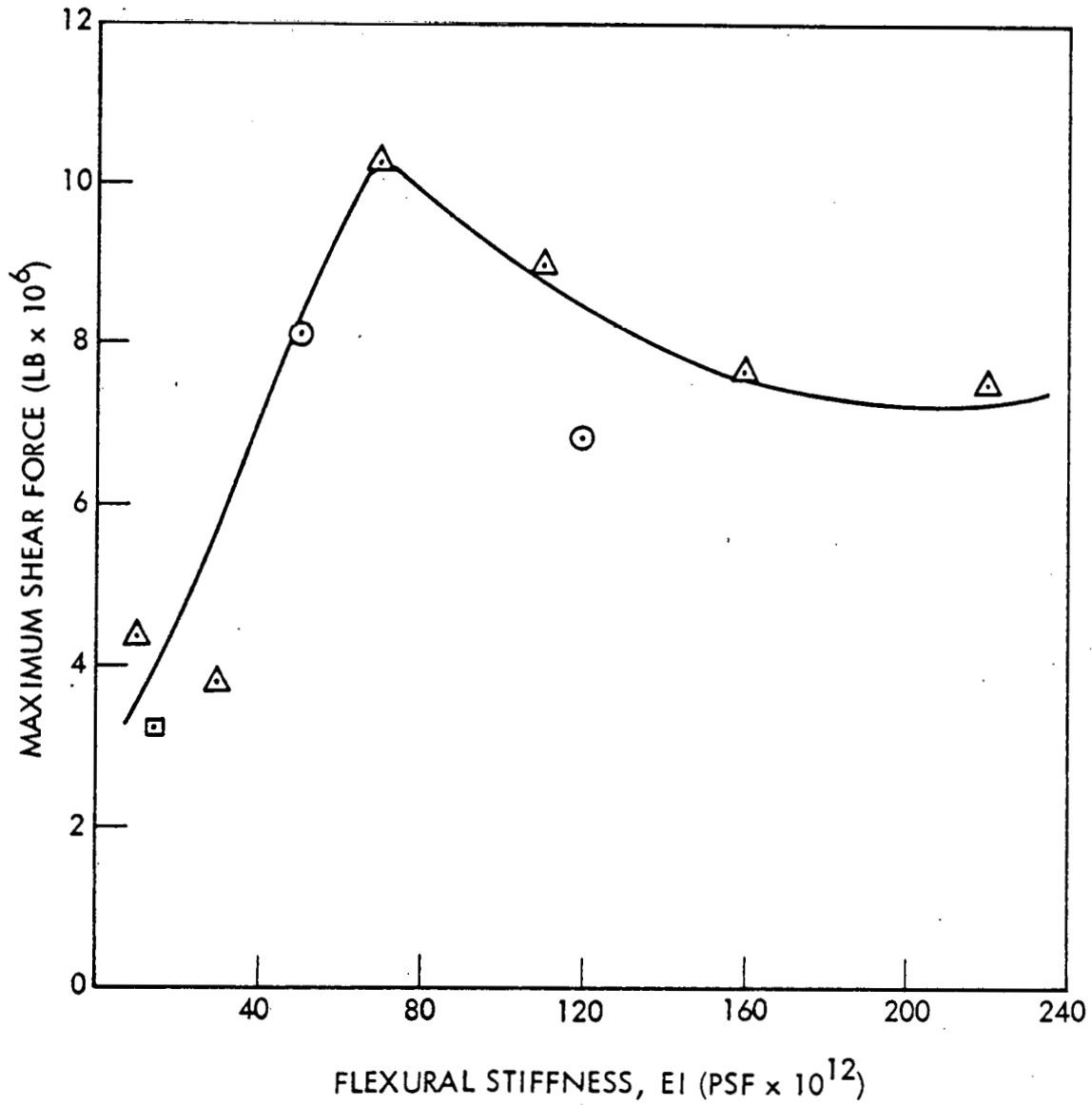


Fig. A-8 Maximum Shear in CWP vs. Stiffness of CWP Spar,  $H_{1/3} = 45.8$  Ft

A-20

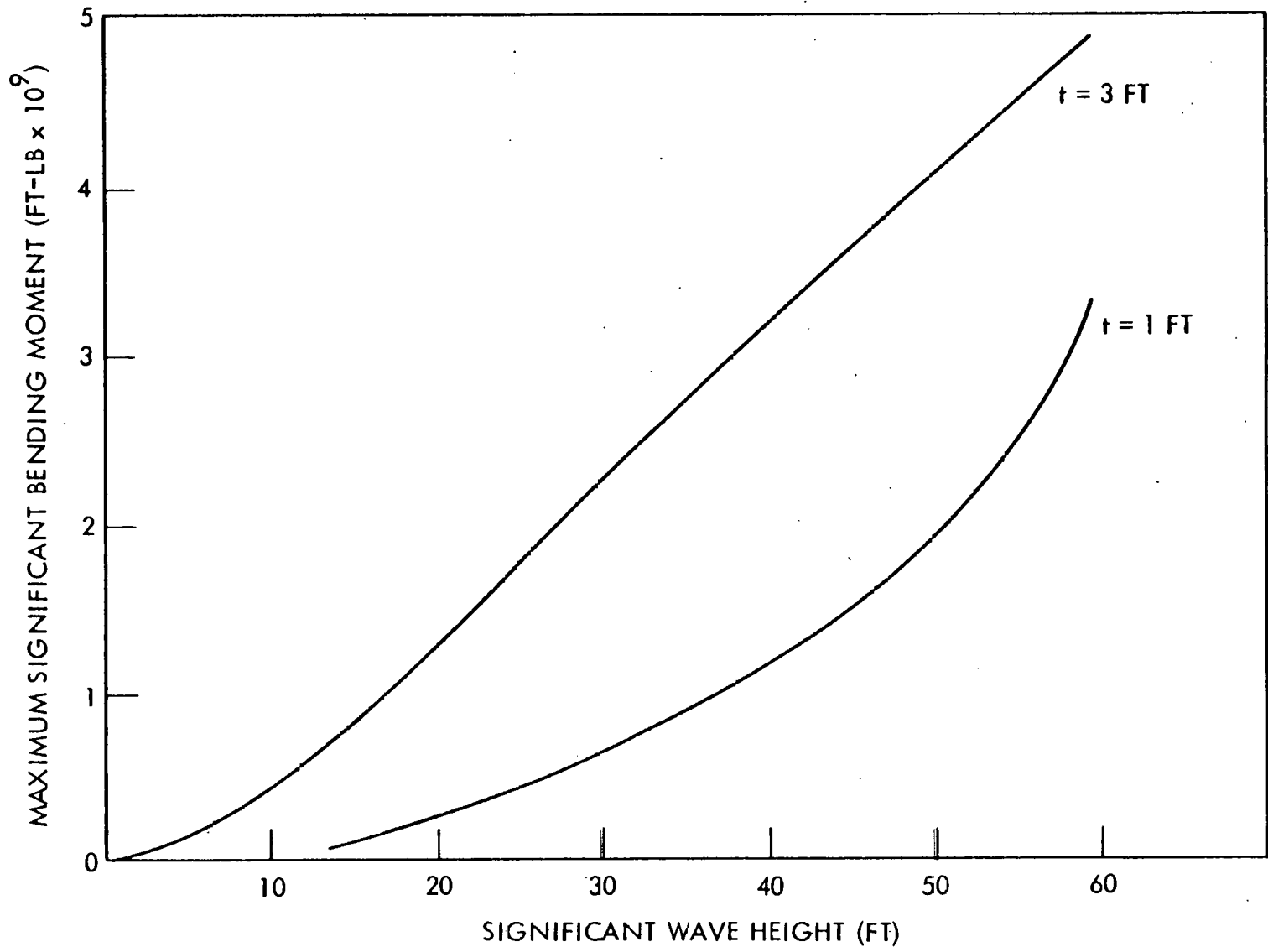


Fig. A-9 Dynamic Bending Moment vs. Wave Height - Internal Spar With Concrete CWP 100 MW(e) (Net)

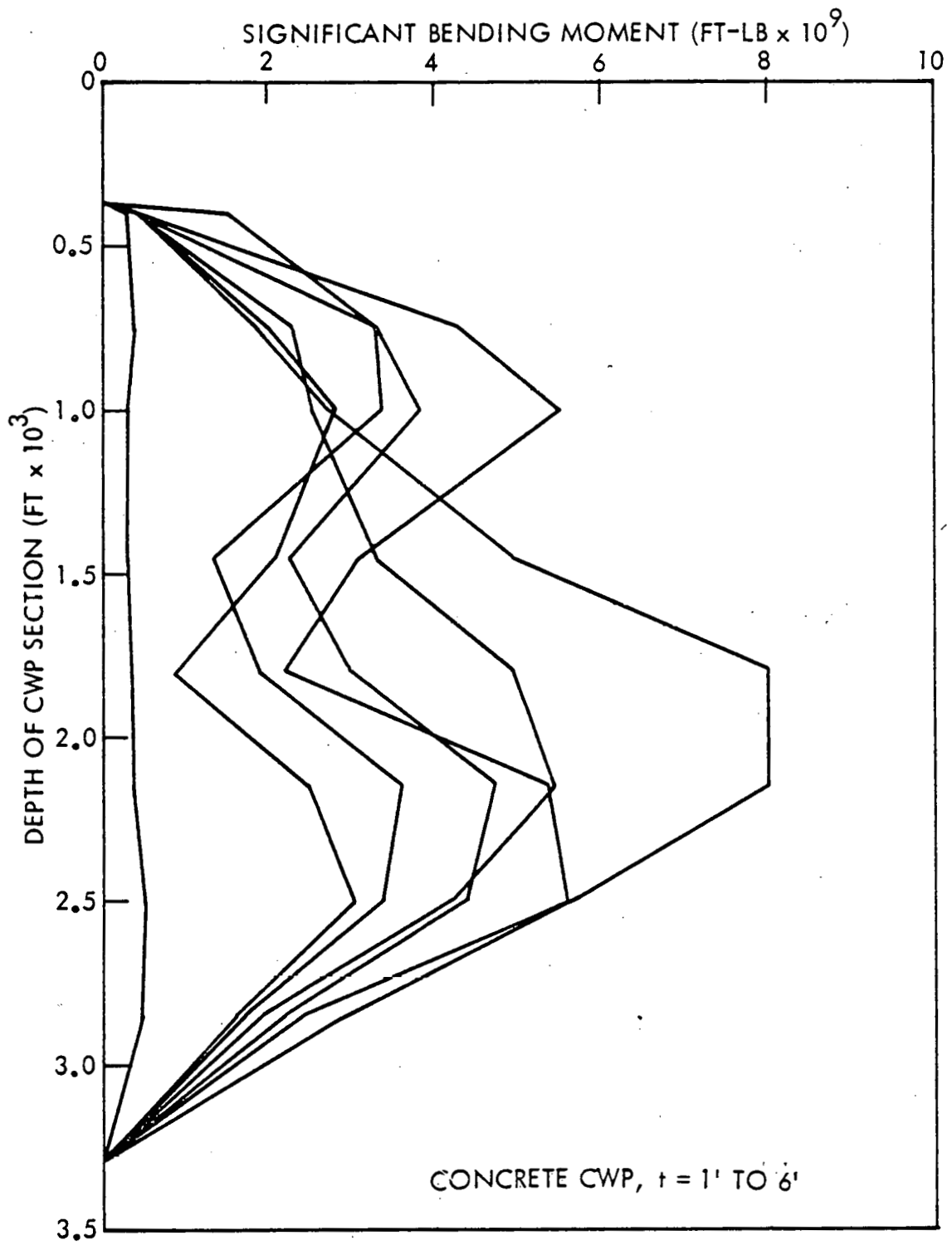


Fig. A-10 Dynamic Bending Moment in CWP  $H_{1/3} = 58.1$  Ft Spar (Internal)  
A-21

$$M_0 = \begin{cases} M_0 \frac{8S}{L}, & s \leq \frac{L}{8} \\ M_0 + (M_{MAX} - M_0) \sin\left(\frac{2\pi(S - L/8)}{L/2}\right), & \frac{L}{8} < s \leq \frac{7L}{8} \\ 8M_0 (1 - S/L), & s > \frac{7L}{8} \end{cases}$$

where:

$$M_0 = \frac{2}{3} M_{MAX}$$

The maximum-moment dependence on pipe stiffness is similar to the shear force, as shown in Figure A-8. Moments for three materials and up to five thicknesses increase with stiffness up to the same stiffness at which the shear force decreases. The moment is therefore assumed to be linearly dependent on stiffness up to  $60 \times 10^{12}$  lb-ft<sup>2</sup> and to be independent of stiffness above this value for a submerged platform(spar).

$$\text{Thus, } M_{MAX} = \begin{cases} 2 \times 1.56 \times 10^{-6} (EI) H_{1/3}, & EI \leq 60 \times 10^{12} \\ 2 \times 10^8 H_{1/3}, & E/I > 60 \times 10^{12} \end{cases}$$

In the case of a surface platform the maximum moment increases uniformly in the stiffness range investigated. ( $EI$ :  $4-220 \times 10^{12}$  psi-ft<sup>4</sup>). Assuming that the ship response is similar to that of the disc (circular barge) the model for maximum moment on the pipe attached to the ship is then:

$$M_{MAX} = 1.3 \times 10^{-6} (EI) H_{1/3}$$

The validity of this functional model of dynamic shear and bending moment can be established by comparison with results obtained with the program which provided the original data set. Of particular interest is the extrapolation of stiffness dependence from the 54 feet (16 m) to 70 feet (21 m) diameter pipe.

