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THE STABLE PLATFORM IN MARINE ENTERPRISE

part 1 - mission analysis

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and

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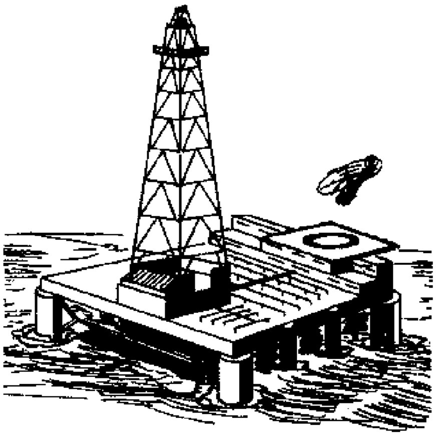

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THE STABLE PLATFORM IN MARINE ENTERPRISE

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by

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Prepared for

U.S. Department of Commerce
National Oceanic and Atmospheric Administration

under

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The figures listed here appear in section VIII at the end of this paper. The figure source is denoted on the figure by the appropriate reference number, or where the reference is written out, that reference appears in the Miscellaneous group at the end of Section VII.

ACKNOWLEDGMENTS

Very few technical reports are the product of the author's labor alone; this work is no exception. Mr. Edward Rosen labored long in the unearthing of many of the references. Mr. Julius Maiman had the onerous task of editing the text and making it readable. Mr. Bert Kieffer prepared every drawing, some of which are excellent renderings from sometimes indistinct photographs. Mrs. Debbie Elias did the typing of all drafts including this final realization. The authors hereby state their appreciation to these people and to those others who assisted in technical preparation but who are here nameless. It is self-evident that this paper is improved by the contributions of the above-named.

I INTRODUCTION

For a long time, the world's oceans played a rather prosaic role in the life of man. The sea was looked upon as the great void and, aside from some inconsequential fishing at its very edges, it remained largely ignored, until man's inquisitiveness and desire for riches launched him into the age of exploration. No sooner did man put to sea than it became (and, unhappily, still is) a glorious battleground. With the advent of serious world commerce, several hundred years ago, the great seas, functioning as highways of trade, still separated land masses and masses of people, although there was gradually developing a considerable awareness of things and people in distant places.

As the world continued to "shrink", we learned that the waters around us, once thought to be of infinite extent, in fact do cover some three-fourths of our planet. Moreover, as we barged into the twentieth century, we were titillated to learn further that the ocean was full of a lot of valuable things, besides fish.

What prompts our current excitement about the oceans? Like most of man's endeavors, it is sometimes fueled by greed or, more charitably, by a desire to improve our well-being. It is a small matter that man's survival may soon depend on his knowledge and use of the sea. This notion is largely ignored; indeed, man has a great propensity for building immunity to survival. Fortunately, there are sufficient future-thinkers who care enough about the fate of man and the oceans to hopefully restrain the kind of mismanagement that has decimated land resources.

In any case, we are keenly aware that the sea possesses untold wealth in natural resources. At least equally important is the space it possesses and, of course, water itself. All these we desire. Thus, the sea beckons and we respond. Unfortunately, it is a rather hostile environment to us.

We require an interface that will ameliorate the hostility and, to this end, we conceive devices that will hopefully afford an accomodation between man and the marine environment. Chief among such devices is the stable ocean platform that is designed to permit man to operate in the sea with a minimum of travail.

The uses of stable ocean platforms are the subject of the study reported here. It has been undertaken none too soon, because things are moving very fast in the world of offshore man-made structures. Indeed, there is a veritable frenzy of activity in getting new kinds of platforms off the drawing boards and into the ocean. There is every indication that man is no longer content to be a transient at sea; he is there to stay - today to work, tomorrow to play and perhaps ultimately to live. If that is the case then it behooves us to design and build platforms that are optimally efficient - that will do the job, with safety and at reasonable cost, without excessive damage to the marine ecosystem.

The purpose of this program is to ascertain the state of the art of stable platforms, to determine present and future mission requirements, and to assess, if possible, the optimal characteristics of platforms so that man can operate effectively and profitably in an often hostile environment. We are attempting, in effect, to synthesize all the available knowledge on platform design and behavior in such a way as to provide the best utilization of technology to achieve mission objectives. Or, alternatively, we aim to provide the means of choosing between alternatives in a way that will result in practical and economical realization of certain mission objectives. The end result will hopefully be greater commercial benefits.

The first phase of the program is completed and is the subject of this report. Its primary purpose is to establish the framework of the study program and to provide the body of data from which all work will proceed.

We began the investigation with a definition of stable platform that would permit the "sea-based system" to be considered. That is, if it was meant primarily to operate at sea rather than transit the sea, it was of interest. Thus, an oil tanker does not qualify but a fishing trawler does. The structures considered here may be as commonplace as a dredge barge or as far out as a jetport (wetport).

Having once established a working definition, the literature yielded almost 300 relevant references, with new material appearing almost daily and some certainly still undetected. This source material permitted us to determine that there were roughly 30 separate missions that required some kind of stable platform.(Section II.) It was also possible to list the kinds of platforms that are utilized in such missions. (Section III.) With this background material, we then undertook to develop the general requirements appropriate to platforms in terms of performance, logistics, economics and environmental effects. (Section IV.) Lastly, we examined each of 12 mission classes (that comprised 30 different missions) to determine the platform requirements for those missions. (Section V.)

This phase of the study concludes with a discussion of the salient features of the problem. This is followed by a list of all the references used in the study (classified according to general requirements and mission requirements - Section VII) and a set of 56 figures (Section VIII) depicting a wide variety of stable platform concepts.

II. LIST OF MISSIONS

The approach taken in this study is mission-oriented. That is, we are interested in stable platforms to the extent that they can perform a particular mission under certain constraints. This notion still admits of the possibility that a platform, with special capabilities, may suggest a hitherto not considered mission to which it can be applied. It goes without saying that a single mission may be served by more than one platform and, conversely, that a particular platform may be advantageously employed in different missions.

The literature search (Section VII) revealed a number of missions of which some were well defined and others were either vague or generally similar to prior-defined missions. Since there were about 30 such missions, they were classified in a dozen groups that reflect the closest commonality of platform requirements. This permitted a certain ease of handling, even though there was some arbitrariness in grouping, as will be seen.

Table I is a list of missions that shows the twelve general categories and the particular activities appropriate to each.

Table I. LIST OF MISSIONS

1. OFFSHORE DRILLING (Petroleum)
    - a. Geophysical exploration
    - b. Oil and Gas Production

2. OCEANOGRAPHIC RESEARCH

3. ELECTRONIC TRACKING AND SURVEILLANCE
    - a. Satellite Tracking
    - b. Communications
    - c. Radar Stations

4. WEATHER MONITORING AND NAVIGATION

5. OCEAN RESOURCE RECOVERY AND BOTTOM MODIFICATION
    - a. Mining
    - b. Dredging

6. FISHING
    - a. Artificial Fishing Banks (Lures)
    - b. Fish Harvesting
    - c. Fish Product Processing

7. OFFSHORE PROCESSING
    - a. Sea Water
    - b. Minerals
    - c. Petroleum

Table I. Continued

8. OFFSHORE POWER GENERATION
    - a. Nuclear
    - b. Current-Driven
    - c. Thermal

9. SURFACE SUPPORT OF SUBMERSIBLES AND BOTTOM STRUCTURES

10. OFFSHORE WORK
    - a. Construction
    - b. Salvage and Retrieval
    - c. Pipe Laying

11. OFFSHORE PERSONNEL SUPPORT
    - a. Living Quarters - Cities
    - b. Recreation - Hotels
    - c. Transportation - Air Terminals
    - d. Military Operations

12. OFFSHORE COMMERCE
    - a. Breakwaters and Artificial Harbors
    - b. Deep-Water Mooring
    - c. At-Sea Storage

There is no special pattern in the arrangement of Table I; each mission has one or more attributes that are common to the group. However, some missions might have been just as suitably located in other groups. Thus, 6C, Fish Product Processing, is included quite naturally in Fishing but would also have fit in Offshore Processing. From another point of view, it is seen that both mining and dredging, which comprise the group of Ocean Resource Recovery and Bottom Modification, utilize ship-like platforms almost exclusively and hence are appropriately grouped. On the other hand, Oceanographic Research utilizes virtually every type of platform available. So, what may be argued as arbitrary grouping in Table I is really an attempt at some form of organization of highly interrelated elements only for ease in handling. For the purposes of this study, particular groupings have no significance.

III. TYPES OF PLATFORMS

In Section II, a number of missions were listed. The common denominator of that wide spectrum of marine activities is the notion that a platform, of some type, is required to carry out the mission. Just as the missions are diverse, so are the platforms - in concept, size, and performance. Some are merely contiguous extensions of man's land domain, such as municipal jetports created by landfill projects; others are true offshore "islands" such as drilling platforms and fish factories. Some of these platforms are fixed to the bottom while others are floating. They may range in size from little more than a buoy handled by a couple of men to something like a small city.

In view of the foregoing, it will come as no surprise that grouping platforms, in some sensible way, is likely to be an onerous task, and so it was. Grouping by mission is quite impossible, since it has already been pointed out that a single platform may serve a variety of missions and that, conversely, a single mission (e.g. oceanographic research) may be served by a variety of platforms.

It was decided, somewhat arbitrarily, that the major divisions would correspond to that basic attribute of platforms which described whether it was fixed to or resting on the bottom (submersible), floating with the flotation unit below the surface (semisubmersible), or floating with the flotation unit in the free surface (floating). Further subdivisions within the major divisions were likewise arbitrary but, as can be seen in Table II, it is a relatively simple matter to locate platforms according to the breakdown of attributes as given.

Table II. TYPES OF PLATFORMS IN CURRENT USE*
(numbers in parentheses correspond to figures in Section VIII)

I	SUBMERSIBLE		
	A. Temporary		
		1) jack-up	(1-3)
		2) monopod	(5)
		3) articulated column	(6)
		4) perforated	(55)
	B. Permanent		
		1) triangular	(27)
		2) quadrupod	(28)
		3) multi-leg	(41,* 44A)
		4) landfill	(36, 44C)
II	SEMISUBMERSIBLE		
	A. Spherical		
		1) buoy	(18)
	B. Vertical columns		
		1) single	(24, 25)
		2) double	(26)
		3) triple	(12)
		4) quadruple	(13)
		5) V-shape	(4)
	C. Hull-shape		
		1) multihull	(11, 14, 15, 44B)

---

* Indicates concept only.

Table II (continued)

III FLOATING	
A. Single Unit	
1) ship	(8B, 35)
2) barge	(8A, 10, 34, 38, 39, 40)
3) buoy	(16, 18-24, 29, 30, 46)
4) cylinder	(17, 48)
B. Multihull	
1) catamaran	(8D)
2) trimaran & outrigger	(8C)
C. Module assembly	(42)

The classification in Table II distinguishes between sea-based systems that have the same physical appearance but have different modes of operation. Thus, the monopod (Fig. 5) is a narrow vertical cylinder that sits on the bottom (I-A-2 in Table II) while the SPAR and FLIP ship (Fig. 25) type of oceanographic research vessel are designed to float (II-B-1 in Table II) and thereby avoid any depth restriction. The buoys (II-A-1 and III-A-3) cover a very wide range of designs.

Only one concept not now in existence was listed (Fig. 41), because most of these sea-based systems of the future do not utilize new platform principles, except the module approach (Fig. 26).

This section, dealing as it does with the spectrum of platforms, complements Section II which listed the different missions. The goal is to match missions with platforms, in order to achieve objectives. The next step toward this end is the establishment of general platform design requirements that will permit assessment of effectiveness so that pairings between mission and platform can be undertaken within a practical framework.

IV. GENERAL REQUIREMENTS

There are a multitude of pertinent design considerations in ocean platform design. This section is intended to outline and briefly describe the most important of these considerations; the next section will detail the specific requirements for each mission. The format of this section will be that of an "annotated outline," because a fully descriptive text would be prohibitively lengthy and not more informative for the purposes of this phase of the program.

There are four basic sets of requirements:

4.1 Performance
4.2 Logistics
4.3 Economics
4.4 Environment and Ecology

Each of these will be briefly structured in the following subsections and each of the elements will be discussed.

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4.1 PERFORMANCE

a) **Motions**

- (1) Operation
- (2) Survival
- (3) Environment input (waves, wind and current)
- (4) Stabilization

b) Station Keeping

- (1) Bottom connected (fixed or anchored)
- (2) Free (dynamically positioned)
- (3) Variable requirements

c) Structural Design

- (1) Loading - waves, wind, current, and towing or moving
- (2) Corrosion allowance
- (3) Design problems
- (4) Analysis techniques
- (5) Cyclic loading analysis
- (6) Materials

4.1.a Motions

Motion requirements vary with the mission and particular platform type. For example, motion specifications that may be reasonable for a semisubmerged platform may be impossible to meet if applied to a monohull ship. Table III illustrates the diversity of operational motions experienced by various types of platforms. The DISCOVERER II is a "conventional" research vessel in the sense that it has a ship's hull. Using it as a datum, it is seen that FLIP and FORDS la are exceptionally stable in heave, which is their design intent, while the BRAVO, which has no such requirement, merely responds to the waves as would a bit of flotsam. The semisubmersibles strive for resistance to heave, pitch, and roll and the measure of achievement is either better or worse than the ship form, as shown in the table. The catamaran performs surprisingly poorly. The DSRVT-1 has exceptionally bad seakeeping characteristics which is to be expected of a true submersible.

As stated above, the motion requirements are fixed by the mission. The spectrum of platforms is likely to provide a choice from among those that can meet the requirements. This is but one of the variety of constraints that must be satisfied to fulfill mission requirements.

A range of sea-state, wind, and current influences must be accounted for in any successful platform design. For this reason, most designs consider several motion performance criteria. Among these are two regarding sea state: one for continued operational capability and another, higher sea state, for survivability. In addition, many platforms must be able to function in two different physical states, that which applies in transit and that which obtains on station. This is perhaps most obvious with the SPAR-type system which is towed to its station in the horizontal position and operates in the vertical.

The motions that are considered to be most important vary with the requirements of each particular mission. For example, roll and pitch angles are very important to a drilling platform, but are of secondary importance for the mother ship of a small submersible vehicle. For the mother ship, heave motion and relative amplitude between the platform and the submersible below are of primary importance, as is the case with all transfer at sea problems.

Table IV ranks some of the floating types of platforms according to severity of motion. In the table, a ship of normal form is taken as the norm. The higher a platform's number, the better its performance in waves. Clearly, the ship form suffers the greatest motion while the submersible, semisubmersible and spar ship are relatively "transparent" to waves.

As stated above, platform motions under tow or in self-propelled transit must also be considered. Damaging effects due to slamming and severe motions can occur, especially for platforms that are forced to transit with much of their ordinarily submerged superstructure exposed to the wind and seas. The factors that lead to seaway-induced speed loss are not well understood for other than ship-like forms.[23] Since, from Table IV, ships are the worst performers, both in transit and on station, stabilization is often necessary to the extent that the mission requires such augmentation.

Table III. MOTION DATA FOR SOME OCEAN PLATFORMS*

Platform	Wave Height (ft.)	Motion		
		Heave (ft.)	Pitch (deg.)	Roll (deg
Buoys				
BRAVO		(same as waves)		
FLIP	25-35	0.25		
LABOUEE	20	3.3		
FORDS 1a	20	0.5		1.12
Semisubmersibles				
SEDCO 135**	20	2.2	1.8	
SEDCO 135**	40	11.5	5.3	
BLUEWATER**	20+		2.0	2.0
MOHOLE	20	3.3	1.7	1.7
FORDS 7a	20	1.38	1.44	
DISCOVERER II	10-26	3-7	3.0	2-4
ASR Catamaran	14.5	13.06	9.72	5.44
DSRVT-1	20		10.0	12.0

*Abstracted from Reference 15.

**Sample of model test data furnished by owner.

Table IV* RANKING OF PLATFORM TYPES BY SEVERITY OF MOTION**

Platform Type	CONDITION OF LOADING In-Transit (light draft)	 On-Station (deep draft)
Ship	1	1
Spar ship	2	4
Jack-up	3	-
Catamaran, Trimaran	4	2
Submersible	5	-
Semisubmersible	6	3

---

*Taken from Reference 23.

**First rank goes to the relatively worst platform (i.e. most severe motions).

4.1.b Station-Keeping

Station-keeping for floating platforms is accomplished in two ways:

(1) Anchoring
(2) Dynamic Positioning

In general anchoring is cheaper. Dynamic positioning, on the other hand, is not restricted by depth of water and by the nature of the bottom. As the technology of dynamic positioning advances, it is becoming more popular and will undoubtedly continue to enjoy increased use.

The anchoring of floating platforms in deep water can be a complicated task. Several good references on the topic are available, however, and industry seems to have developed suitable anchoring techniques for most operations. 49, 50, 52, 54, 56, 57, 59, 62, 64.

Dynamic positioning seems to hold great promise as an open ocean position-holding technique. Several designs have proven feasible and the future looks bright for this technique.[51, 53, 55.] Dynamic positioning systems become more desirable as the water gets deeper and anchoring becomes progressively more difficult. Dynamic positioning has been accomplished using a variety of propulsion schemes including regular marine propellers, tunnel thrusters and cycloidal propellers. The relative merits of the competitive schemes depend largely on the platform configuration and mission. References 55 and 61 treat some of the advantages and disadvantages of the three schemes for a particular type of platform, a monohull drill ship.

4.1.c Structural Design

Structural Design of fixed ocean platforms has received much attention in the literature and some reasonably sophisticated design-analysis tools are now available. 87, 91, 96, 97, 101, 104.

An extensive body of data concerning wave-induced force analysis on fixed ocean structures has also become available in recent years.[93, 82, 108.] The stresses experienced during earthquakes and storm wave conditions have been dynamically modeled to assess the behavior of fixed platforms under severe conditions.[88, 104.] These references cover a span of the last two decades. To review the literature on the subject of forces on structures is to engage in a project of dimensions equal to this one. Thus, only a hint of what there is appears here.