The pipe bending stiffness is reduced by introducing flexible joints connecting sections of pipe to form the 1000 m length of pipe. The effective stiffness is obtained as follows:

$$\frac{1}{(EI)_{EFF}} = \frac{1}{(EI)_K} + \frac{1}{(EI)_{SEGMENT}}$$

where,

- EI = Stiffness of CWP
- $(EI)_K$  = Joint stiffness, =  $K\ell$
- $(EI)_{EFF}$  = Equivalent pipe stiffness
- K = Rotational stiffness of joint
- $\ell$  = Section length
- I = Sectional moment of inertia
- E = Young's modulus

then,

$$E_{EFF} = \frac{K\ell E}{EI + K\ell}$$

The section length is assumed to be approximately 100 feet for ease in handling, while rotational stiffness of  $10^{11}$  ft-lbs/radian provides significant reduction in bending moment and is a feasible design requirement. The resulting effective stiffness for a jointed concrete CWP is approximately ten percent of the unstiffened pipe.

### Resultant Stress

The combined stress is obtained by assuming that the dynamic loads are in phase over the entire length of pipe and may be superimposed on the static loads. Then, the resultant maximum principal stress is given by:

$$S = \frac{S_1 + S_2}{2} + \left[ \frac{(S_1 - S_2)^2}{4} + S_3^2 \right]^{\frac{1}{2}}$$

where:

$$\begin{aligned} S_1 &= S_{AT} + S_{ZT} + S_{DT} + S_{CT} \\ S_2 &= S_{HT} \\ S_3 &= S_{DS} + S_{CS} \end{aligned}$$

### Material Properties

The allowable stress for each material provides a safety factor of two or more on ultimate strength. This is considered appropriate for the extreme loads imposed by the 100 year storm. The mechanical properties of materials

and fabricated costs used in the analysis are listed in Table A-4.

TABLE A-4  
PROPERTIES OF MATERIALS

<u>MATERIAL</u>	<u>ALLOWABLE STRESS, PSI</u>	<u>YOUNG'S MODULUS PSI, 10<sup>-6</sup></u>	<u>DENSITY LBS/FT<sup>3</sup></u>	<u>POISSON'S RATIO</u>	<u>COST, \$/LB</u>
Lightweight Concrete	2,500	3	110	0.15	0.19
GRP	10,000	2	93.7	0.3	2.0
Aluminum	23,000	10.2	176.6	0.33	1.5

Pipe thickness required to develop combined stress that is within the material allowable is dependent on external loading, while loading is dependent in part on thickness. As thickness decreases to zero the dynamic loads go to zero, if the above functional model is valid in the limit. The constraint imposed on thickness arises from the elastic stability requirements which vary with the type of load. In addition, concrete minimum wall thickness is approximately 1 ft. The stability criteria for transverse bending of the pipe is:

$$S_B = 0.72 \frac{E}{(1 - \mu) \pi} \frac{t}{R}$$

while that for external pressure is:

$$S_P = 0.25 \frac{E}{1 - \mu^2} \left(\frac{t}{R}\right)^2$$

Twice the thickness determined by these criteria provides adequate factor of safety against inelastic buckling. Of the two criteria, stability under external pressure requires the larger thickness and is the lower bound of pipe wall thickness. This thickness is then increased to provide adequate strength in those lengths of pipe where combined stress would otherwise exceed the allowable stress. The result is a CWP of minimum material having non-constant thickness lengthwise. An example of results for a concrete pipe are shown in Table A-5.

Pipes with other than thin-walled sections, composite materials, added buoyancy on pipes detached from the platform are not considered. The high cost

Table A-5  
 CONCRETE CWP DESIGN CHARACTERISTICS

HEIGHT FT	THICKNESS FT.	AXIAL PSI	HOOP PSI	CUR.SHEAR PSI	CUR.BEND PSI	DYN.SHEAR PSI	DYN.BEND PSI	RESULT PSI
401.00	.96	154.55	57.32	.04	.54	110.53	2039.49	2200.
802.00	1.41	258.80	43.12	.09	1.73	30.80	2139.93	2450.
1203.00	1.02	514.49	55.47	.32	8.24	5.21	1934.29	2457.
1604.00	1.05	654.91	59.37	.61	20.49	83.27	946.59	1626.
2005.00	1.18	735.07	66.65	.90	37.63	75.18	1708.52	2483.
2406.00	1.76	641.52	47.88	1.12	47.79	3.19	1786.04	2475.
2807.00	1.45	935.32	65.14	3.11	117.79	29.97	1417.16	2470.
3208.00	1.20	1295.76	92.05	8.60	311.55	91.37	0.00	1613.

A-25

MATERIAL LIGHTWEIGHT CONCRETE  
 WEIGHT(AIR),LT 38929.  
 (WATER),LT 16279.  
 DIAMETER(ID),FT 70.000  
 ,M 21.341  
 MATERIAL COST,\$M 16.8

INSIDE DIAMETER,FT.70  
 MATERIAL (CONC.=1,SRP=2,ALUM=3,NYLON=4)1  
 SIGN. WAVE HEIGHT 50  
 JOINTED PIPES?(T OR F) T  
 SHIP?(T OR F)T

of syntactic foam (\$3/lb of payload) to provide a buoyant pipe is not a cost effective design solution compared with providing added buoyancy on the platform itself (\$0.27/lb of payload). Further, strength to support axial loading due to weight is adequately provided by the section required for stability under external loading.

The indicated costs include material and fabrication costs, and in the case of jointed pipes, a cost for material and fabrication of the joints (see Figure 3.2.2-2). Costs for a single joint, based on \$1.35 per pound of steel, is \$574,263 for the joint assembly and \$7273 for the ring assembly. Based on Crawford's learning curve, the steel cost for 27 units required in the pipe on the spar (29 for the pipe on the ship) is \$11M. Including \$3M for the rubber inserts and graphite bearings, total joint cost is approximately \$14M. Although this cost assumes that all joint costs are equal to the cost of the uppermost joint, in fact, less steel is required at lower elevations since the axial load decreases with depth. Pipe joint costs are assumed to be constant with diameter as axial load is independent of diameter.

## RESULTS

CWP results are presented for jointed and non-jointed designs attached to the 400 MW(e) ship and spar, Figures A-11 thru A-14 . In all cases pipes with sections connected by joints having specified rotational fixity require thinner wall sections and are therefore lower cost concepts. Further, concrete is shown to yield significantly lower cost designs than either the highest cost glass-reinforced plastic (GRP) or aluminum. The pipe attached to the spar is lower in cost than the pipe-ship combination for aluminum and GRP, while for the concrete pipe the ranking is dependent on diameter and site (wave height).

The costs of jointed pipes, Figure A-11, with diameter of 21 to 30 meters (70 to 100 ft) for New Orleans range from \$32M to \$36M for concrete, \$116M to \$166M for aluminum, and \$126M to \$196M for GRP. Cost increments for a pipe of 21 meters (70 ft) diameter attached to the ship are zero for concrete, \$1.0M/ft for aluminum and \$1.1M/ft for GRP. In contrast, costs for non-jointed pipes decrease with increasing diameter, Figure A-12 .

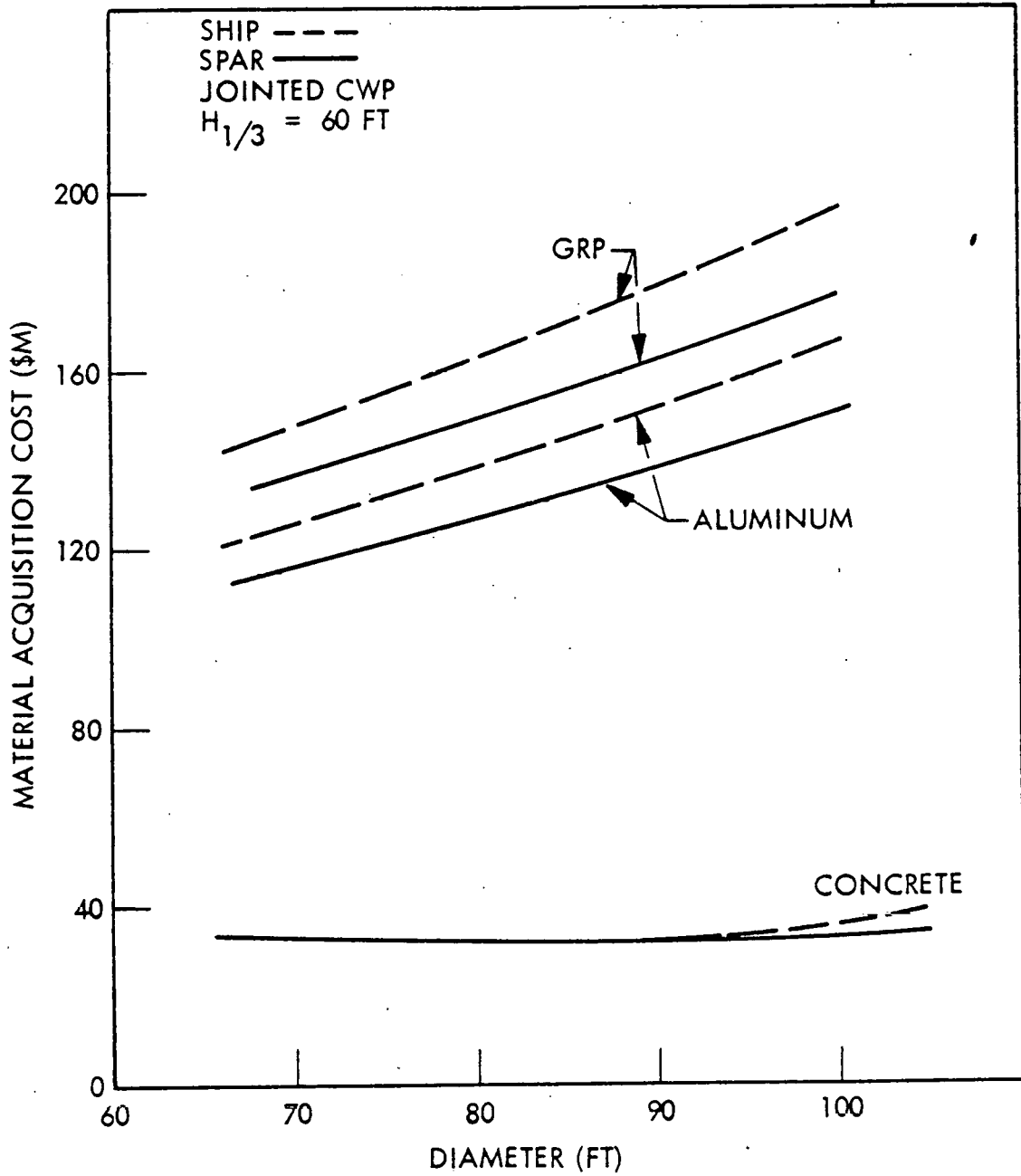


Fig. A-11 Variation of CWP Cost With Diameter - 400 MW<sub>e</sub> Net

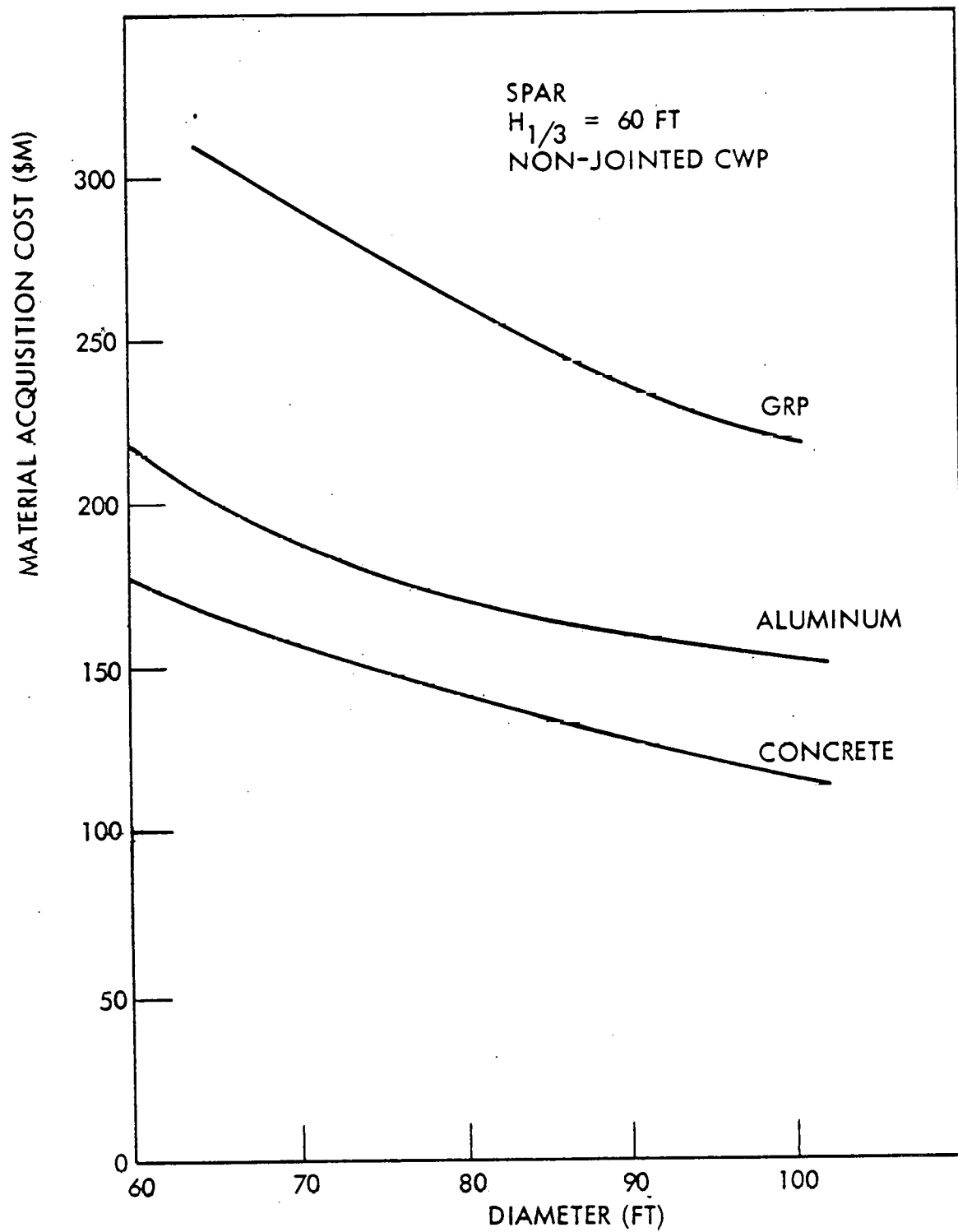


Fig. A-12 Variation of CWP Cost With Diameter - 400 MW<sub>e</sub> Net  
 A-28

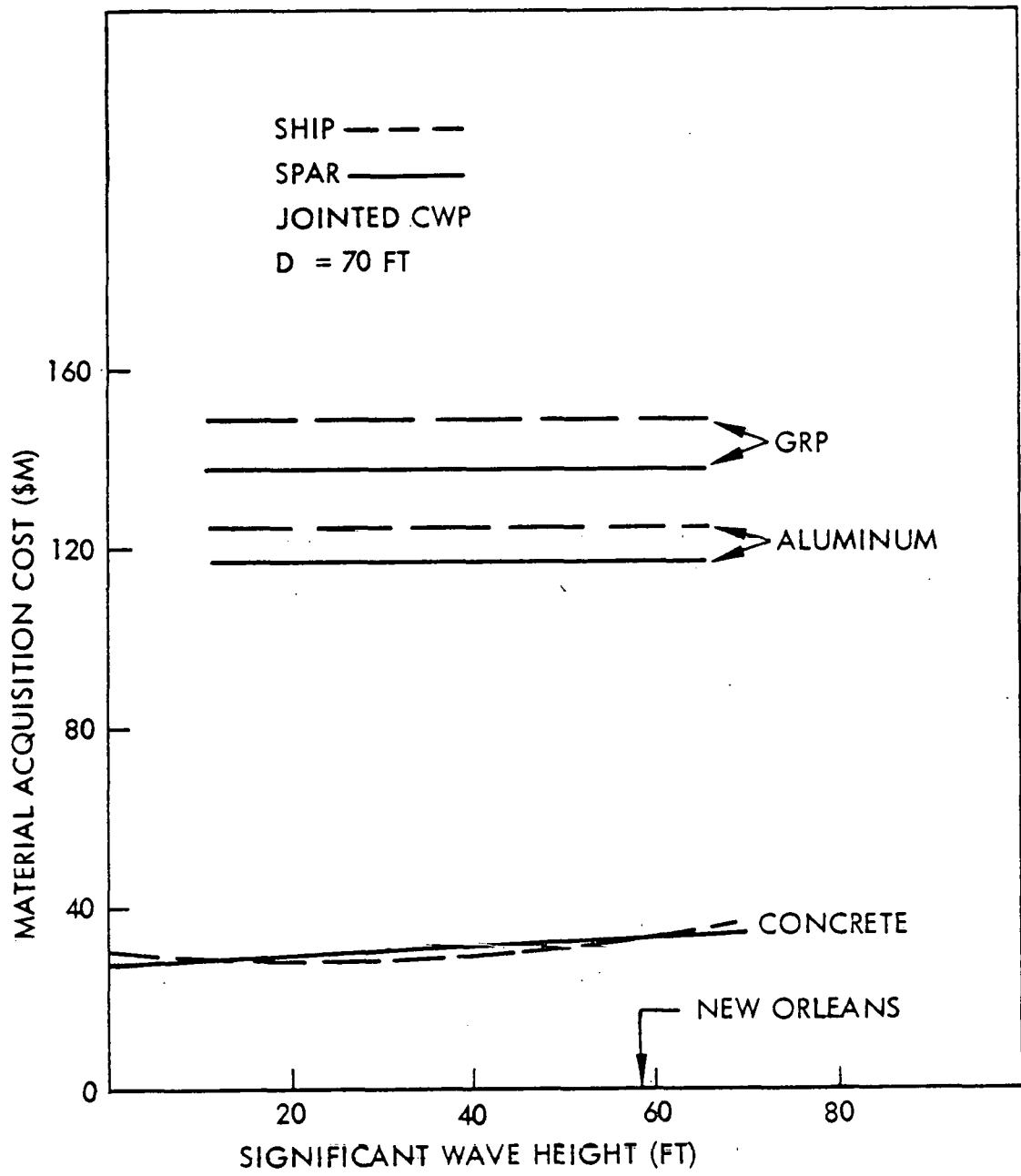


Fig. A-13 Variation of CWP Cost With Wave Height - 400 MW<sub>e</sub> Net  
A-29

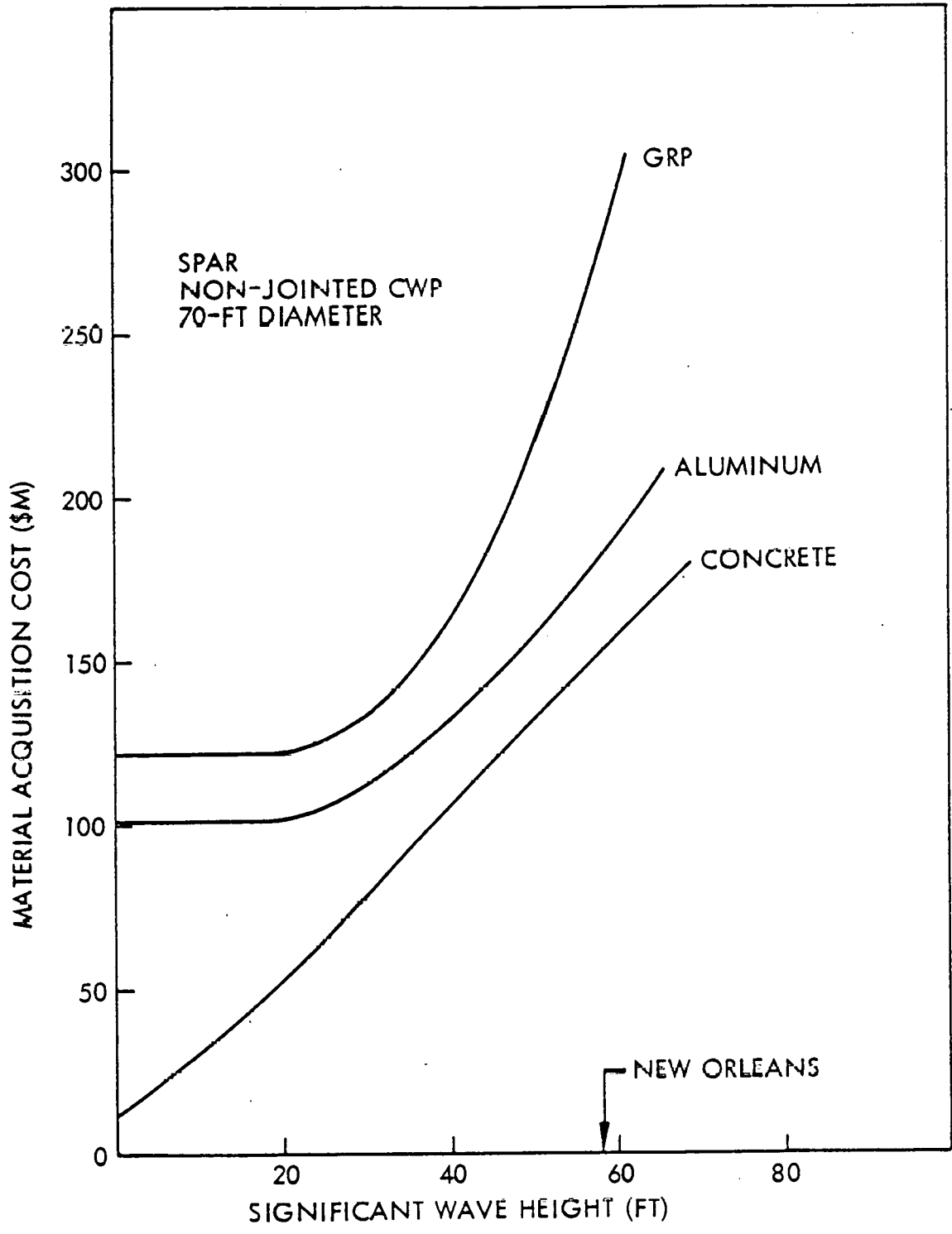


Fig. A-14 Variation of CWP Cost With Wave Height - 400 MW<sub>e</sub> Net

Thinner wall thickness ratios,  $t/R$ , are required for larger diameter pipes since the pressure difference across the wall decreases with diameter for constant flow rate requirement. In opposition, the dynamic bending moment and shear increase with diameter due to increased stiffness. However, these dynamic loads are assumed to be independent of stiffness for stiffness values beyond the range of existing data as defined in the preceding section.

Site dependence is characterized by wave height in the 100 year storm (Ex. 58.1 feet for New Orleans). Current-induced shear and bending stresses for these large diameter pipes are negligible and therefore do not provide discrimination of pipe costs between sites for jointed pipes. The GRP and aluminum pipe costs are shown to be independent of wave height (Figure A-13). This results from the adequacy of pipe wall thickness, which is driven by the requirement for shell stability, to accommodate dynamic loads in the range of wave heights 0 to 60 feet. However, the concrete pipe costs increase with wave height from \$27M at zero wave height to \$33M at New Orleans. In the case of non-jointed pipes, cost significantly increases above 20 foot waves for GRP, \$121M to \$290M and aluminum, \$100M to 187M. Cost of non-jointed concrete CWP increases uniformly from \$12M at zero wave height to \$152M at New Orleans. In all cases the flexibly-jointed pipe is lower in cost than the non-jointed pipe.

The cost for the jointed concrete CWP selected as a baseline for New Orleans is \$24.5M for the ship and \$22M for the shorter length of pipe for the spar.