The state-of-the-art of structural design for mobile or floating platform design is not as well developed. Efforts to improve existing analysis techniques have been hampered due to the structural redundancy incorporated into the design of floating platforms.[23.] The American Bureau of Shipping has published a set of rules for building and classifying mobile drilling units and several firms are actively pursuing full scale test programs.[84, 92, 111.] Comparisons between actual and theoretical stresses are difficult to obtain for two reasons: 1) the expense of instrumenting full scale platforms and 2) the difficulty in properly measuring (or estimating) actual wave heights.

The results of studies performed and reported to date suggest that present methods tend to overpredict dynamic stresses.[84, 92].

From these and other studies, the following preliminary conclusions regarding structural design of platforms have been drawn:

1. Designing for maximum wave height loading may not be enough to assure survivability. Cyclic loading, induced by waves of lesser amplitude but greater frequency of occurence, may cause more damaging stresses.
2. Cathodic protection is effective in reducing corrosion in underwater portions of the structures (and thereby prolonging structural life).
3. Stresses experienced in transit (under tow, or self-propelled,) can be very severe, especially for the legs of jack-up type platforms. This explains the dual design criteria, one for transit condition and one for operation on-site.
4. The design maximum wave heights for early floating platforms were probably too low for most ocean areas. This accounts for the high mortality rate of those platforms.

The most common material used to construct almost all mobile and fixed platforms has been some alloy of steel even though the effects of corrosion can be serious, especially if mild steel is used. Careful consideration must be given to corrosion characteristics in selection of materials.[107] Much can be done to reduce corrosion in the "splash zone" and this area has received considerable attention.[100]

The use of prestressed concrete is gaining in popularity, because it exhibits the desirable attribute of increasing in strength with immersion in sea water. Most of the large floating or submerged structures of recent design have utilized concrete.[179, 184, 227, 252, 253]

4.2 LOGISTICS

a) Mobility

- (1) Primary or secondary requirement - required speed.
- (2) Sea state, wind and current influences
- (3) Maintenance and drydocking requirements

b) Delivery System

- (1) Self-propelled
- (2) Towed
- (3) Stability in transit
  1. Intact
  2. Damaged

c) Support Systems

- (1) Supplies
- (2) Personnel - habitability
- (3) Emergency and Safety
  1. Equipment failure
  2. Accident/fire
  3. Reserve buoyancy and damaged stability
- (4) Product handling
  1. Removal
  2. Storage
- (5) Interface between platform and subsystems
  1. Ship, boat, barge or surface effects craft
  2. Helicopters
  3. Pipe Line
  4. Electric power lines

4.2.a Mobility

The mobility requirements for a platform refer to the need for the platform to get around, as it were. There are several aspects to mobility. Since survivability is the prime concern, it automatically defines minimum mobility. After survivability, the mission role dominates, if greater mobility is required. From a logistics standpoint, delivery of the system and maintenance and drydocking requirements are next and are considered to be second order mobility requirements. That is, they don't determine if a platform can perform but rather how well it can perform. The relationship between mobility and mission requirements, for a given platform activity, will be discussed in Section V (Mission Requirements).

Certain offshore vessels, such as work barges, are not designed structurally to withstand severe weather conditions and must therefore possess a reasonable degree of mobility to assure their safety. Likewise, platforms that require drydocking or protected harbors for maintenance operations must be mobile enough to avoid lengthy delays in transit to and from the work site. Drilling platforms are an interesting example. They are designed and constructed to withstand the most severe operating conditions. Hence mobility is no problem, unless the drilling platform is in transit; i.e. at any time when it is not performing its primary function of on-site operations. Many drilling rigs have been lost or severely damaged by bad weather while in transit or during a jacking operation.

4.2.b Delivery System

The decision between self-propulsion or towed delivery is a function of platform's mission requirements, expected on-station service time, and availability of towing vessels.

One of the primary concerns of the designer is the intact and damaged stability of the platform while it is in transit, whether under its own power or towed.[23, 70, 73, 74]. Most sea-based systems are highly susceptible to severe wind and wave loads during transit. The controllability and course keeping ability of a transiting platform is a prime design consideration. Bad wind, wave, or current conditions can severly limit transit speed, cause extensive damage, and even loss of improperly designed platforms.

4.2.c Support Systems

The "life-line" of the ocean platform is the set of support systems that service it. There are many aspects to support but, in the first instance, it may be said that the kind of support required will depend mainly on: the specific mission, platform type, location (distance from supply sources), number of personnel and required safety margins. Since the function of support is to maintain operations safely and efficiently, it is clear that there is virtually no service that is not called upon to satisfy these objectives.

Support systems are basically of two kinds, those that interface between the platform and the "outside" and those that provide ancillary services aboard. In the latter case, services run the gamut from maintenance, repair, and firefighting to feeding and entertaining personnel.

The interface between the platform and the "outside" is largely a means of transferring a product (equipment, supplies, personnel, etc.). The kind of interface used will be determined by: type of product being transferred, geographic location, safety and emergency requirements, and weather conditions.[72, 76, 184.] The most common interfaces are: ship, boat, barge, helicopter, pipeline, electric power line. Serious problems often arise when the weather is bad and transfer is being made between two systems, in close proximity, and both responding to the seaway. The transfer-at-sea problem is one of concern to the U.S. Navy and is presently receiving attention.

From the foregoing, it is evident that even an ocean platform is not an island unto itself. There is a strong requirement to consider support systems in basic design, especially those systems that interface with the platform.

4.3 ECONOMICS

a) Initial cost

b) Operating cost

c) Maintenance cost
  1. In position
  2. Drydocked

d) Insurance costs

e) Expected service life

f) Down-time costs

g) Moving costs

h) Subsystem economics

i) Product market development

Economics, of course, pervades all design and mission decisions. If any one element is too costly, then a more economical alternative must be found or the project may have to be abandoned. Likewise, if a suitable product market does not exist, then it is likely to be foolish to invest in a system designed to produce a product for which there is not sufficient demand to justify investment.

Very little detailed economic information appears in the literature. This is probably due to the proprietary nature of such information and because the literature usually (and quite properly) addresses itself almost exclusively to technical matters. There are some exceptions; i.e., initial cost data for some drilling rigs are available. Table V lists some representative tdata on the initial cost of drilling platforms. The reliability of such data is not known. However, it is generally acknowledged that some rigs can cost 20 million dollars and more.

If capital investment for platforms is not generally published, then data on operation and maintenance is even more scarce. These costs are likely to be buried in a morass of bookkeeping. However, it is equally likely that such figures are available for specific platforms (although highly proprietary), especially when it is required for company policy decisions. In either case, the data exists; accessibility is the problem.

Table V MOBILE RIG CONSTRUCTION COSTS*

Name	Description	Water Depth (in ft.)	Estimated Cost (in million $)	Delivery Date
	JACKUPS			
Earl Rowe-San Antonio	Three triangular legs, triangular hull, LeTourneau design.	250	8.5	July 197
Ocean Tide	Four legs, ship shape, self-propelled, Offshore Mercury type.	250	11	July 197
Penrod 60	Three square legs, triangular hull, LeTourneau design.	300	11	Aug. 197
Marlin No. 6	Three legs, Levingston design, National jacking system.	300	9.5	Oct. 197
J. Storm II	Three cylindrical legs, mat supported, Bethlehem design.	250	8	Oct. 197
Stormdrill VII	Three cylindrical legs, mat supported, Bethlehem design.	250	8	Nov. 197
Penrod 61	Three square legs, triangular hull, LeTourneau design.	300	11	Late 197
Zapata**	Three leg, triangular hull LeTourneau design.	300	11	Jan. 197
Penrod 62	Three square legs, triangular hull, LeTourneau design.	300	11	Feb. 197
Diamond M**	Three square legs, National jacking system, Levingston design.	300	9.5	Apr. 197
Fluor Drilling**	Three legs, triangular hull, LeTourneau design.	300	9.5	May 1972

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*Offshore News, June 1971

**Name of Company, if rig has no formal name.

Table V (continued)

India Government** (Offshore Co. labor contract)	Ship shape, self-propelled, Offshore Mercury type, 4 legs.	200	14.65	Late 1972
Crestwave Offshore Services**	Three legs, triangular hull, LeTourneau design.	300	9	Fall 1971
Rowan International**	Three legs, triangular hull, LeTourneau design.	250	8.5	1972
Rowan International**	Three legs, triangular hull, LeTourneau design.	200	7	1972
	<u>SEMISUBMERSIBLES</u>			
Penrod 70	Similar to Project Mohole design.	800	12	Dec. 1971
Sedco-J	3 columns, tripod design.	800	15	Sept. 197
Sedco-K	3 columns, tripod design.	800	15	Dec. 1972
Pentagone 81-2	Propulsion assisted, pentagonal hull, 5-columns.	600	20	Late 1972
Sedco-700	Rectangular with 2 lower barge shaped hulls, dynamic positioning, self propelled.	2,000	20	Spring '7
III-Mark 2	Self-propelled, 2 lower hulls, 6 columns, 1 rectangular upper hull.	600	20	Early 197
Ocean Voyager	Self-propelled, "Ocean Prospector" type.	600	12	Fall 1973

**Name of company, if rig has no formal name.

Table V (continued)

SHIP SHAPE AND BARGES

Belle Isle	Inland, posted	22	2.5	Aug. 1971
Sedco 445	445 ft., ship shape, self propelled, dynamic positioning.	Unlimited	15	Oct. 1971
I.J. Pierce	Tender/platform.		5	Oct. 1971
Cyclone	Ship shape, 380 ft., self propelled, converted C1-MAV1 cargo hull.	600	7	Nov. 1971
Le Pelican	Ship shape, 476 ft., self propelled, dynamic positioning.	Unlimited	14	Dec. 1971
Saipem II	Ship shape, dynamic positioning, 431 ft.	Unlimited	13.5	Feb. 1972
Glomar XII	Ship shape, self propelled, Grand Isle class, 400 ft.	600	10	Apr. 1972
Petrobras**	Ship shape, self-propelled, Discoverer type.	600	8.5	1973

**Name of company, if rig has no formal name.

Source: Ocean Oil Weekly Report

Reference 23 provides some comparative figures for insurance costs of platforms of conventional ships that may be useful in estimating such expenses. See Table VI for a summary of this data. General insurance information may be found in Reference 68. It is quite clear from Table VI that insurance rates for semisubmersibles are considerably higher than for regular ocean-going ships. The record of marine insurers has not been good and that may account for the high rates. However, when one considers that the annual premium on a platform may be as high as 2-million dollars, it is small wonder that consortia of oil producers are banding together to self insure.

Table VI COMPARATIVE INSURANCE COSTS*

Configuration	Insurance Costs - Percent Per Annum Insurance Rates
Oceangoing Ships	2 - 3
Ship Type Platforms	4-1/2 - 5-1/2
Semisubmersible Platforms	7-1/2 - 9-1/2

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*Reference - 23.

The expected service life of a platform is a prime consideration in estimating return on investment. The key elements here are the expected longevity of the mission and the ability of the platform to perform during that period. Obsolescence is a potential hazard to expected service life that is even more difficult to assess.

Down-time costs are fairly easy to estimate for design purposes. Statistics of past experience in similar situations are utilized to establish an annual reserve of say 3-6% of capital costs, or some other appropriate figure, in terms of restoration of the platform to duty. The loss in production, due to down-time, is quite another matter and depends entirely on platform production records under similar conditions.

Moving costs and subsystem economics fall logically under operating costs and are fairly easy to calculate. Acquisition of such data, from proprietary sources such as oil companies, is not often achieved.

4.4 ENVIRONMENT AND ECOLOGY

a) Pollution and waste disposal
    (1) Normal production by-products
    (2) Accidental

b) Aesthetic design and "fitting" with natural surroundings

c) Interaction/Compatibility

Environmental and ecological considerations have come to the forefront in recent years. Every day newspapers feature articles on air and water pollution and their adverse effect on our environs and ecological base of life. It is the responsibility of engineers and designers to minimize the likelihood of any type of leakage or spillage of a harmful substance that might occur in the operation of a platform.[261.] This may require costly redesign or additional development work, but both the public and the law make it quite clear that the environment must not be placed in undue jeopardy as a consequence of either government or commercial ventures. The likelihood that pollution will result from product handling, waste disposal and/or normal production by-products must be assessed and accounted for in the design process.

The effort to alleviate two important sources of pollution - air and noise pollution by aircraft and thermal pollution due to generation of power - have led to proposals for new types of ocean platforms. Section V will provide descriptions of these platforms.

For those platforms that may operate in locations that bring them under the scrutiny of the public eye, (e.g., in harbors or close to recreational beach areas), the physical appearance of the platform can be an important factor in acceptance by the public. For such areas, the aesthetics of a proposed design can be very important.[179.]

The technology of ocean platform design must be rooted in a thorough understanding of the marine environment. A designer must account for the many added design parameters that the sea forces upon him. Corrosion, waves, accessibility, weather, bottom topography and erosion are but a few of the problems the offshore platform designer must consider.[113, 114, 115.]

V. MISSION REQUIREMENTS

In this section, the requirements for each of the missions listed in Table I (pp II-2,3) will be analyzed according to the framework developed in Section IV and will comprise discussions of:

- * Performance
- * Logistics
- * Economics
- * Environment and Ecology

to the extent that information on these elements are available in the open literature. In Section II (List of Missions), an attempt was made to group missions on the basis of similar platform requirements and on similarity of performance criteria. However, as stated earlier, there are cases where several different types of platforms may satisfy one mission (oceanographic research) or where one platform may perform well on more than one mission.

The purpose of stating the mission requirements is to provide a basis for selection of the optimum platform to satisfy each set of mission constraints and/or to select those design characteristics that will produce a multi-mission platform system. To arrive at either or both of these solutions, detailed analyses of total systems (of which the platform is one element) are generally required. This is beyond the intended scope of Phase I which is aimed at providing input to solution of the optimum platform-design problem. To that end, this section describes concepts for ocean platform utilization and illustrates existing and/or proposed platform-mission relationships.

It will not come as a surprise that there is considerable data available on some missions and a paucity of data on others. Thus, oil drilling and oceanographic research, which have been active for some time, claim a large portion of space, while electronic surveillance and resource recovery occupy considerably less space, as befitting their roles as relative newcomers. Moreover, there has been much published on the technical aspects of performance and design yet cost data is virtually nonexistent in many cases.

It may be said that whatever we have learned from the literature has been augmented by what the literature has failed to reveal thereby focusing attention on one deficiency or another.

5.1 OFFSHORE DRILLING

There is a mass of data and information available on oil drilling and production-type platforms. The oil companies, in their search for new oil and gas deposits, have spearheaded the development of offshore platforms and the results have been phenomenal (Fig. 7). Originally, their efforts were restricted to shallow-water (30' to 150') fixed-type platforms, but the search for oil has been leading the industry to greater and greater depths. To meet this challenge, the oil companies have been supporting the development of new types of semi-fixed (jack-up) and floating type platforms. The development of these platforms has enabled companies to drill and produce oil in deep water (1000' and more) and thus tap previously untouchable oil reserves. A rapid growth of technology is occurring because of the oil company efforts. Figures 1 to 6 show a variety of vertical-column platforms. Figures 8 - 10 are ship form drilling rigs. Figures 11 - 15 are semisubmersibles designed exclusively as drilling platforms but combining the attributes of vertical columns and ship hulls. Figures 16 and 17 are proposed drilling rigs without any design precedent. Figure 7 shows the interesting evolution of offshore drilling platforms.

Oil industry technology and experience has formed the basis for other deep ocean drilling activities. The principal benefactors to date have been geophysical research drilling efforts.[127, 134] The well-heralded success of the "Glomar Challenger" (Fig. 7, bottom)[135] is evidence of the fruits of this technology sharing. Other industries and agencies have likewise found applications for oil industry drilling expertise and offshore fixed and mobile rig technology.[136]

Almost every type of marine platform or structure has found a use in the offshore petroleum exploration and production industry. Following is a list of specific missions and the types of vehicles most often used to fill the job.

1. <u>Exploratory oil and geophysical exploration</u>:

   Ship-type forms are most often employed for these activities (Fig. 8). Their primary attributes are high mobility and deep water drilling capabilities. Most of the platforms used for this type of mission are self-propelled and most of the new ones have dynamic positioning capability (Fig. 9).
   The petroleum industry is also using large semi-submersible and jack-up type rigs for this type of work. They are generally less mobile than ship-types but are capable of performing as production platforms in the event it is necessary. They also possess a high degree of stability and low motion response while drilling.

2. <u>Pilot well drilling and interim oil production</u>

   All types of semi-submersibles, jack-ups, barges, submersibles, fixed platforms and even buoys are employed for this phase of offshore oil production (Figs. 1-15). In general, whatever is available is used. If anything, there is a present shortage in this area.

3. Long term oil production and workover of existing wells

   In shallow water (up to 100'), this work is performed exclusively by fixed-type platforms except where bottom conditions are so bad that submersible-type platforms or barges must be used. In deeper waters (100' to 300'), articulated columns, buoys, jack-ups and a few fixed platforms are employed. It is anticipated that as production goes even deeper (in excess of 1000 feet), anchored semi-submersibles and even buoy-type platform concepts such as appear in Figs. 16 and 17, will eventually be used. Feasibility studies on very long articulated columns also indicate their suitability for deep water oil production.[119, 121]

The motions of ship-like stable platforms can cause drilling difficulties. Several schemes for reducing the angular displacements (roll, pitch) of such vessels have been proposed, including both active and passive compensation systems.[43, 44, 45, 48] For drilling, it would appear that heaving is of secondary importance and can be compensated for in the drill-line assembly.[42] Yaw and surge motions of floating type platforms can be of serious consequence in drilling operations and are of primary importance in the design of anchoring and/or dynamic-positioning systems.