#### ALTERNATE CONCEPT

A soft pipe concept has been proposed for the OTEC CWP. Although this concept has not been sufficiently developed to provide reliable costs, preliminary estimates indicate that costs of soft CWP are comparable to jointed concrete pipe costs. The estimated cost for assembled, rubber impregnated nylon fabric for an 80 foot diameter pipe is \$27M. This cost is extrapolated from costs for smaller fabric designs and therefore does not include increased costs for handling larger fabric assemblies. Also, it does not include joints and the system for pressurizing the annulus. Since the pipe weight in water is negligible

compared with concrete, the soft pipe concept requires minimal buoyancy on the platform for pipe support, thereby reducing platform costs. This concept is, therefore, shown in both ship and spar platform designs and costs.

The soft pipe consists of an inner and outer rubber-nylon fabric wall connected by a set of 50 radial webs in the annulus. The outer wall diameter for an 80 foot ID pipe is 140 feet. For a pipe having 3 psid collapse pressure, a static pressure of 7 psid in the annulus must be maintained continuously to provide stability of the configuration. The pipe weight in air is 2857 Lt and 610 Lt in water, including 607 Lt of sand ballast in the bottom to react current loads. Material ultimate strength is 2500 to 4000 pounds per lineal inch (PLI), allowable stress is 1000 PLI, flexural stiffness is  $2.3 \times 10^{11}$  lb-ft<sup>2</sup>, extension stiffness is  $1.3 \times 10^8$  lbs, and fabric specific gravity is 1.06.

Further analysis and development is required to validate this concept and to substantiate the costs. This includes dynamic loads analysis, fatigue strength and water absorption predictions for material in seawater for 40 years, fabric to joint connection to minimize fatigue and constructability of large panels.

#### Reference

1. Effect of Oceanic Flow Patterns on the Thermal Efficiency of Ocean Thermal Energy Conversion (OTEC), D. J. Fry, Carnegie-Mellon University, Report COO/2895-3, April 1976.

APPENDIX B

OTEC COST ESTIMATING SHEETS AND NOTES

## APPENDIX B

### OTEC COST ESTIMATING SHEETS AND NOTES

This appendix provides detailed cost breakdowns to the third or fourth levels of the WBS as appropriate, and is intended as background information to the cost summaries presented in Sections 3.11 and 4.11 for the ship and spar hull configurations, respectively. Discussion of relevant points is presented in the form of notes to the cost estimating sheets. For the sake of brevity, these notes are arranged by WBS element number, with ship and spar configurations treated together. Phased cost information was not developed in most cases and consequently is provided only where desirable to explain differences between the costs of first and follow-on units.

#### Basic Costing Approach

The eight OTEC plants forming the OTEC park are regarded as production units of identical design. It is assumed that no major manufacturing or technological advances are required of the first unit, and so its basic construction cost is the same as that of the following seven units. Facility, tooling and equipment, and design costs are allocated arbitrarily to the first unit. They could just as reasonably be treated as a capital expenditure to be amortized over the eight units in the OTEC park. However, by virtue of it being the first of its kind, the cost of engineering systems integration and project management-related activities will be higher for the first unit than for follow on platforms, and this is reflected in the parametric approach followed in estimating these costs, discussed in Section 3.11.

#### Notes to Cost Estimating Sheets

##### WBS 1.0 PLATFORM SYSTEM

Tables B.1 to B.4 show the cost breakdown for WBS element 1.0 for the first and follow-on units of both the ship and spar configurations. The difference in cost between first and follow-on units for both types of platform

are accounted for by three factors:

- o Higher platform integration and engineering costs (WBS element 1.1) for the first units, as discussed in Section 3.1.12.
- o First unit design costs affecting WBS elements 1.2, 1.3, 1.4, 1.6, and 1.7. These estimates are rough order of magnitude figures based on engineering judgement.
- o The cost of assembly fixtures and forms (WBS element 1.6), also charged to the first unit and estimated on the basis of engineering judgement and fragmentary information from similar projects.