Most exploratory drilling platforms and production platforms are constructed of some type of steel. The only exceptions are some of the early shallow-water fixed platforms that were supported on wooden piles. In early designs, concrete was employed only as pile anchors and as high mass anchors for buoys or floating platforms or for protection of steel parts in the splash zone.

This is not true of newer designs, especially offshore oil storage facilities. Most storage facilities planned to date have included concrete as the predominant structural material.[266]

The support systems of most drilling platforms include the following:

1. Power generation
2. Communications
3. Accomodations for about 50 men
4. Personnel transportation systems
5. Drilling or pumping facilities
6. Production handling facilities
7. Safety and emergency systems
8. Storage tanks and stores storage areas
9. Environmental protection devices

Power is usually generated by diesel or gas turbine generators. The power to support life and hotel systems, production or drilling machinery, and communication systems, must be self-produced. For dynamically-positioned systems, power for positioning is generally drawn from the main propulsion machinery and not from the support system power generators.

Personnel transportation to and from on-station platforms is usually via helicopter or crew boats.[72, 77] These, or similar vehicles, are used to carry supplies to working platforms. Almost every drilling platform in operation today has provision for helicopter landing and take-off (helipads). Among the advantages of the helicopter are high speed, pinpoint landing capability and the fact that it is not hampered by high seas.[72] The major disadvantages are limited range and payload.

Almost all production from oil platforms is removed, via pipe lines, to mass storage areas or directly to waiting tankers.

The danger of explosion and fire are ever present on oil drilling and production platforms. Safety devices are required by law and can be of major importance in preventing disaster. The causes of failures are not always known, but Reference 15 provides the following list:

1. Hurricane or severe storm
2. Instability
    (a) Improper ballasting, free surface, excessive topside weight
    (b) Material failure
    (c) Unknown
3. Blowout and fire
4. While Jacking
    (a) Structural leg failure
    (b) Unexpected sinking of spuds
5. Structural failure of derrick
6. Failure of pressure vessel
7. Unknown causes

The moving of jack-ups from one location to another is especially dangerous and several failures have been noted.[23, 81]

Environmental protection has come to the forefront of offshore oil production problems. The Santa Barbara Channel oil leakage, tanker mishaps, and numerous oil spills have resulted in a veritable eruption of public feeling against offshore oil production. With the passage of new environmental protection laws, strong and emotional environmentalist outcries, the general concern of the public, and the tightening of government leasing policies, it is obvious that environmental protection must be a primary consideration in the design process of any offshore platform. This is especially true for Arctic region programs.[154, 155, 164]

The economics of offshore drilling and oil production are quite complex and beyond the scope of this report. That oil drilling is big business is quite clear from the construction cost of mobile units as shown in Table V (pages IV-19 to IV-21). A $20 million investment for a single drilling platform is not uncommon and provides a small indication of the scope of investment in the offshore oil exploration and production business.[157]

The estimated $5000 per day cost of operating a semi-submersible rig provides some idea as to the extent of moving and down-time expense.[15] Present day operating costs of $10,000 per day are not unusual and probably more near the norm for larger platforms.

The expected service life of most rigs fall in the 15 to 20 year category. Storage facilities and fixed platforms are generally designed for 20 to 25 years of service.

5.2 OCEANOGRAPHIC RESEARCH

Oceanographic research, perhaps the most widely diversified of all the missions, employs four principal types of platforms:

1. Ships
2. Buoys
3. Semisubmerged
4. Fixed

The oceanographic research area has employed all of the above platform types in the past. Recently, however, Scripps Institute has planned two innovative research platform facilities.[179, 184] The first is a "super-stable platform" (Fig. 26) with the following characteristics:

1. Extremely small waterplane area to achieve a high degree of stability and steadiness at sea.
2. Vertical legs that pivot to the horizontal to permit towing.
3. The platform will be composed of two identical modular units towed to sea independently and then joined together to form the operating platform.
4. The use of steel for superstructure elements and prestressed concrete and steel for the legs.

The most important innovation is the modular construction principle. This same principle is being proposed for several other types of large ocean platforms and, if proved feasible, could be a very important breakthrough.

The second Scripps platform is a bottom-fixed concrete "island" and is designed to provide a calm water harbor and base for a whole array of oceanographic research facilities. It will be located in 75 ft. of water and about 2000 ft. from shore. This type of platform could be a prototype for future offshore shipping terminals and artificial harbors.

Other types of stable platforms have been used for oceanographic research. The "FORDS" (Floating Ocean Research and Development Station) is a self-propelled semi-submerged platform designed as a mobile oceanographic research base.[176, 177] Buoys have also found wide-spread application. For example "FLIP" is a huge spar buoy (20 foot diameter) designed to provide a stationary research platform.[171] "SPAR" is a similar buoy (16-foot diameter) designed for acoustic research[172] in deep ocean areas (Fig. 25) and the "Monster Buoy" is an unmanned buoy for ocean monitoring.[194] The "Texas Tower" type fixed platform has also found use as an oceanographic research station, but it is fixed to the bottom so its use has been restricted to shallow ocean areas (Fig. 27).

The motion performance of oceanographic research platforms is critical to the success or failure of a mission. This is evident from the trend toward "super-stable" platforms. Buoys must also have good motion characteristics since the successful telemetering of data is dependent on buoy motions. For this reason, research on stable buoy configurations has received attention in recent years.[224, 193, 204]

In general, to reduce motions, it is good design (and operating) practice to remove the natural period of motion(s) from the significant period range of wave encounter. The heave natural period may be increased by increasing the underwater volume and reducing the waterplane area. The natural period of pitch may be increased by reducing the waterplane moment of inertia while the center of gravity is placed below the center of buoyancy. These principles are the basis for the design of FLIP and SPAR. See Table III (page IV-6) for data on motions of platforms.

5.3 ELECTRONIC TRACKING AND SURVEILLANCE

Fixed ocean platforms of the "Texas Tower" variety (Fig. 27) have been the primary type of platforms used for these missions.[189] Most of the technology for their design and construction has come from the oil industry. The subsystems required for these platforms are very similar to those for oil production platforms with the exception that power is generated primarily for communications and tracking equipment instead of drilling or pumping machinery. Also, accomodations for fewer men are required with a consequent reduction in overall subsystem capacities. With the exception of the electronic equipment on board, the design of these platforms is essentially the same as the design of fixed platforms for oil production.

As with oceanographic research platforms, the danger of fire is greatly reduced in comparison with oil drilling types.

Where there is a requirement for deep-water operation, ships are used. For satellite tracking, stability is essential to prevent loss of signal reception. To this end, the radar platforms are normally stabilized independent of any basic ship stabilization. Some kind of anti-roll system is usually incorporated. Such ships do not require either speed or mobility and they are normally self-sufficient for long periods of time.

5.4 NAVIGATIONAL AIDS AND WEATHER MONITORING

The above missions have several things in common: 1) they are principally accomplished by use of moored buoy-type platforms, 2) with the exception of navigational aids that function only as channel markers, the buoys employ sophisticated telemetry systems, and 3) they are unmanned.*

Navigation buoys are designed to aid ocean going vessels in performing their navigational position checks and have been designed and used to replace lightships at the entrance to both east and west coast ports.[201] Weather and oceanographic information buoys are currently in use in the Pacific and a network of buoys is planned.[191, 195, 198] Some buoys perform both functions.

The most successful design appears to be one by General Dynamics Corporation called the "Monster Buoy."[191] The basic design has been used for all of the above missions and appears to be quite successful.

The "Monster" is essentially a 40' diameter disk with a central tower used to mount instruments, sensors, and broadcasting antennas. It can be anchored in any depth water and is designed to survive 150-knot winds, 60-foot waves and 10-knot currents.

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*This does not take into account the weather ships which are manned. However, these vessels are slated for extinction as the automatic unmanned systems come into widespread use.

Competing systems have been developed recently under a NOAA contract with Lockheed Missile and Space Company. This buoy has a streamlined, boat-shaped hull and is supposed to have a better chance of survival in severe storms (Fig. 30). Its missions would be the same as for the General Dynamics design.

Figures 18 - 24 show a variety of buoys used for different purposes.

For telemetry purposes, the dynamic response of buoy platforms must be within tolerable limits as shown, for example, in Table III (page IV-6). A position watch circle on the order of 50-100 feet is usually adequate for most purposes and can be achieved with a single taut-line mooring system.

Most buoys are required to operate in a sea state 5 (and survive hurricane seas). An exception is the Lanby buoy (Fig. 29) which is purported able to withstand winds up to 100 knots, waves to 40 feet and tidal currents to 7 knots.[201]

The published design data on buoys have been sparse on structural information. In general, rugged construction at least sufficient to withstand dynamic loading (waves) is recommended.

Speed is no consideration here; nor is mobility. Delivery is effected by a vessel of some kind. However, anchoring is very important and, as stated earlier, a single taut-line anchor system is usually adequate. The mooring line may consist of chain, cable, or polypropylene that permits a free watch circle motion of the buoy.

Little auxiliary support is required, since the systems are designed to operate unattended for long periods of time (4 to 6 months between servicing). A shore-control station may be needed to carry out checks on the buoy's equipment.

The costs to acquire, operate, and maintain such systems naturally vary with the size of the buoy and its complexity. As a rule, the buoy platform is considerably less expensive than a conventional manned vessel. The Lanby buoy, mentioned earlier, costs about half as much as a modern liteship and that includes shore-based monitoring equipment. Its operating costs are about 10% those of a liteship.

5.5 OCEAN RESOURCE RECOVERY AND BOTTOM MODIFICATION

Interest in offshore dredging and deep ocean mining has intensified in recent years. As harbor facilities are outstripped by ship size, offshore dredging has become more and more in demand as have deep mooring and offshore ports (see 5.12). More seaworthy and deeper operating dredges are required.[205, 207, 213]

Several proposals for the mining of deep sea mineral nodules have been put forth.[210] The most promising are:

1. Continuous bucket-line dredging (Fig. 31), and
2. Hydraulic dredging.

Prototype systems of both of these systems have been built and tested. Reference 212 describes the results of continuous bucket line dredging at depths of 12,000 feet. Reference 211 describes a prototype hydraulic mining system.

Both of the ventures listed above appear to hold promise and could be competitive in many respects.

The vessels employed to date have been conventional ships converted to perform a specific mission. It is likely that such ship forms will continue to find favor for ventures of this type because of the high mobility required for ocean mining. Hydraulic ocean-mining vessels will most likely be propelled or towed during operation and therefore will require only normal anchoring and no dynamic positioning systems. Bucket-dredging vessels must align themselves perpendicular to the current for maximum efficiency and therefore will probably require positioning thrusters, as well as a conventional anchoring system.

The economics of mining ventures are highly dependent on the quality of the recovered ore. Indications are that the ore deposits are of sufficient quality to allow for commercial exploitation.[6] A review of the economics of manganese nodule mining is provided in Reference 208.

The ecological aspect of bottom modification has received too little attention. Any perturbation of the bottom, on the scale being undertaken at present and contemplated for the future, is bound to have effects that must be assessed as soon as possible.

5.6 FISHING SYSTEMS

There are two principal techniques, employing ocean platforms, that are espoused for fish and sea life extraction from the world's oceans and inland waterways.[219] The two systems are the highly mobile and the fixed or semi-fixed types.

Mobile systems are presently in use by many nations, especially Russia, and are usually composed of a central or processing ship being attended to by a fleet of smaller "collecting vessels" (Fig. 35).[217]

Another example would be a whaling factory ship and its associated smaller hunter-killer vessel fleet. The principal advantages are that a mobile fishing fleet can ply waters far away from intended markets for extended periods of time and can follow the seasonal migration of the quarry, and existence of much hydrodynamic design knowledge (since the vessels are much like a conventional ship). The station-keeping requirements are quite loose and only a general vicinity boundary is applied. Such a ship is usually required to survive extremely severe weather conditions and to serve as a tender for the smaller vessels in the event of trouble or disaster.

Economic information on such systems was not discovered in this literature search. Much information is known to be available, however, from the National Fisheries Service and related government agencies.

A fixed or semi-fixed system employs a stable platform, either permanently fixed to the bottom, or anchored to remain relatively stationary. It has been found that commercially marketable fish tend to gather and school around offshore structures under changing current and seasonal conditions.[220] Ideas to "herd" or harvest fish using lights and submerged tent-like devices have been sparked by such discoveries.[218, 222] Indeed, proposals for a fixed fishing platform which would attract, harvest and process fish have appeared in industry literature.[221] A pilot platform may be in operation in late 1971 or early 1972 (Figs. 32-34), that would be located in deep water (1,200 feet), mounted on pylons and well beneath the effects of surface weather.[225] The platforms would serve as a base of operation for underwater fish harvesting. Another proposed system would use a platform to pump deep nutrient laden sea water to the surface and thus provide an environment attractive to commercially desirable fish. Power to pump the nutrient laden water would be provided by wave action generation of electricity.

Other uses for platforms, aside from harvesting fish, have been proposed. For example, U.S. Patent 3,499,421 is a platform designed to provide basic facilities for rearing lobsters.[224]

The motion requirements for such platforms have not been noted in the reviewed literature. Heave, pitch and roll motions of anchored type platforms may, however, play an important role in the efficiency of fish retrieval, especially if the retrieval devices are located substantially below the platform's normal operating height and thus have long moment arms from the center of motion. Also, excessive motion may result in the loss of fish attracting ability or efficiency. The platforms should be capable of surviving extreme conditions since, as they are presently conceived, mobility is of secondary importance and they will be expected to stay on station for extended periods of time.

For bottom-fixed structures, deformation under wave-loading and toppling in high seas must be considered. Station-keeping is no problem and sea state usually is not either.

The economics of this type of fishing have not been fully explored. This is largely due to certain unanswered biological questions. Dr. E.F. Klima has made a preliminary cost estimate, however, and provides these figures for a typical platform of the type he is developing:[218]

Initial cost	$350,000
*Fixed costs per year	$ 87,000
Operational Costs per year	$ 60,000
Annual expected profit	$100,000+

He notes that market development for fresh and frozen fish of the type expected to be harvested has not occurred. All his estimates, therefore, are based on processed fish products. His platform does not include processing facilities, but relies on barge transportation of the captured fish to land based processing plants. Other proposals include processing plants on the central platform.[221] The National Marine Fisheries Service is sponsoring much research in the fishing platform area.

Auxiliary support in the form of a transportation link to the support base is required. Such a link might be a supply boat, ocean-going tender or helicopter, depending on a variety of factors.

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*includes depreciation, interest, insurance, maintenance and repairs for a service life estimated at 10-20 years.

In the Gulf of Mexico, 2,200 platforms are located from one to 75 miles offshore and extending into the path of the Caribbean Current. Since these platforms first appeared, an almost six-fold increase in the commercial fish catch has been reported.[220] Where the fish came from is not known. What environmental imbalance is being created is also not known. The apparent benefit must be truly assessed.

5.7 OFFSHORE PROCESSING

The concept of large offshore platforms being used for such diverse activities as mineral processing, oil refining and processing of medicines and fresh water from sea water has been put forth in References 226 and 227. The principal advantages of offshore processing are:

1. Processing of materials close to raw material sources and provision for a central distribution point for world market products.
2. Elimination of air pollution near populated areas and alleviation of thermal pollution of coastal waters.
3. Harnessing of large ocean currents to supply energy for processing.

The engineering and economic parameters for offshore processing plants have not been formulated in any detail. It would appear that the concept of offshore processing is only in the feasibility stage of development.

5.8 OFFSHORE POWER GENERATION

Offshore power generation will soon become a reality. The United States Navy already has nuclear-powered weather-monitoring buoys at sea and Westinghouse and Tenneco have announced joint plans to build platform-mounted nuclear power plants for offshore installation.[230, 235] Several places, such as the Southern California area, have a great need for more electrical power, but at the same time find it necessary to curtail environmental deterioration resulting from land-based power operations. Power plants located twenty to fifty miles at sea might be capable of solving the dilemma.[232] The Westinghouse-Tenneco effort has been designed for protected areas but could be adapted to solve problems like those in Southern California. The project would satisfy the following needs:

1. Provide nuclear generating plants economically close to load areas.
2. Shorten construction time and reduce lead time for regulatory procedures by standardizing plant design.
3. Reduce thermal effects because the sea would be used as a heat sink.
4. Reduce utility land acquisition costs.

Power would be transmitted ashore by means of underwater cables.

Safety from ship collision would be provided by an artificial island surrounding the platform (Fig. 36).

A concept has also been proposed that would employ large turbines to harness strong ocean currents.[227]

5.9 SURFACE SUPPORT OF SUBMERSIBLES AND SEABED HABITATS

The support of deep diving vehicles and seabed habitats depends heavily on stable operating platforms on the surface that act as lifelines for the vulnerable underwater systems. The "mother-ship" principle has been employed frequently for deep-diving research vessels. In the past, most "mother-ships" were converted barges, but recent designs have employed catamarans.[236, 238] The superior stability and motion characteristics of the catamaran (compared to a barge), its large deck area, and its high mobility, make it desirable for small submersible support.

Seabed habitats, especially those located a distance away from shore, must have a surface platform for support. This support must be equipped to provide: power generation, supply depots, emergency facilities, and surface communication. Several types of platforms may be feasible for use as support structures for undersea habitats. Among those being considered for shallow water use are jack-up rigs, catamaran hulls and through-hull barges.[239]

The use of a dynamically positioned support platform for unmanned submersible vehicles has also been proposed.[237]

It is anticipated that the technology for any of these platforms would be firmly based on offshore oil platform development and experience.

The required operational sea state is normally given as sea state 5. However, the very sensitive mission of such a sea-based system makes it mandatory that operation be extended to the highest sea state possible.