Hull and structure costs (WBS element 1.2) are estimated on the basis of volumetric concrete requirements, assuming a cost of 750 \$/M<sup>3</sup> for hull components and of 1050 \$/M<sup>3</sup> for columns. These unit costs are some 25% lower than those used in subcontractor reports (Sections 3.6 and 4.6). The figures used by the subcontractors are applicable only to first unit construction, and consequently include the cost of design and assembly fixtures and forms, which are accounted for separately in this report, as well as production engineering costs which are also shown here under separate headings. Estimates of concrete requirements were taken from the report by T. Y. Lin International.

Tables B.5 to B.8 provide cost breakdowns to the fourth WBS level for the position control system. In all cases, mooring lines, representing over 99% of WBS element 1.3.2, are the dominant cost component. Lines are assumed to have a six year life, and future line replacement costs are present worth at an 8% discount rate, assuming 5% yearly cost escalation. Hardware costs in this area were derived from supplier quotes.

Tables B.9 to B.12 present a further breakdown of auxiliary systems costs to the fourth level of the WBS. For the sake of consistency, the cost of WBS elements 1.4.3, 1.4.4, 1.4.6, and 1.4.7 were taken from the report prepared by Morris Gualnick Associates. HVAC costs for each platform were provided by the respective subcontractors. The cost of electrical and control systems was derived by adding \$800,000, to cover the cost of DACS and communication/

navigation systems as estimated by Earl and Wright, to the cost estimated for the WBS element by Morris Guralnick Associates, which did not include these items. Finally, WBS element 1.4.8 reflects the cost of ballasting and mating systems in the detachable power modules envisaged for the spar type platforms. It might also be noted here that in Tables B.1 to B.4 WBS element 1.5, Outfit and Furnishings, was assumed to be the same for both plants and the (higher) estimate prepared by Morris Guralnick Associates was adopted.

Tables B.13 and B.14 provide cost breakdowns for WBS element 1.7, seawater systems (excepting the cold water pipe). Seawater pump costs are the major cost component, amounting to over three quarters of the total for the WBS element. The warm water screens, accounting for roughly 15% of total cost, are the only other significant cost component of the seawater systems. Seawater pump costs were derived on the basis of vendor information received in the course of earlier OTEC work. Screening costs were extrapolated on the basis of size from (much smaller) commercially available screens; this may have resulted in a substantial overestimate. Finally, all other costs were estimated on the basis of weight and similarity to shipyard work or to received cost quotations, particularly for WBS element 1.7.7.

#### WBS 2.0 COLDWATER PIPE SYSTEM

Tables B.15 to B.18 present costs of the cold water pipe system to the third level of the WBS. Cost differences between first and follow-on units are due to the first unit being allocated all design costs, as well as higher estimated systems engineering-related expenditures. In all cases, pipe sections account for over half of total cost and inlet and screening for roughly 30%. In both cases, cost data was obtained from vendors; as was the case with warm water screens, the process of scaling up costs to screens of the dimensions required by OTEC plants may have resulted in a substantial overestimate. CWP/hull interface costs were estimated by LMSC on the basis of material requirements; no equipment is contemplated that would come under WBS elements 2.5 and 2.6.

## WBS 5.0 SYSTEMS ENGINEERING AND INTEGRATION

Tables B.19 and B.20 show the cost breakdown for WBS element 5.0, Systems Engineering and Integration. As discussed in Section 3.11 of this report, this WBS element is expected to amount to roughly 2% of the basic cost of the first plant, and 1% of that of follow-on units. This cost is expected to be roughly equally divided between the two third level WBS elements shown in the tables.

## WBS 6.0 SYSTEM TEST AND EVALUATION

Tables B.21 and B.22 provide a cost breakdown for WBS element 6.0, System Test and Evaluation. This cost component is expected to account for 4% of first unit costs, and 2% of that of follow-on units. In the latter case, all costs are expected to come under WBS element 6.3, covering the actual performance and evaluation of contemplated tests. The greater total cost expected for the first unit includes a somewhat higher cost for this WBS element, as well as comparatively small allocations for test planning and specialized test equipment.

## WBS 7.0 OPERATIONAL SUPPORT

Operational Support has been split into two subelements, 7.0-A, Capital Cost, and 7.0-B, Operating Cost. The estimating sheet for the former is shown as Table B.23, and the corresponding fourth level breakdown as Table B.24. The supply/maintenance base envisaged as WBS element 7.3.1 consists of a water-front administration building, limited storage and machine shop facilities, and a loading pier for tugs and workboats. The hotel barge, on which plant maintenance crews live while on site, is assumed to have a displacement of roughly 5000 tons and accommodations for roughly 160, as well as a 5000 KW(e) electrical plant and limited material storage and handling capability. Finally, the central DACS is assumed to be used as a park control center and contains individual displays and control consoles for each plant. Estimates for this WBS element were prepared on the basis of extrapolated earlier OTEC work, particularly the Test Facility Study (contract number E(04-3)-1156); they must be considered only approximately correct in the absence of more detailed requirements definition.

Table B.25 shows the costs associated with the second subelement of WBS element 7.0, annual operating and maintenance costs. The cost estimates assume all plants in the OTEC park are on an automatic operational mode, monitored from a central control center. This control center, located in the hotel barge on which all park personnel live while on site, is manned around the clock, thus necessitating three live-in, 20-man control crews. Plant maintenance is carried out by 12-man maintenance crews following the maintenance procedure developed in the course of the Power System Development Study. Operating in day shifts and with one support vessel each, two such crews, are expected to be required for routine maintenance of the plants in the park. In addition, a half a crew and a support vessel are kept in readiness at all times at the hotel barge to handle any unexpected problems that might occur; consequently, accommodations for 42 maintenance operators and five 6-man workboat crews are required on board the hotel barge. Administrative and other personnel bring total park personnel to approximately 160. Catering is provided from the support base on the mainland at a cost of 25 \$/man-day. Workboats, including their crews, are leased at a rate of 1200 \$/day. The average yearly cost of control, maintenance, and administrative personnel is 40,000 \$/man. All crews serve on a rotation cycle of two weeks on and two weeks off. Crews and supplies are transported by (leased) crew/supply boats operating a twice a week shuttle service. A five day platform hull inspection is carried out once a year by a submersible leased at a cost of 8000 \$/day. The operation of the hotel barge and supply center, the only support equipment owned by the OTEC park operator itself, is expected to cost roughly 2.2 million dollars per year. The cost of platform-related spares is estimated at  $\frac{1}{2}$  of 1% of the average cost of the platforms, or roughly six million dollars per year. Expendable materials are estimated at one tenth of the spares. For the purposes of reporting in Table B.25, some of the costs discussed above have been grouped as follows.

WBS 7.3 Peculiar support equipment: hotel barge and supply center operation, dedicated plant maintenance workboats

WBS 7.4 Common support equipment: crew/supply boats, submersible

## WBS 7.5 Personnel: crew wages and catering

It should be noted that the costs reported in Table B.25 do not include the cost of major power system maintenance at a drydock. This is expected to cost approximately 18 million dollars per year, of which roughly one half is accounted for by drydock costs, and one quarter each by tug fees and maintenance costs proper.

## WBS 8.0 DEPLOYMENT

Tables B.26 to B.29 show the cost estimated for WBS element 8.0, Deployment, broken down to the third level of the WBS. The difference between deployment costs for the first unit and follow-on units is due to the flotation chambers required from deployment which are charged only to the first unit. The deployment procedure and equipment requirements are as described in Section 3.1.7 and 3.2.7 for ship and spar platforms, respectively. Individual equipment costs assumed are as follows:

8000 hp tugs	6,500 \$/day
1500 hp tugs/workboats	1,500 \$/day
Large barges	2,500 \$/day
1500 ton crane barges	37,000 \$/day

A 50-man rigging crew is required on site for platform, mooring system and cold water pipe deployment, and a 15-man crew for power system deployment, at an average cost of 260 \$/man-day. While on site, these crews live on the park hotel barge, which is towed to the operating site along with the first plant. The mobilization site was assumed to be 1000 miles from the operational site; tug speeds of 3 knots when towing and 12 knots otherwise were assumed. The cost of hotel services and shore mobilization have been allocated to the four third level elements shown on the basis of their direct costs.

## WBS 9.0 INDUSTRIAL FACILITIES

Tables B.30 and B.31 provide rough cost estimates of construction facility costs; the limitations of these estimates have already been discussed in

Section 3.11. Ship platforms require a large construction basin for the hull and eight graving docks, each capable of accommodating simultaneously two heat exchanger/seawater pump subassemblies. The spar platform required a smaller construction basin, a deep water dock, and eight graving docks for power module construction. It has been assumed (arbitrarily) here that all plant components must be built at a dedicated facility. This is probably correct for the central core/hull, given its unique construction facility requirements. However, the power module subassemblies could be built easily in already available graving docks should this prove desirable.

#### WBS 10.0 ENVIRONMENTAL, LEGAL, LICENSING, REGULATORY, AND INSURANCE

WBS element 10.0 was calculated on the basis of average basic platform cost, as 3% of basic first unit cost and 2% of the cost of follow-on units, and Tables B.32 and B.33 are included here mainly for reference.

#### WBS 11.0 PROJECT MANAGEMENT

The costs estimated for WBS element 11.0 are 9% of first unit cost and 6% of the cost of other units, Tables B.34 and B.35. These costs are allocated among their component third level elements, with WBS elements 11.1, 11.4, and 11.6 being allocated twice the relative importance of the remaining individual elements.

Table B. 1 SHIP

SHIP PLATFORM , FIRST UNIT  
OTEC COST ESTIMATING SHEET -SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEM													207.6
1.1	Platform Int. & Engin.	P		5.0										10.0
1.2	Hull & Structure	B		10.0										46.7
1.3	Position Control Sys.	B		2.0										34.7
1.4	Platform Service Sys.	B		2.0										17.6
1.5	Outfit & Furnishings	B												0.5
1.6	Assembly Support Serv.	P		0.3				6.5						6.8
1.7	Sea Water Systems	B		2.0										91.3
1.8	Bio. & Corr. Control													0

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.

Table B.2 SHIP

SHIP PLATFORM, 2nd - 8th UNITS  
OTEC COST ESTIMATING SHEET -SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEM													179.8
1.1	Platform Int. & Engin.	P												5.0
1.2	Hull & Structure	B												36.7
1.3	Position Control Sys.	B												32.7
1.4	Platform Service Sys.	B												15.6
1.5	Outfit & Furnishings	B												0.5
1.5	Assembly Support Serv.	P												0
1.7	Sea Water Systems	B												39.3
1.8	Bio. & Corr. Control	B												0

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.

Table B.3 SPAR

SPAR PLATFORM, FIRST UNIT  
OTEC COST ESTIMATING SHEET -SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEM			7										262.4
1.1	Platform Inc. & Engin.	P		5.0										10.0
1.2	Hull & Structure	B		10.0										79.5
1.3	Position Control Sys.	B		2.0										32.7
1.4	Platform Service Sys.	B		2.0										33.6
1.5	Outfit & Furnishings	B												0.5
1.6	Assembly Support Serv.	P		0.3					12.5					12.8
1.7	Sea Water Systems	B		2.0										91.3
1.8	Blo. & Corr. Control													0

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.

Table B.4 SPAR

SPAR PLATFORM, 2nd - 8th UNITS  
OTEC COST ESTIMATING SHEET -SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEM													328.6
1.1	Platform Inc. & Engin.	P												5.0
1.2	Hull & Structure	B												69.5
1.3	Position Control Sys.	B												30.7
1.4	Platform Service Sys.	B												33.6
1.5	Outfit & Furnishings	B												0.5
1.6	Assembly Support Serv.	P												0
1.7	Sea Water Systems	B												89.3
1.8	Blo. & Corr. Control													0

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.







Table B.11 SPAR

SPAR PLATFORM, FIRST UNIT  
OTEC COST ESTIMATING SHEET - SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.4	Platform Service Sys.													35.6
1.4.1	Engineering/ Design	P												2.0
1.4.2	Heat, Vent., Air Cond.	B												11.8
1.4.3	Material Handling	B												3.3
1.4.4	Power Generation	B												2.0
1.4.5	Control and Electrical	B												3.7
1.4.6	Ancillary Systems	B												1.6
1.4.7	Ammonia System Support	B												2.6
1.4.8	Special Purpose/ Ballast	B												8.6

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.

Table B.12 SPAR

SPAR PLATFORM, 2nd - 8th UNITS  
OTEC COST ESTIMATING SHEET - SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.4	Platform Service Sys.													33.6
1.4.1	Engineering/ Design													0
1.4.2	Heat, Vent., Air Cond.	B												11.8
1.4.3	Material Handling	B												3.3
1.4.4	Power Generation	B												2.0
1.4.5	Control and Electrical	B												3.7
1.4.6	Ancillary Systems	B												1.6
1.4.7	Ammonia System Support	B												2.6
1.4.8	Special Purpose/ Ballast	B												8.6

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.













Table B.25 SHIP/SPAR

SHIP/ SPAR PLATFORMS, ALL UNITS- AVERAGE ANNUAL OPERATING COST OF PARK OF 8 PLANTS  
 OTEC COST ESTIMATING SHEET - SM

WBS		ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
NO.	TITLE					TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
7.0-B	OPERATIONAL SUPPORT													24.2
7.1	Spare Parts	P												6.0
7.2	Expendable Materials	B												0.6
7.3	Peculiar Support Eqpt.	B												3.5
7.4	Common Support Eqpt.	B												0.6
7.5	Personnel	B												13.5
7.6	Technical Manuals	B												0

\*ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.