5.10 OFFSHORE WORK PLATFORMS

There are four principal applications for offshore work platforms:

1. Construction
2. Salvage and retrieval
3. Pipe and cable laying
4. Surf-zone construction

Most offshore construction platforms of early design are of the barge type. One of the principal drawbacks to such a configuration is the poor seaworthiness of barge-like vessels. If severe weather conditions threaten, the barge-type vessels are either unable to function or they must retreat to protected waters. This was not a severe penalty to pay when most construction occurred in near shore waters. As the oil industry has moved further out to sea, the offshore construction vehicles have been required to move further and further from protected waters. This trend has resulted in the design of new types of offshore construction vessels. These new types include the "semi-submersible barge" types (Fig. 39),[240, 241] and "self-elevating" or jack-up types.[244] Both of these types have proven themselves in service and represent a genuine advancement for the offshore construction industry. Salvage and retrieval platforms are generally of the ship-like form, probably because of mobility requirements and availability.[246] Most of the advances in this area have come in the salvage technique itself, rather than in the platform design.[243]

Pipe-laying is generally accomplished through the use of a construction platform (Fig. 40) for handling the pipe and a barge for pipe storage. The technology is thus closely related to offshore construction platform design.[242]

Two unusual platform configurations were discovered in the course of the literature search. The first one is a platform designed for surf-zone construction.[247] The platform literally "walks" in the surf. The second is a barge that holds an observation tube for supervising underwater civil engineering work (Fig. 38).[245]

Figures 38-40 show some selected samples of construction barges.

5.11 OFFSHORE PERSONNEL SUPPORT STRUCTURES

There are three general missions for offshore personnel support:

1. Floating cities, hotels and recreation centers[11, 250]
2. Floating air terminals[252]
3. Mobile ocean base for military operations.[254]

All of these concepts have one thing in common, the use of modular units to "build up" a platform of the desired dimension. The feasibility of this concept is being tested at the present time by the Scripps Institute Project mentioned in Reference 184.

A floating airport in a coastal region has several advantages over the land based airport. It eliminates the necessity of acquiring expensive land; it removes danger, noise, and pollution from neighboring communities; and, finally, it will not interfere with existing flight patterns. Flair, Floating Airport,[250] concept is a scheme using a moored buoyancy chamber. Vertical columns connect the flight deck with the buoyancy chamber of precast concrete and the whole system is moored to mass anchors by cables under tension. This floating airport is recommended for a 200 to 400-foot depth of water (Fig. 42). The following design characteristics are given for FLAIR:

Wave height (operational)	40'
Wind (survival)	130 mph
Designed Life Span	25 years
Material	Steel and concrete
Cost per module per sq. ft.	$29.40
Total cost of proposed air terminal	$1.1 to 1.4 billion

An idea very similar to FLAIR, except that it would have to be more mobile, is the at-sea ocean base briefly mentioned in Reference 254. Developmental work on this concept is being carried out by the U.S. Naval Civil Engineering Laboratory (Port Hueneme, California). Once again, concrete has been selected as the primary construction material and modular construction is proposed.

Seatel, Sea Hotel,[225] is planned for a reef off the Queensland coast of Australia. The project envisages a circular building standing on stilts on a reef. The seatel has a roof-top helicopter pad, underwater observatory and shark-proof swimming pool (Fig. 41).

5.12 OFFSHORE COMMERCE FACILITIES

Interest in offshore commerce facilities has risen as a result of the development of bulk-carrying super-tankers and the attractiveness of offshore material storage. Few world harbors are capable of handling today's super tankers. With even larger ships being proposed (as large as 1,000,000 tons), existing harbor facilities will become even more restrictive. For this reason, oil and ore interests are looking toward deep water terminals for their vessels. Presently, the most popular solutions are "monobuoy" mooring (Figs. 46, 48, 49)[269, 273] and the lightering at sea concept (Fig. 45). Other proposals have been made and include the following:

1. Semi-submerged platforms as offshore ports and storage areas for all types of ocean going ships (Fig. 51)[262]
2. Many variations of the "single point mooring" concept.
3. A variety of fixed platforms in near-coast waters with calm water harbors protected by floating breakwaters (Fig. 56) capable of being "tuned" for the predominant wave length.[179, 227, 261, 267]
4. Mobile ore loading for land areas with rich mineral resources but with no natural harbors.[268, 273]

Super tankers have lead to still another concept - the storage of bulk materials at sea. The desire to minimize tanker loading and unloading time has resulted in the development of deep water storage facilities. Another advantage of offshore storage is that such a facility provides a central collection point for offshore oil field production. Most offshore storage facilities are of the bottom fixed type (Fig. 55)[266] but proposals have been made to employ mobile, articulated column-type platforms as well.[272]

Most floating research ocean platforms and buoys are anchored in position. Station keeping is generally not as important as it is for offshore drilling platforms. Ability to remain in one place is generally no more critical than the accuracy of the navigation system that estimates where the platform is located.

Mobility is usually of secondary importance for ocean research platforms. An exception is the "FORDS" design which is self-propelled and designed as a mobile base. Almost all other types rely on towing to reach their destination and some type of anchoring system to keep them on station.

The structural design of ocean research platforms would require the same type of analysis as would their drilling platform counterparts. The "Spar" and "Flip" type buoys require special consideration because of their horizontal transit position. They must be designed to withstand the rigors of wave-induced bending moments during the transit as well as the hydrostatic loads in the sections that are deeply submerged when on station.

The use of concrete for underwater structural components is gaining popularity and represents a new trend in offshore platform design.[184]

The principal support systems for these platforms are power generation, communication systems, and anchoring systems for unmanned platforms, plus life support systems for the manned platforms. The oceanographic research mission generally produces some form of telemetered or recorded data and/or marine samples. Service vessels for manned platforms usually comprise ship or helicopter systems and for unmanned platforms, they are almost exclusively ship systems. These vessels are required for supply, repair, and personnel transfer duties.

Environmental protection and ecological considerations are minimal for research platforms, but care must be exercised to assure that fuel is not lost and that waste products are not allowed to escape in a harmful form.

Safety must be built into ocean research platforms in much the same manner as for oil-industry platforms. The big difference is that the danger of a blowout or fire is insignificant for research platforms.

There was no useful economic data uncovered in the literature search.

VI DISCUSSION AND CONCLUSIONS

It was not intended at the outset that this modest undertaking should result in a tome of this magnitude. In retrospect, it is not surprising. Consider that we are preparing input for a study involving some 30 missions at sea utilizing every conceivable sea-based system and treating technical, economic, and ecological aspects. No, it is not surprising; indeed, from all the written material uncovered we were surprised that relatively little hard data was forthcoming.

The source material used in this report comprises everything that could be found in the literature. To this end, some 300 references are reported herein. Since the subject of ocean platforms is relatively new, most of the references bear dates of the last 10 years and the majority of those have appeared in the last 5 years. More important, even as this is being written, reports are being published at the rate of almost one a day. Of course, many deal with the same subject, but the spate of words will not be denied.

Table VII is a breakdown of the distribution of references that is quite revealing. Approximately half the references (152) are purely technical while most of the others (134) are expository in nature, appearing in "popular" trade magazines and the like. Also included are a handful of newspaper accounts (6). Perhaps most indicative of the spectrum of published sources are the two successive entries, Royal Society of London, Proceedings,

Table VII DISTRIBUTION OF REFERENCES

Number of Refs.	Kind of Information*	Source
(4)	+	Amer. Bureau of Shipping
(1)	*	Amer. Institute of Aero. and Astro.
(1)	+	American Scientist
(4)	*	Amer. Soc. of Civil Eng.
(1)	*	Amer. Soc. of Mech. Eng.
(1)	*	Amer. Towing Tank Conf.
(1)	*	Architecture Forum
(3)	*	Books
(1)	*	California, U. of; Report
(3)	+	Center for Study of Democratic Inst.
(2)	+	Congressional Record
(1)	*	Davidson Laboratory, Stevens Inst. of Tech.
(1)	+	Europe and Oil
(2)	+	Fortune
(1)	*	Genie Civ. (French)
(5)	*	Geo-Marine Technology
(1)	*	Houille Blanche
(1)	*	International Shipbuilding Progress
(2)	-	Long Island Commercial Rev. (Newspaper)
(3)	+	Machine Design
(1)	*	Marine Engineering Review
(7)	*	Marine Tech. Soc.; Journal
(13)	*	Marine Technology
(8)	*	Marine Tech. Soc.; Trans.
(7)	+	Maritime Reporter/Engineering News
(2)	*	Mass Inst. of Tech.; C.E. Dept.
(1)	*	Naval Electronic Lab.; Rept.
(1)	*	Naval Research Lab.; Rept.
(2)	*	Naval Ship Res. & Dev. Ctr.; Rept.
(6)	*	Netherlands Ship Model Basin; Symposium
(3)	-	New York Times

Table VII (Cont'd)

(74)	+	Ocean Industry
(6)	+	Oceanology International
(10)	+	Offshore
(6)	*	Offshore Exploration Conf.; Proceedings
(1)	+	Offshore Oil and Mining
(26)	*	Offshore Technology Conf.; Proceedings
(7)	+	Oil and Gas Journal
(1)	+	Optical Spectra
(1)	+	Petroleum Soc. of CIM
(3)	*	Royal Inst. of Naval Arch.
(1)	*	Royal Soc. of London; Proc.
(1)	+	Saturday Review
(1)	+	Science Horizons
(2)	+	Scientific American
(1)	*	Scripps Inst. of Ocean.; Rept.
(1)	+	Sea Frontiers
(1)	*	Ship Research; Journal of
(47)	*	Soc. of Naval Arch. and Marine Engrs.
(1)	+	Southwestern Legal Foundation
(6)	+	Undersea Technology
(1)	+	Underwater Journal
(1)	*	Underwater Science & Tech. Journal
(1)	*	U.S. Navy Symp. on Military Oceanogr.
(1)	-	Wall St. Journal

* The symbols in this column may be interpreted as follows: (*) basically technical information; (+) general expository articles dealing with concept, may contain some technical data; (-) primarily items of newsworthy nature; technical data questionable.

and Saturday Review. However, a quick scan of the publications in Table VII will show the range and also suggest that there are a number of sources which have not yet been tapped.

The largest source of hard technical information came from the Society of Naval Architects and Marine Engineers (including Marine Technology) with 60 entries. Only the Offshore Technology Conference, an annual convention, with 26 entries was remotely close. The unusual aspect of this revelation is that platforms, as such, play a very small role in the activities of the Society of Naval Architects. In fact, a technical panel to consider the subject was only formed within the last year.

The purpose of this phase of the program is to provide input to a complete analysis of 1) optional platform design for each mission, and 2) general platform design for multi-mission possibilities. Judging from the frenzy of activity in getting platforms off the drawing boards and into the sea, we have undertaken this study none to soon.

The prime source of offshore technology development is, without dispute, the petroleum industry. Almost every existing or proposed offshore platform, with the exception of navigational and weather buoys, has its roots in a design based on offshore oil technology. A look at ocean platform technology must therefore begin with a view of the offshore oil industry. Other industries, however, are beginning to develop modified concepts designed to provide more optimum configurations for their particular objectives. This is especially evident in oceanographic research and is beginning to appear in the design of large oceanic base concepts.

The most notable developments here are the use of concrete and steel and the emphasis on modular construction. One of the most promising areas in offshore design is the development of versatile modular units.

We have assembled a body of information here that has been gleaned from the open literature. There is undoubtedly more to be discovered and a considerable amount of data that is unpublished that can be obtained for legitimate use. All in all, there is enough input for the various missions and platforms that appropriate analyses of performance, logistics and economics can be undertaken. If there is a paucity of data it is in the environment and ecology area. We just don't know what the effect of platforms, that assume the prominence of morphological features in the ocean, is likely to be, either locally or in the far field, either now or in the future. In the next phase of this work, we hope to shed some light on this area.

VII - REFERENCES

The following references were the primary source material for this study. The documents that were gleaned from the literature cover the entire spectrum of scientific reporting from lengthy dissertations in erudite journals to one liners in newspapers and advertisements in trade magazines.

To maximize the value of the references, they have been grouped according to general requirements of platforms (Section 4) and according to the mission requirements (Section 5) as listed in the Table of Contents. Within each group, the references are alphabetized according to author. Where there is no author, alphabetical arrangement by title follows the authored papers. Occasionally, references in another group are referred to in a footnote at the end of a particular group. This is not the limit of overlap. Obviously, some papers would fit quite properly in a number of groups.

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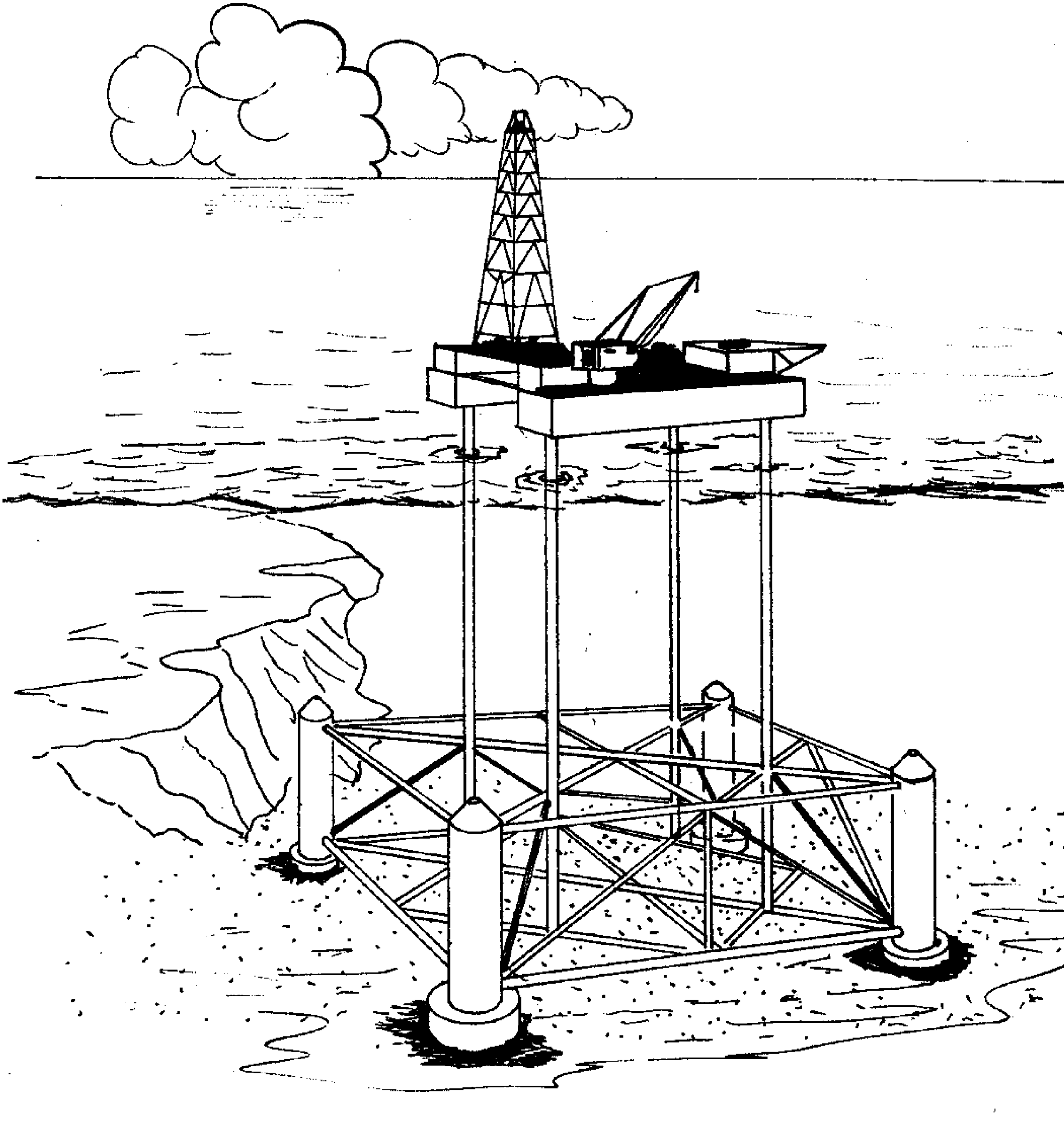


FIGURE I JACK-UP TYPE SUBMERSIBLE PLATFORM.
(OCEAN INDUSTRY, JAN. 1969)

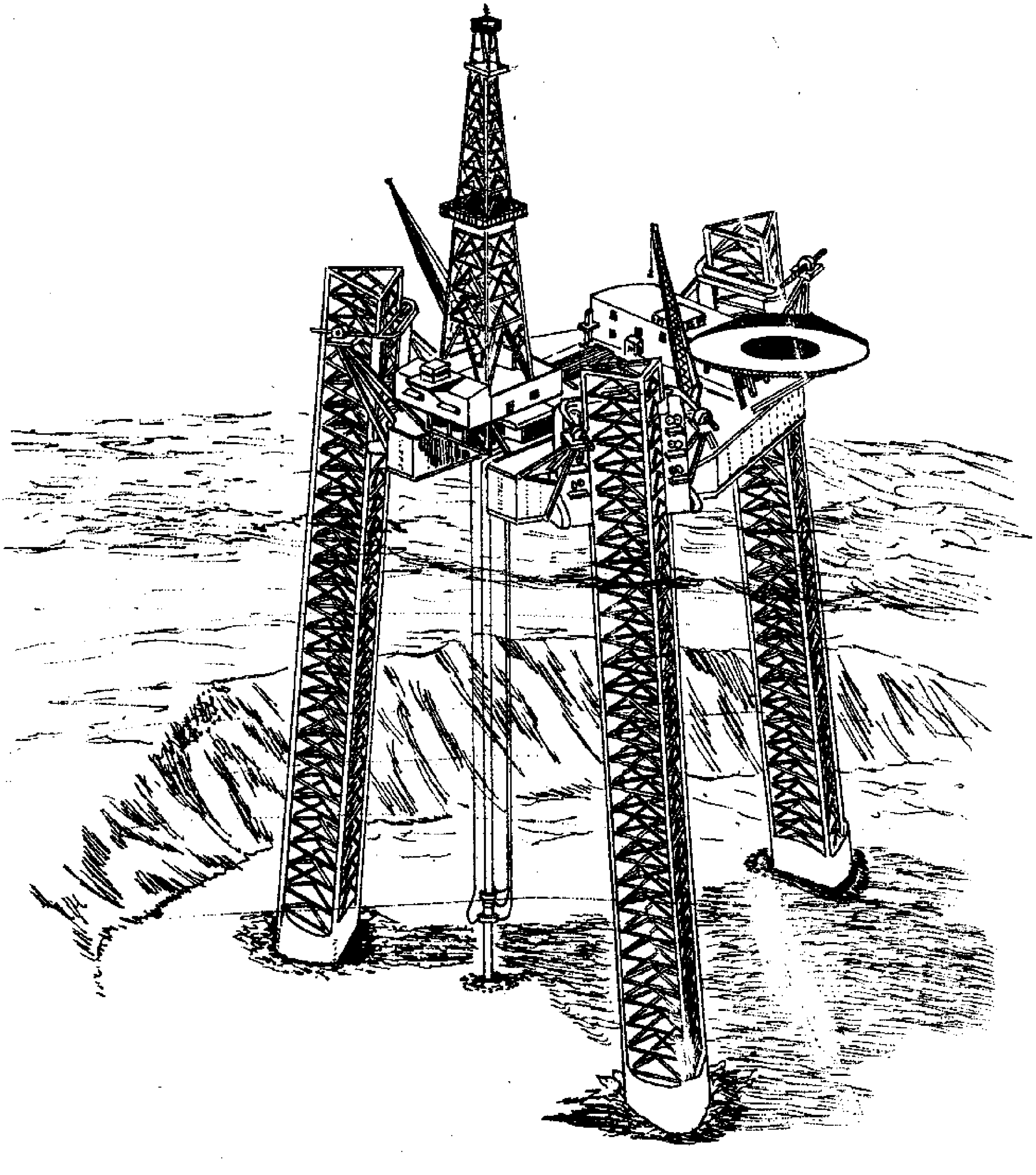


FIGURE 2 JACK-UP TYPE OIL DRILLING PLATFORM.

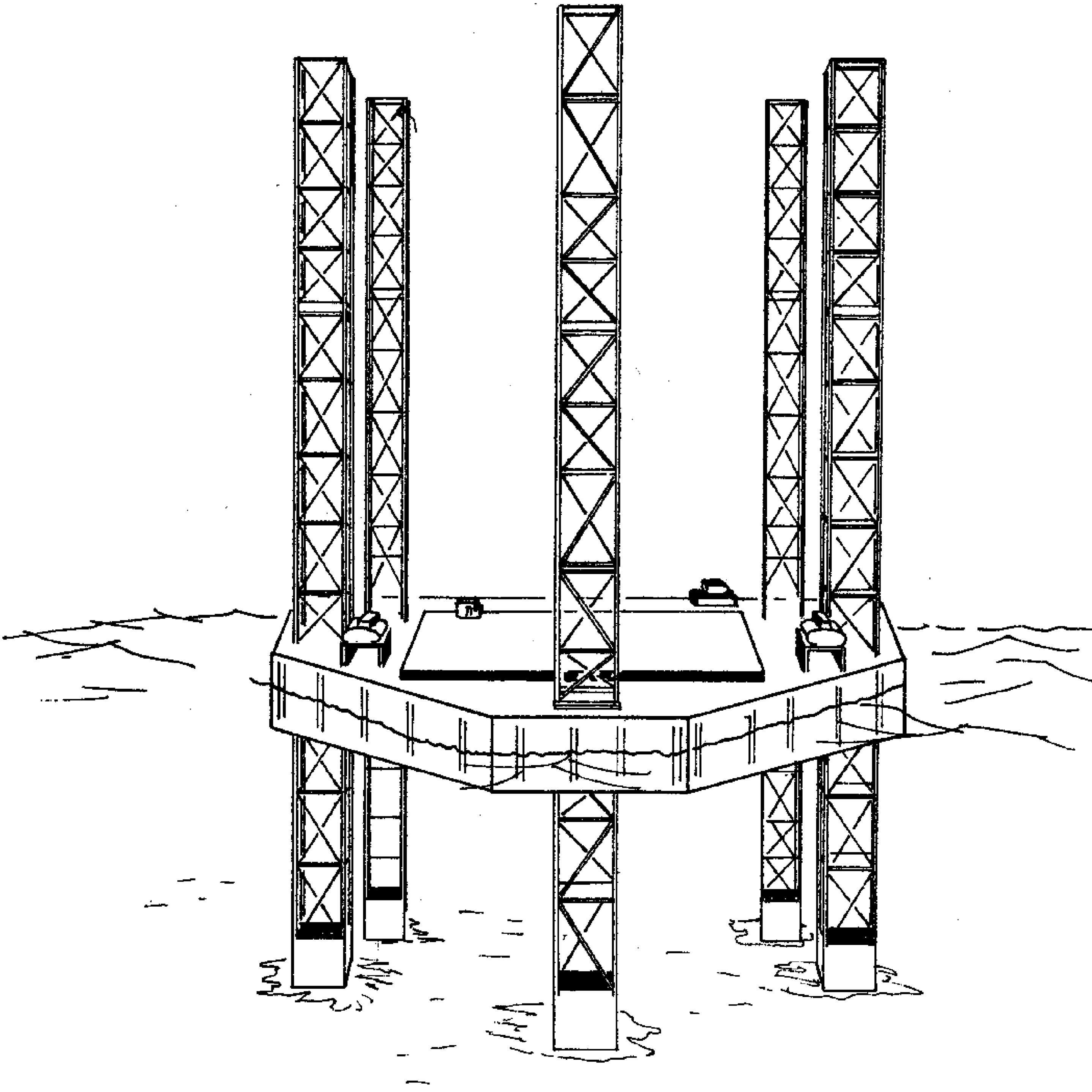


FIGURE 3 SELF-ELEVATING PENTAGONAL PLATFORM.
(OCEAN INDUSTRY, MAR. 1970, VOL. 5, NO. 3)

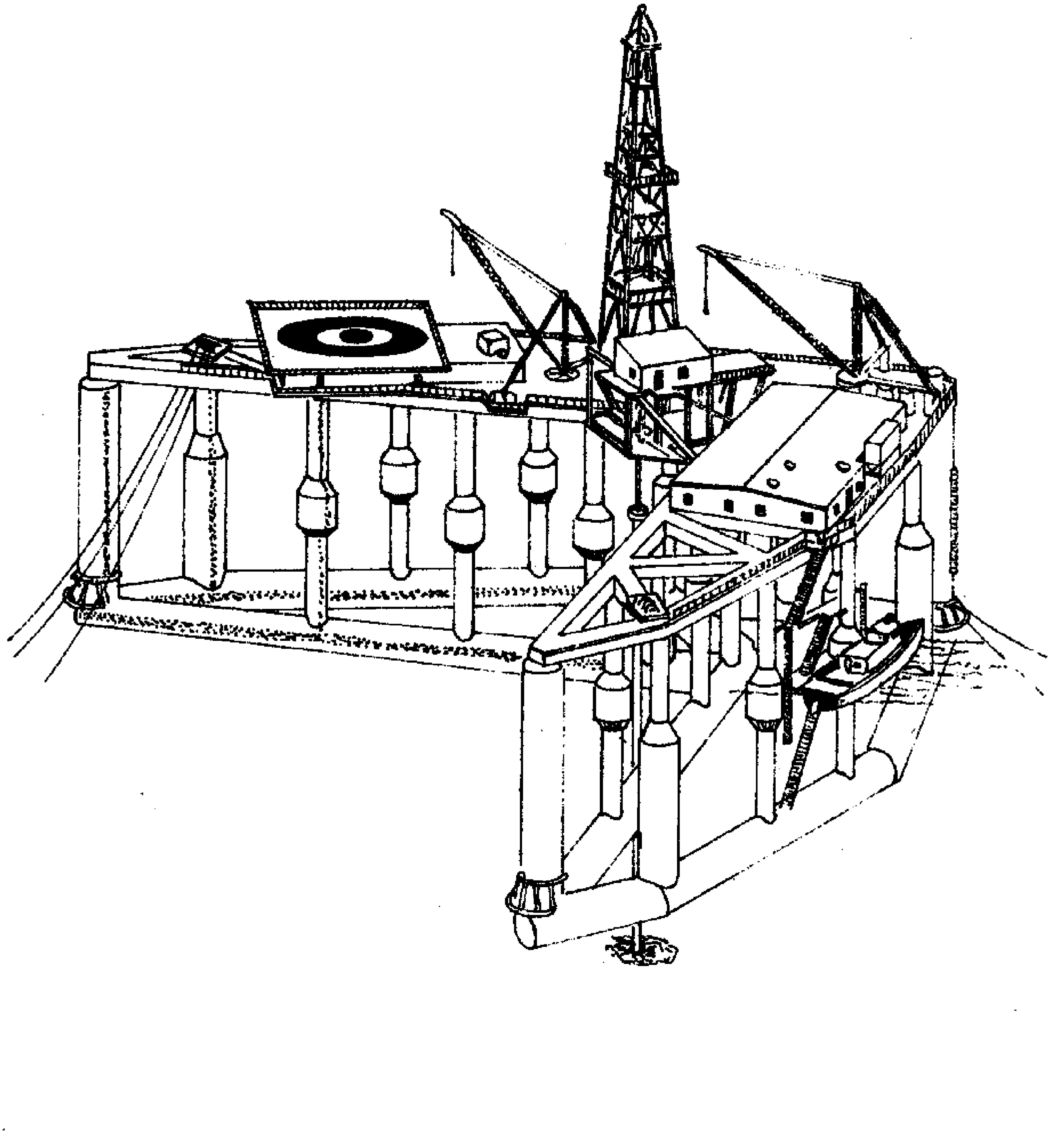


FIGURE 4 V-SHAPE DRILLING PLATFORM.

(FORTUNE MAGAZINE, FEB. 1965)

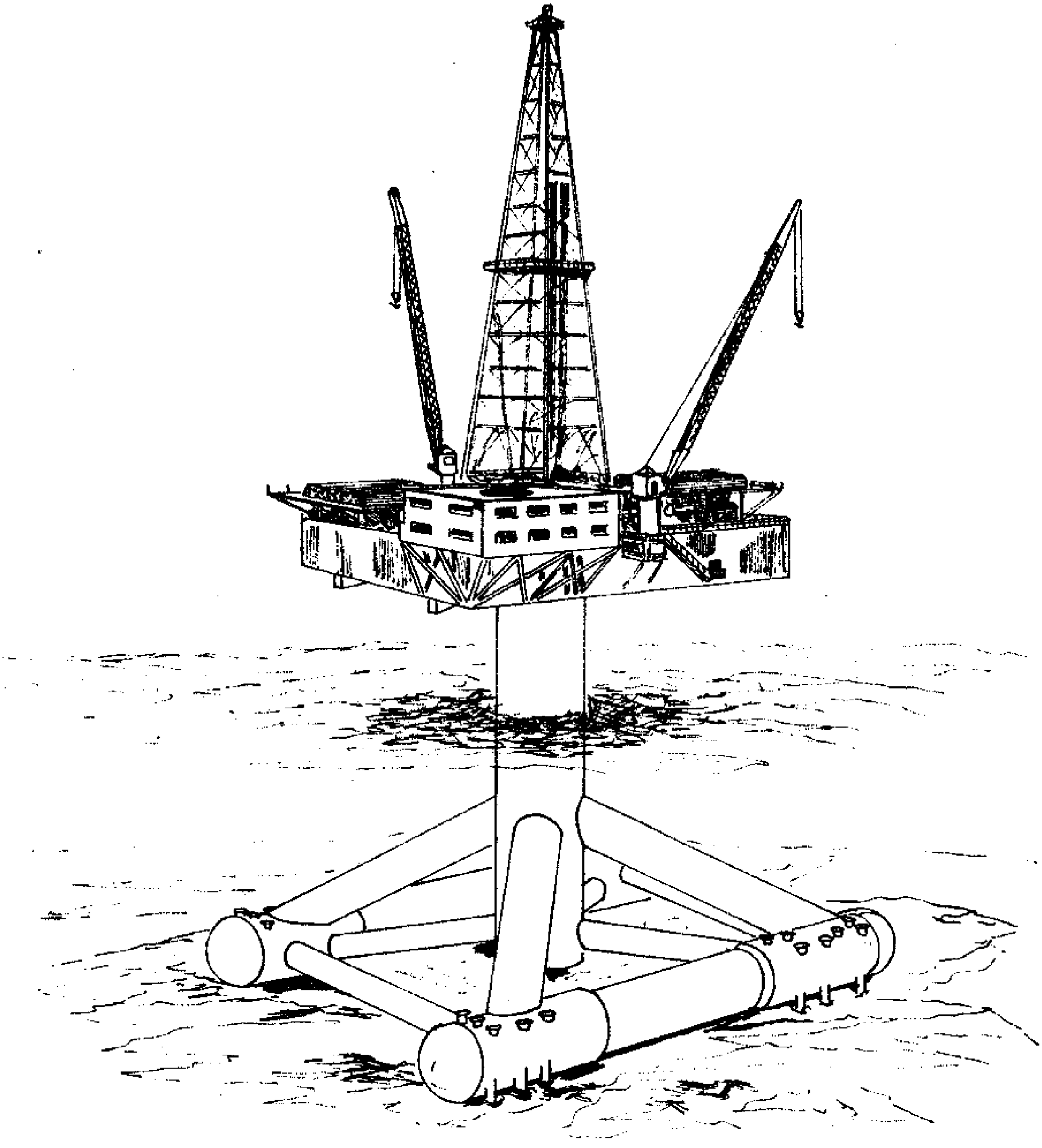


FIGURE 5 MONOPOD - TYPE DRILLING PLATFORM, (REF. 15)

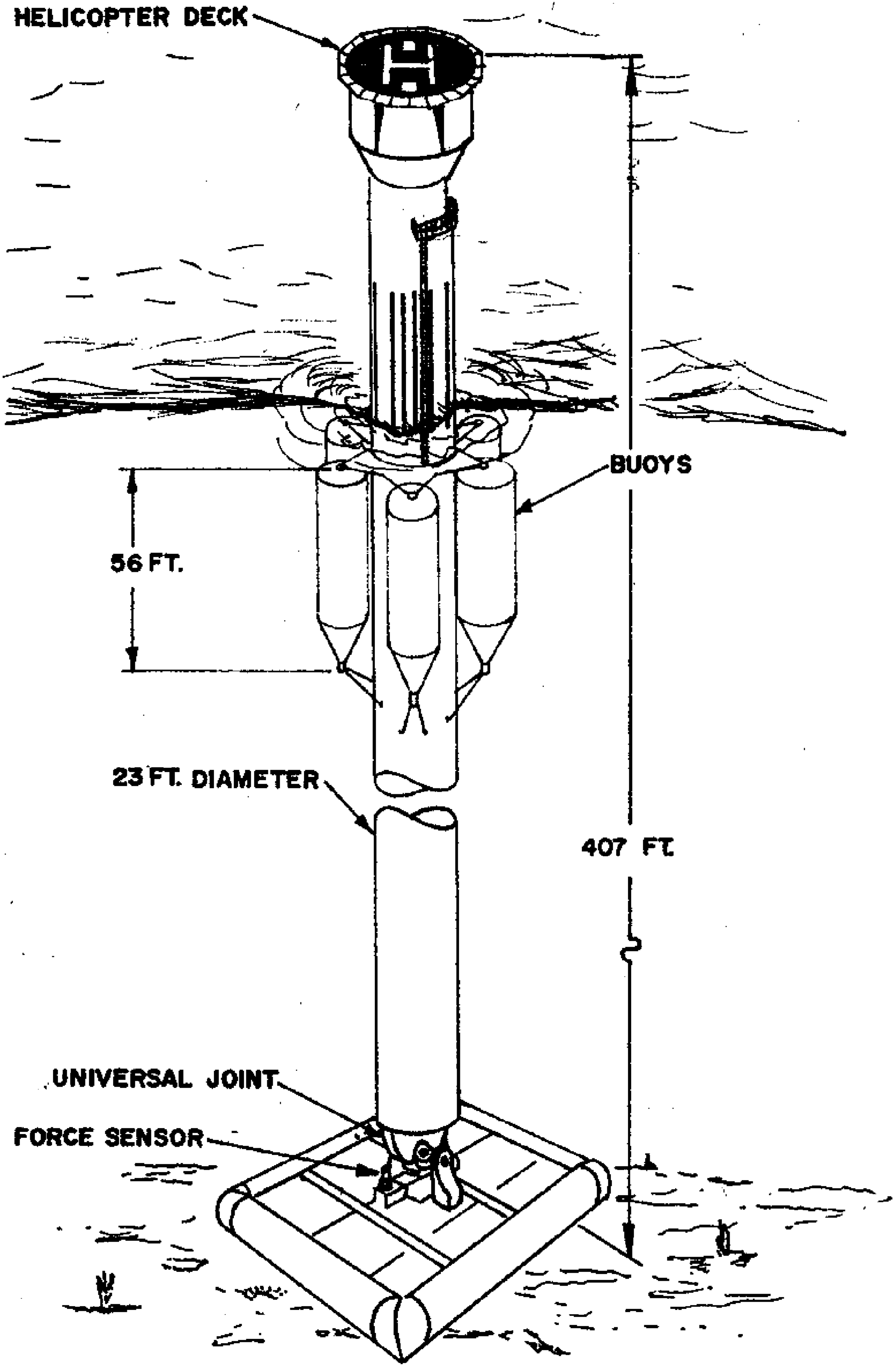


FIGURE 6 ARTICULATED COLUMN SUBMERSIBLE PLATFORM. (REF. 119)

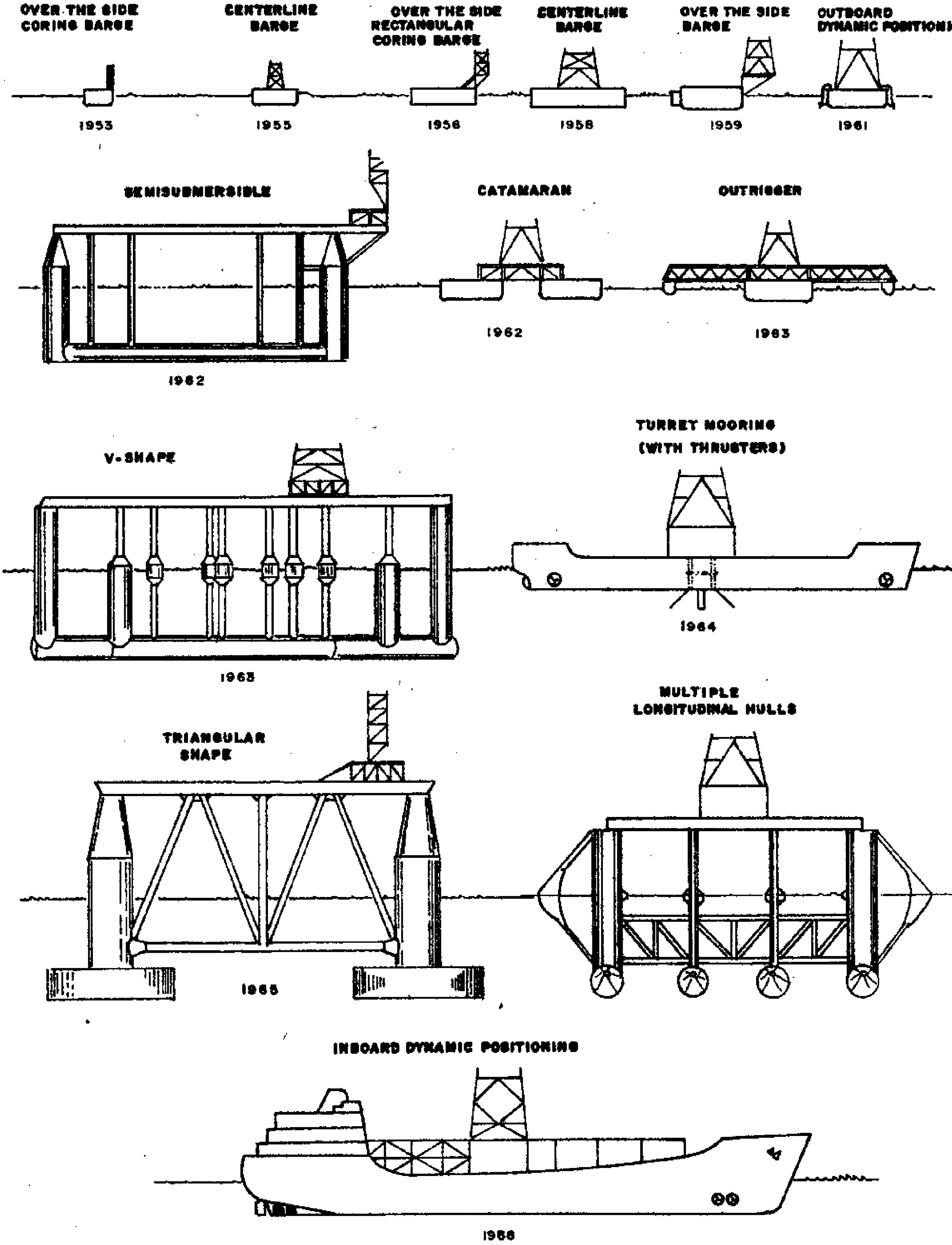


FIGURE 7 CHRONOLOGY OF FLOATING RIGS, 1953-1968. (REF.4)

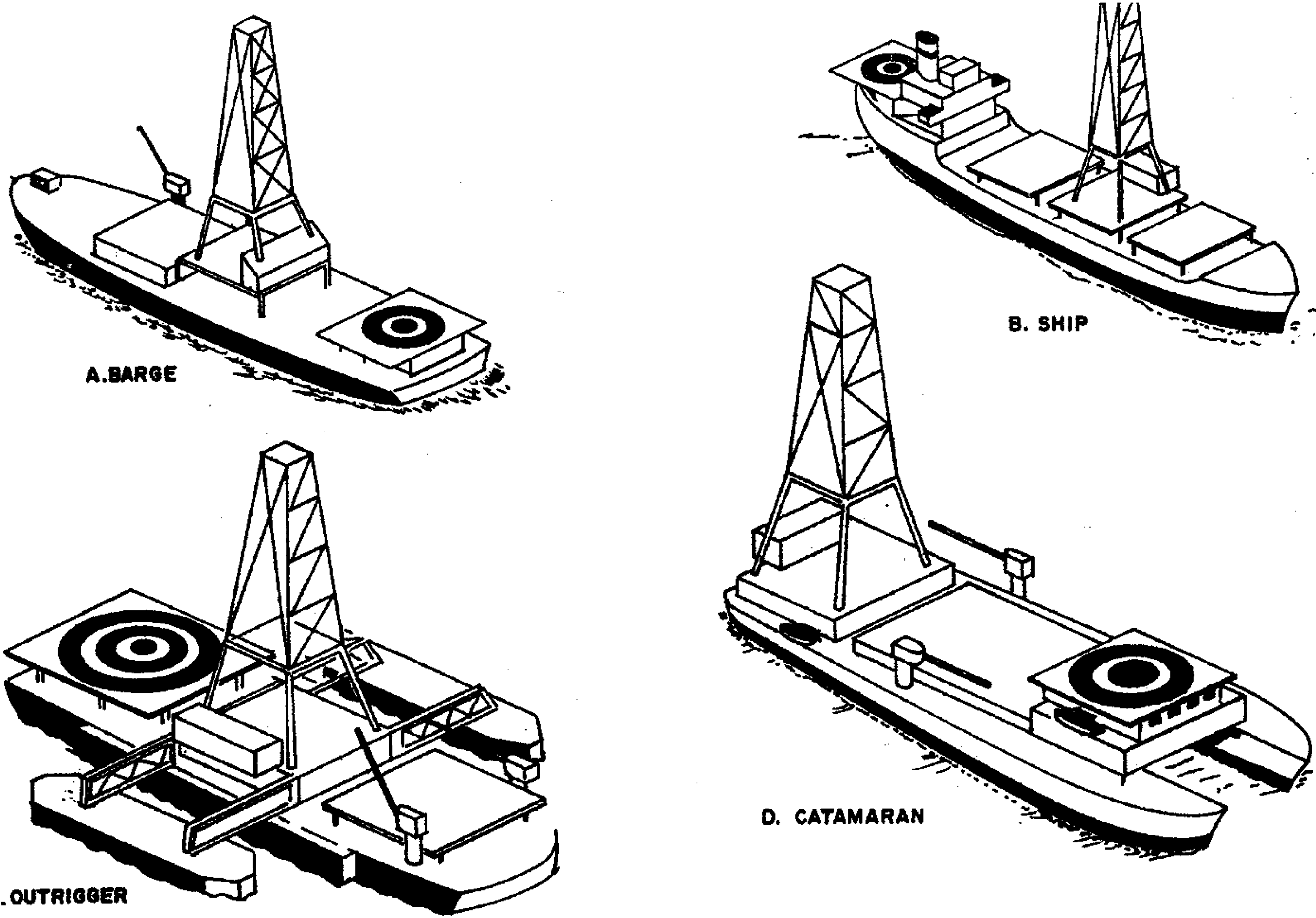


FIGURE 8 SURFACE HULL-TYPE DRILLING SHIPS. (REF.143)

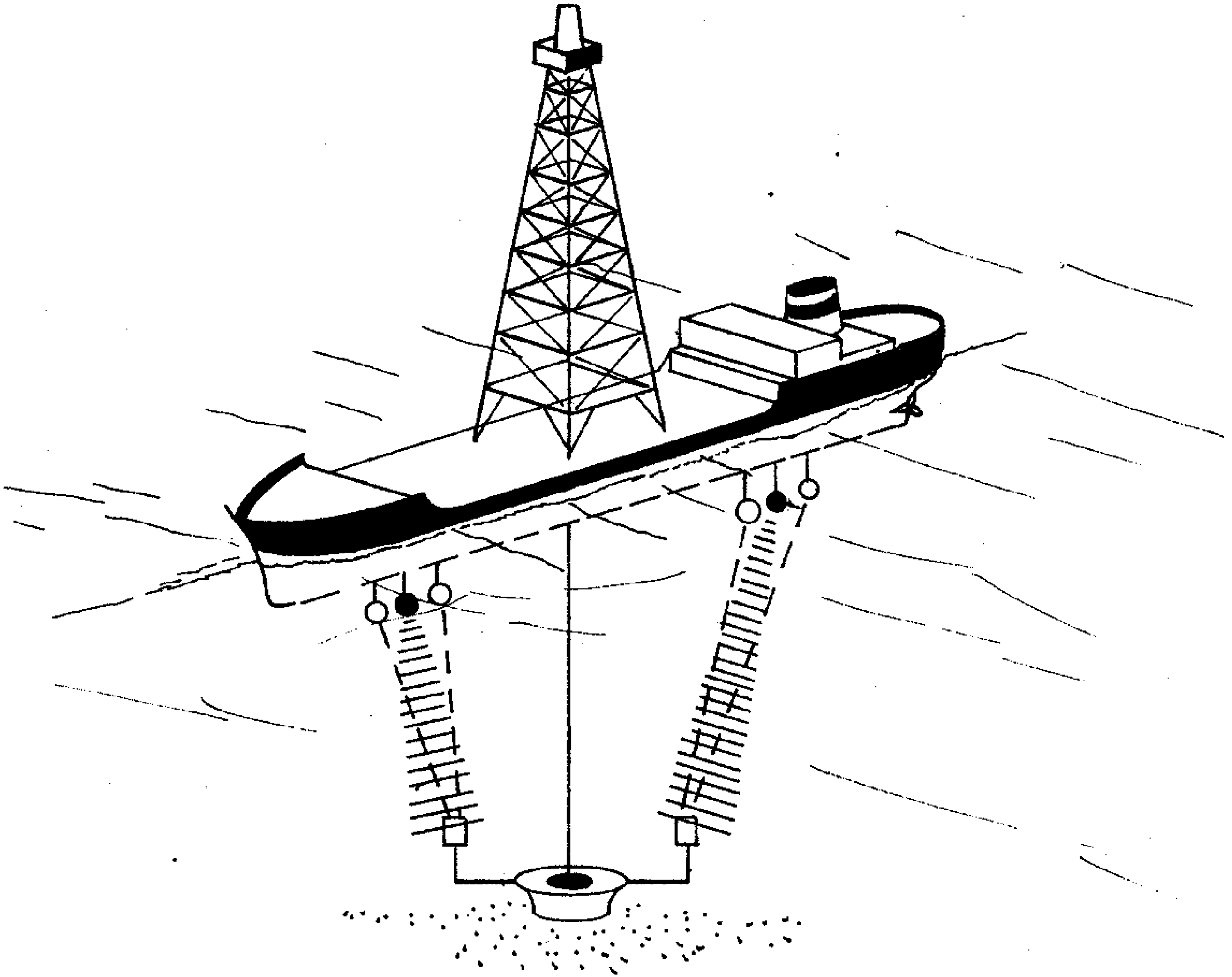


FIGURE 9 SOMASER'S ACOUSTIC REFERENCE FOR DYNAMIC POSITIONING.

(OIL & GAS JOURNAL, 6/7/71, P.68)

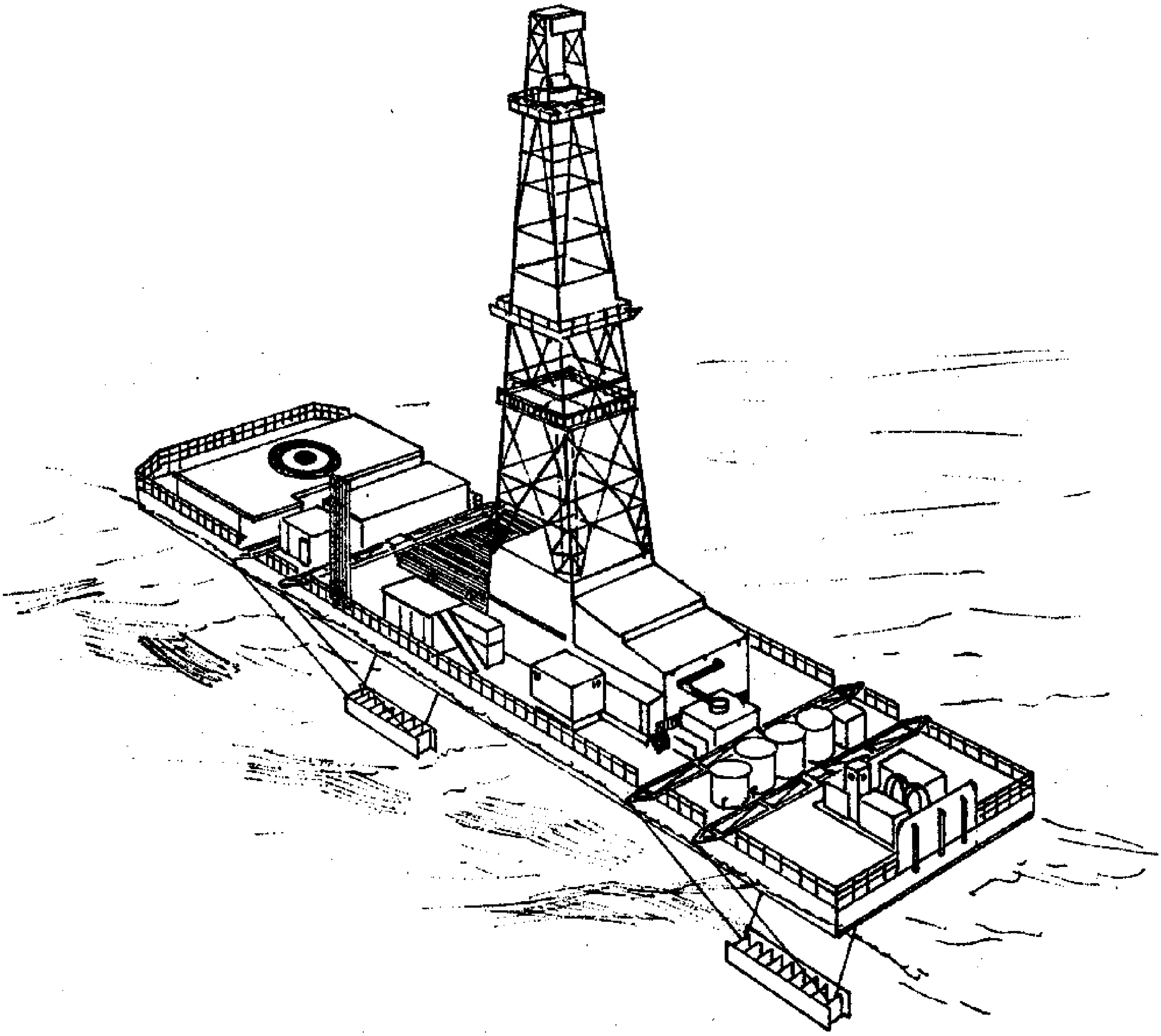


FIGURE 10 DRILLING BARGE WITH ENTRAPPED MASS STABILIZING DEVICE.
(WODECO ADVERTISEMENT-OCEAN INDUSTRY MAGAZINE)

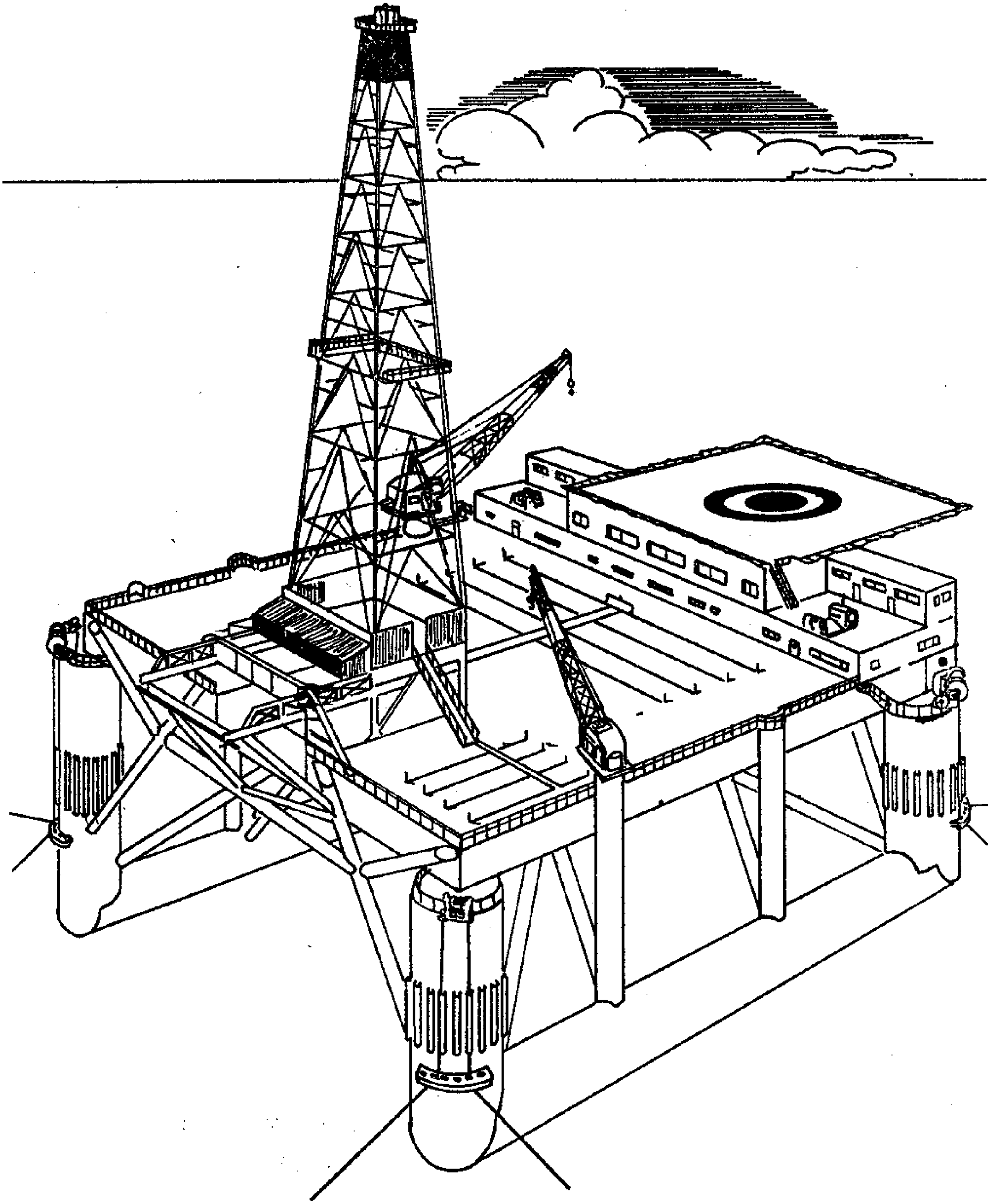


FIGURE 11 MULTIHULL SEMISUBMERSIBLE. (REF. 45)

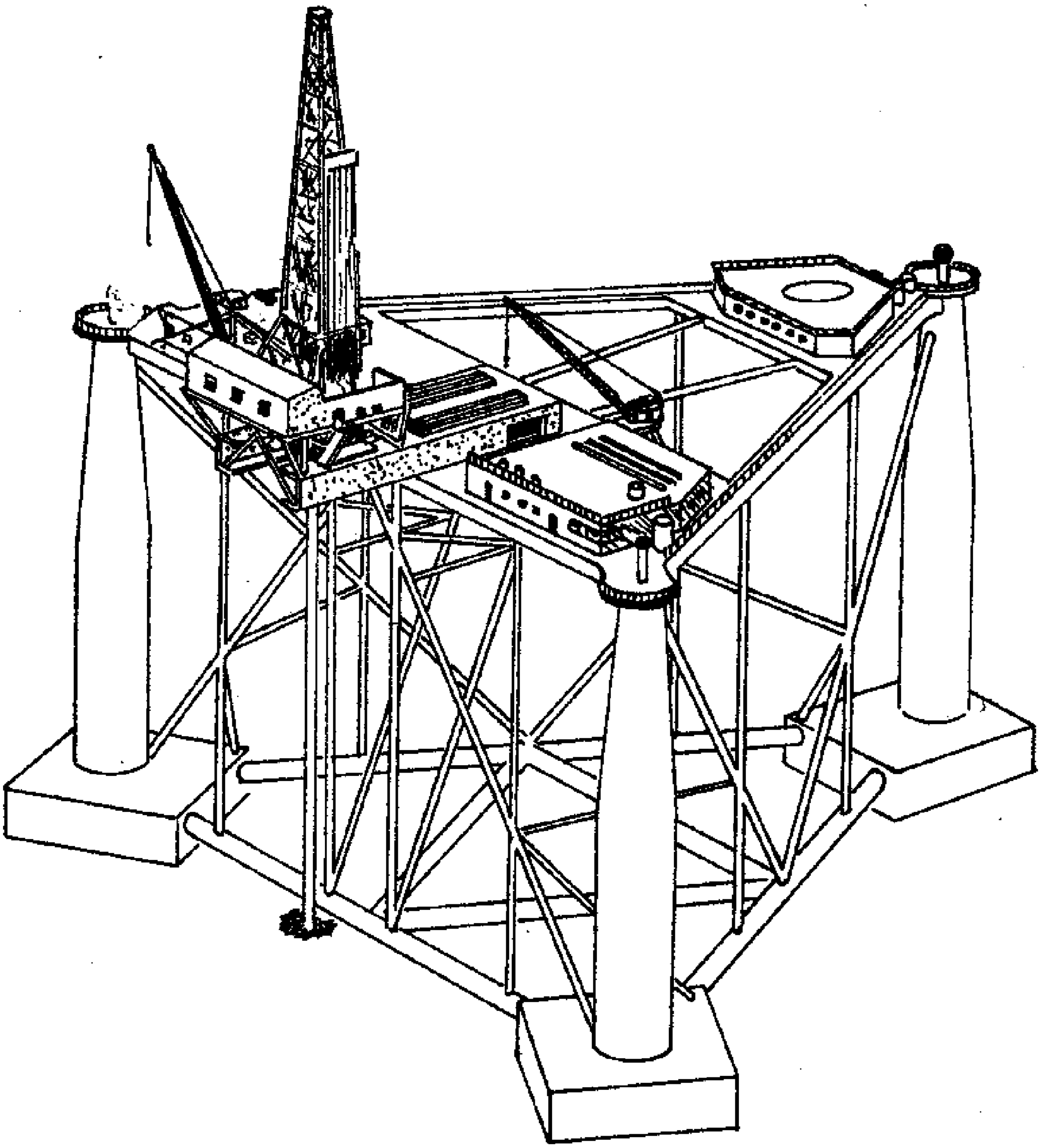
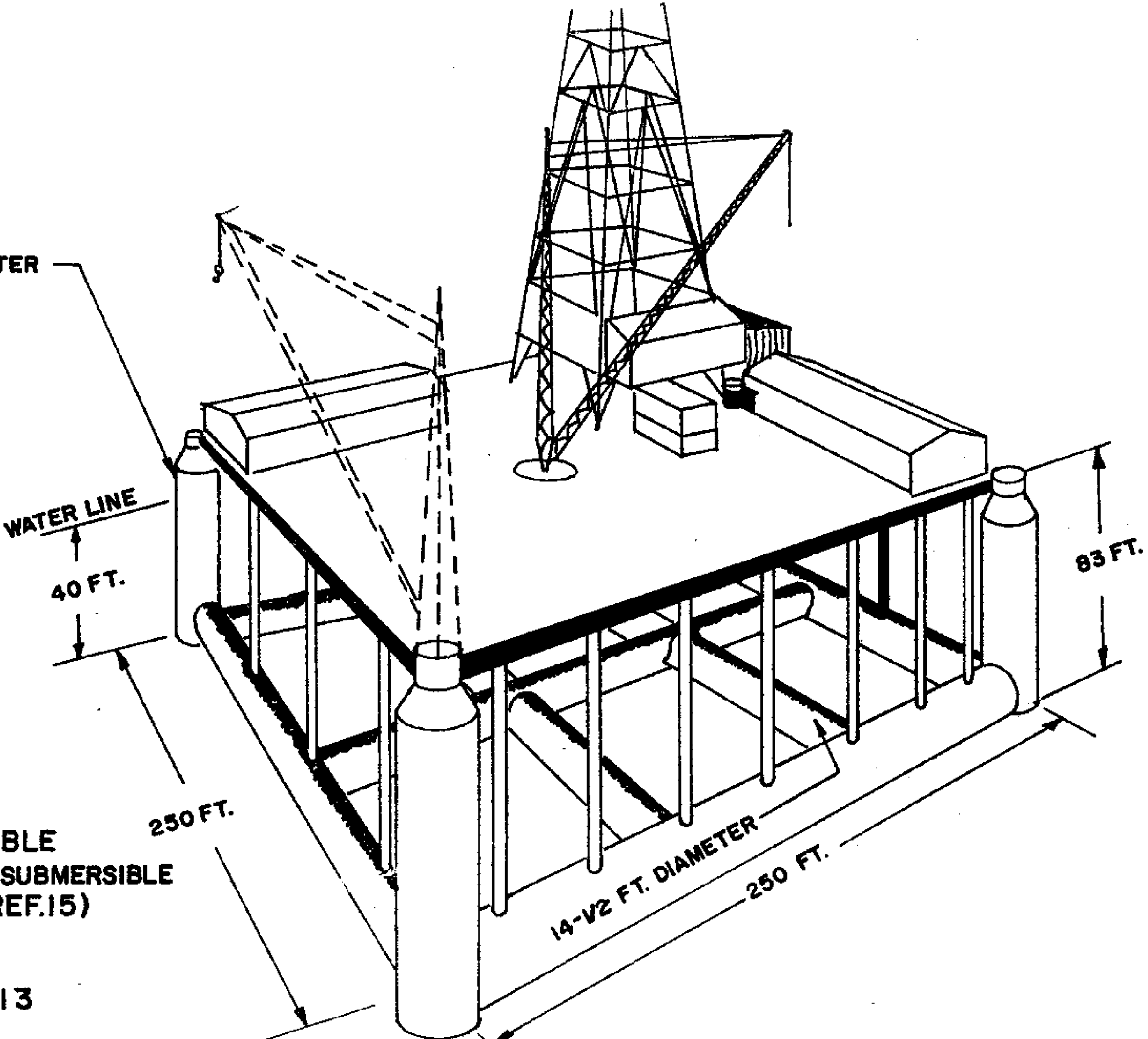


FIGURE 12 TRIANGULAR SEMISUBMERSIBLE DRILLING PLATFORM. (REF. 40)



FOUR-POD
SEMISUBMERSIBLE
(DETAILS OF SEMISUBMERSIBLE
BLUEWATER) (REF.15)

FIGURE 13

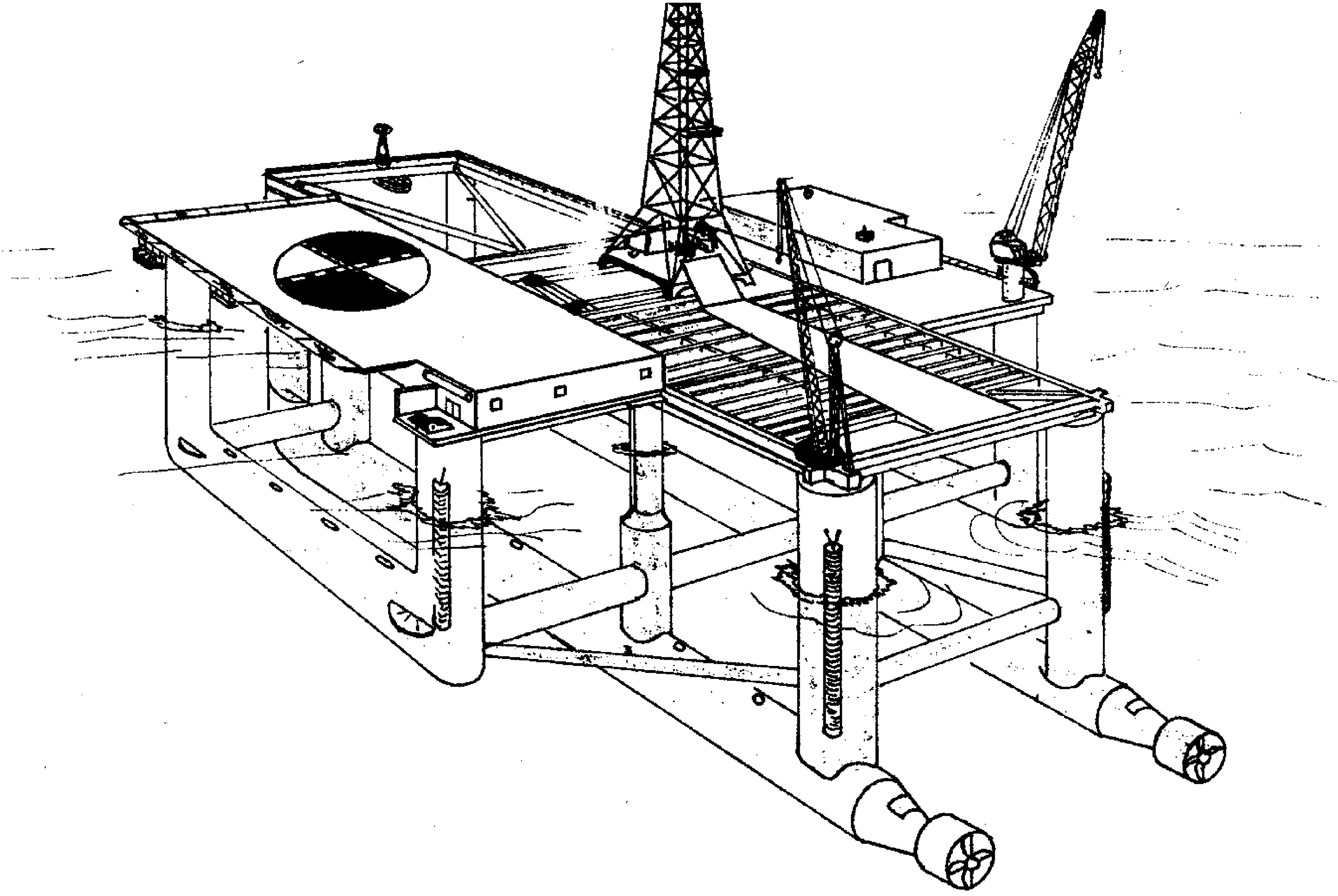


FIGURE 14 OCEAN VICTORY-SELF PROPELLED SEMISUBMERSIBLE.
(OIL & GAS JOURNAL, 9/13/71, P. 88)

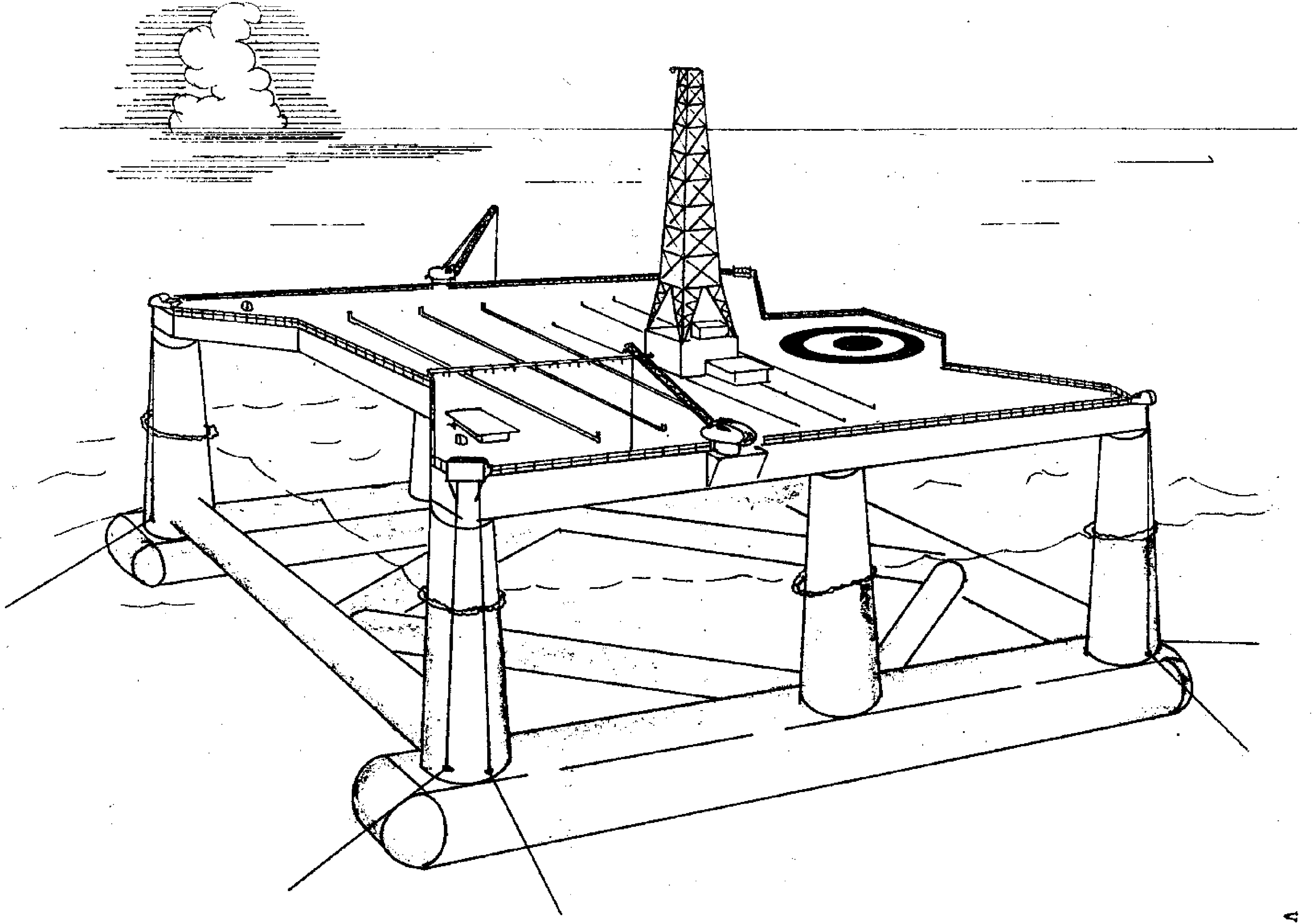


FIGURE 15 LATE MODEL SUPER DRILLING RIG.

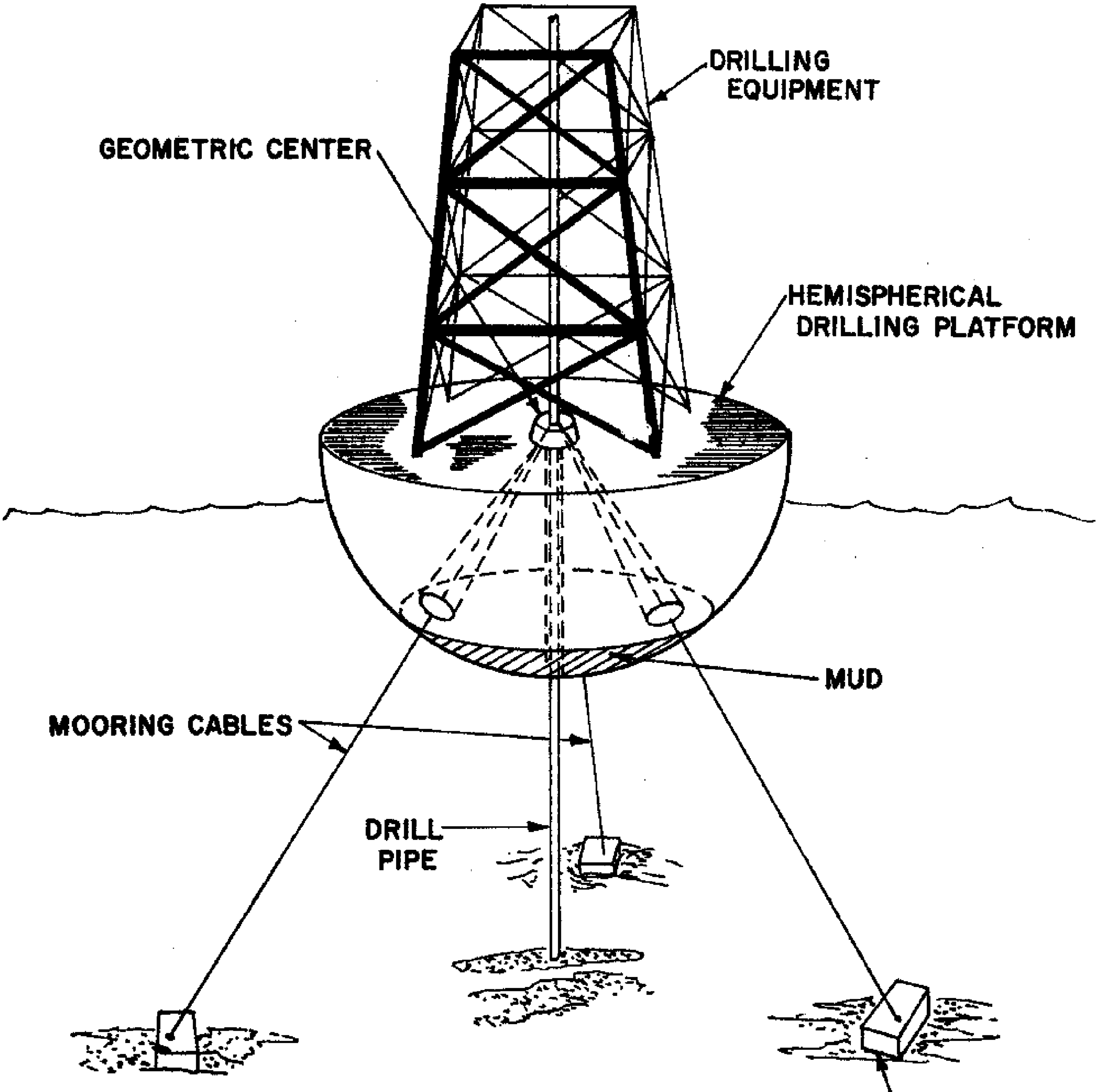


FIGURE 16 MONOHULL SEMISUBMERSIBLE (SPHERICAL) (REF. 224)

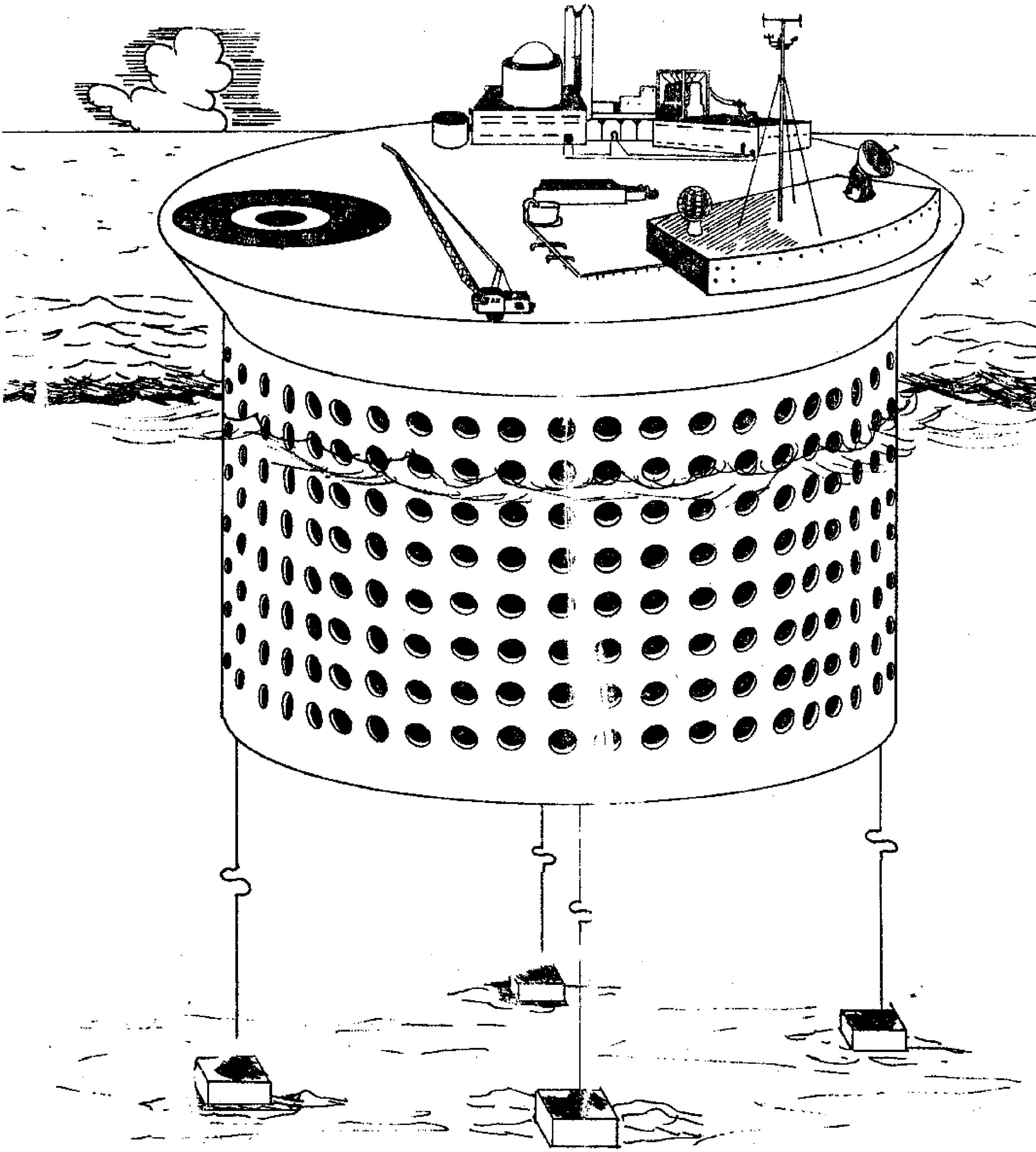
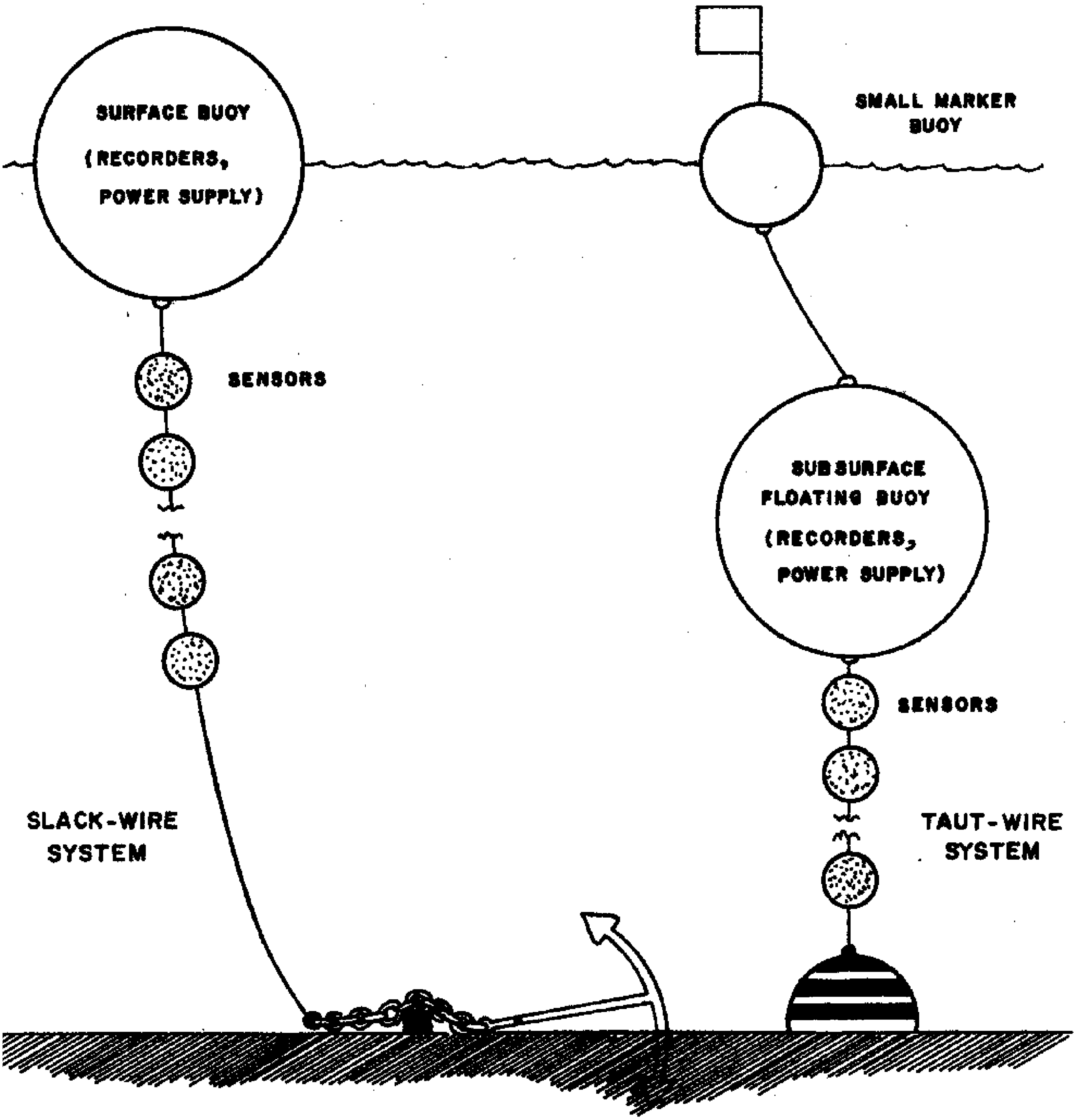


FIGURE 17 PERFORATED STABLE PLATFORM CONCEPT.



IGURE 18 ANCHORED BUOY SYSTEMS USED AS FIXED PLATFORMS IN OCEANOGRAPHIC AND METEOROLOGICAL WORK: (A) SLACK-WIRE SYSTEM, (B) TAUT-WIRE SYSTEM. (OPTICAL SPECTRA, MAY 1970, P. 58)

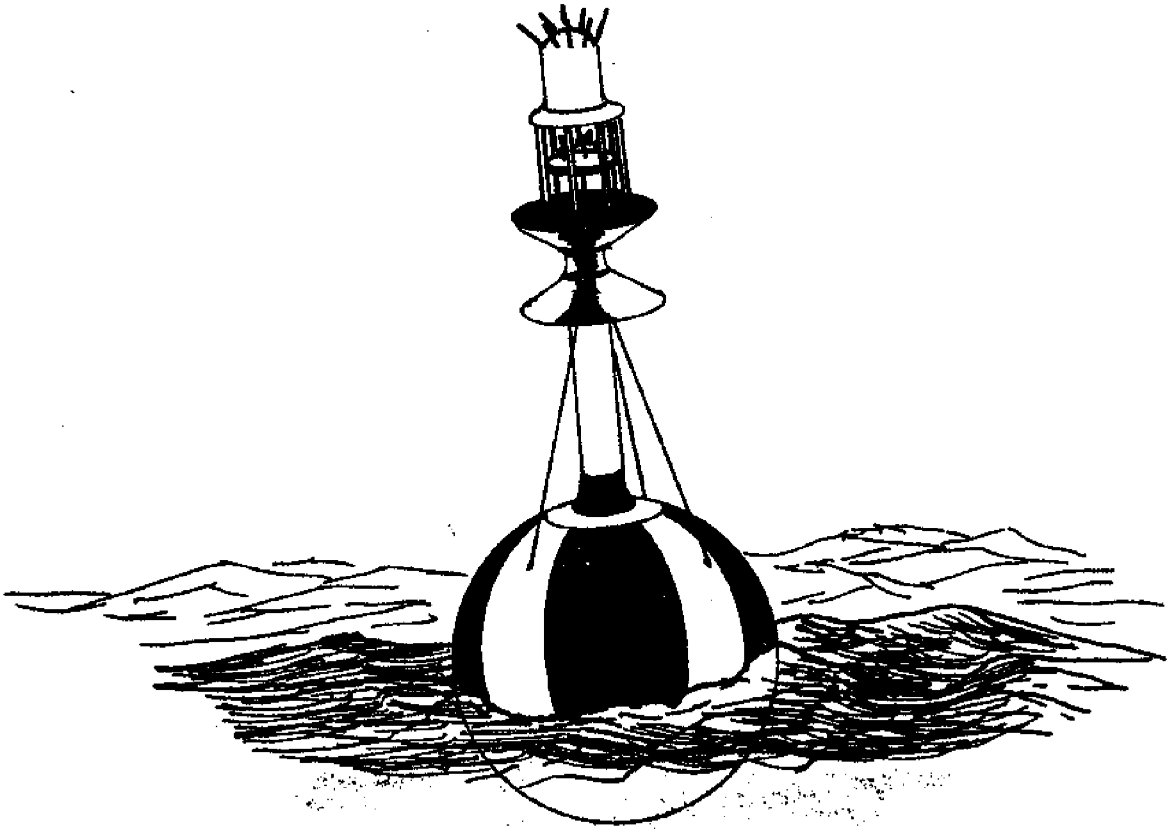


FIGURE 19 NEW LIMITED CAPABILITY BUOY BEING DEVELOPED FOR NOAA.
(OCEANOLOGY INTL., SEPT. 1971, P. 20)

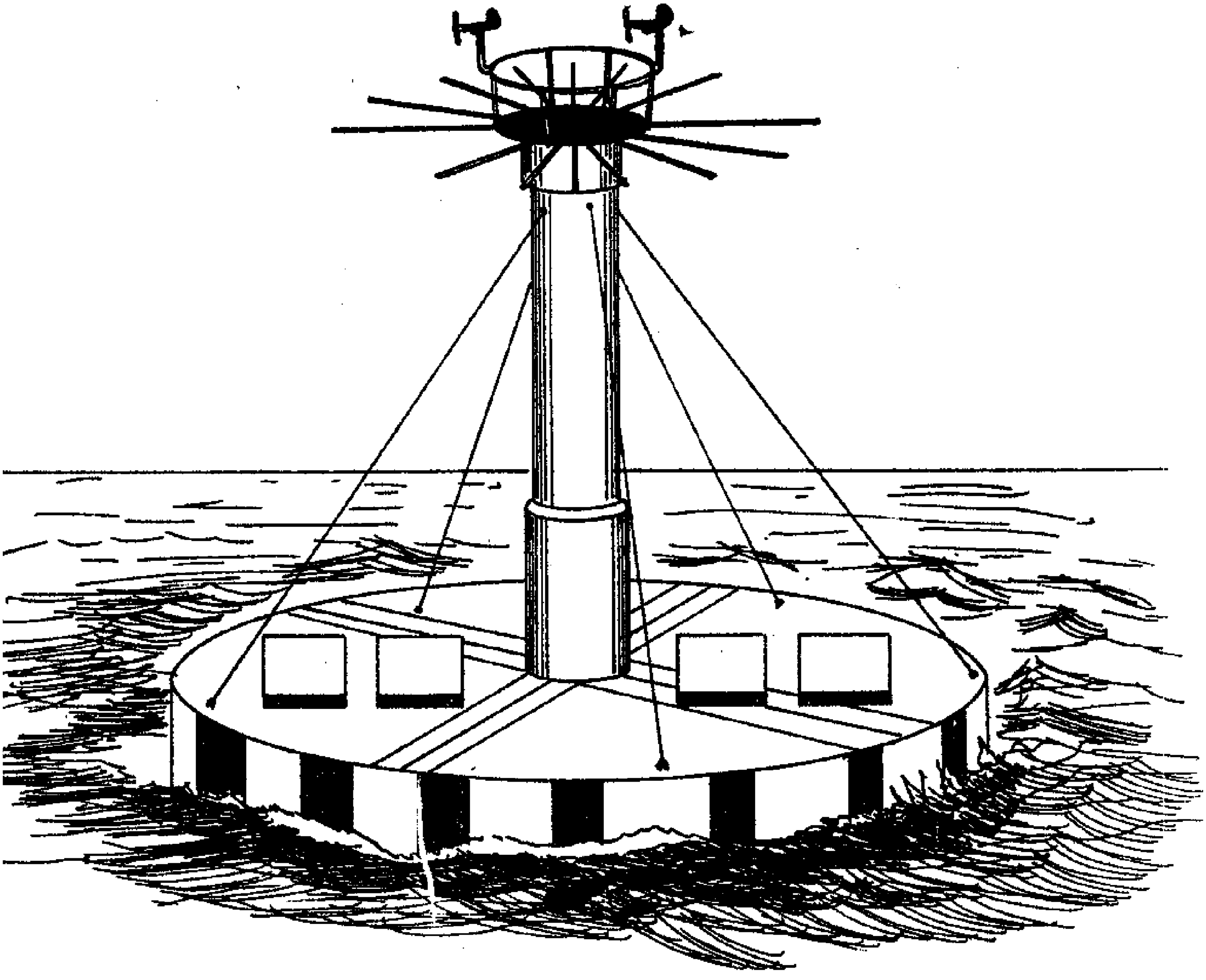


FIGURE 20 GIANT 100-TON WEATHER BUOY.
(PROC. 6TH ANNUAL CONF., MAR. TECH. SOC., 6/70, P. 551)

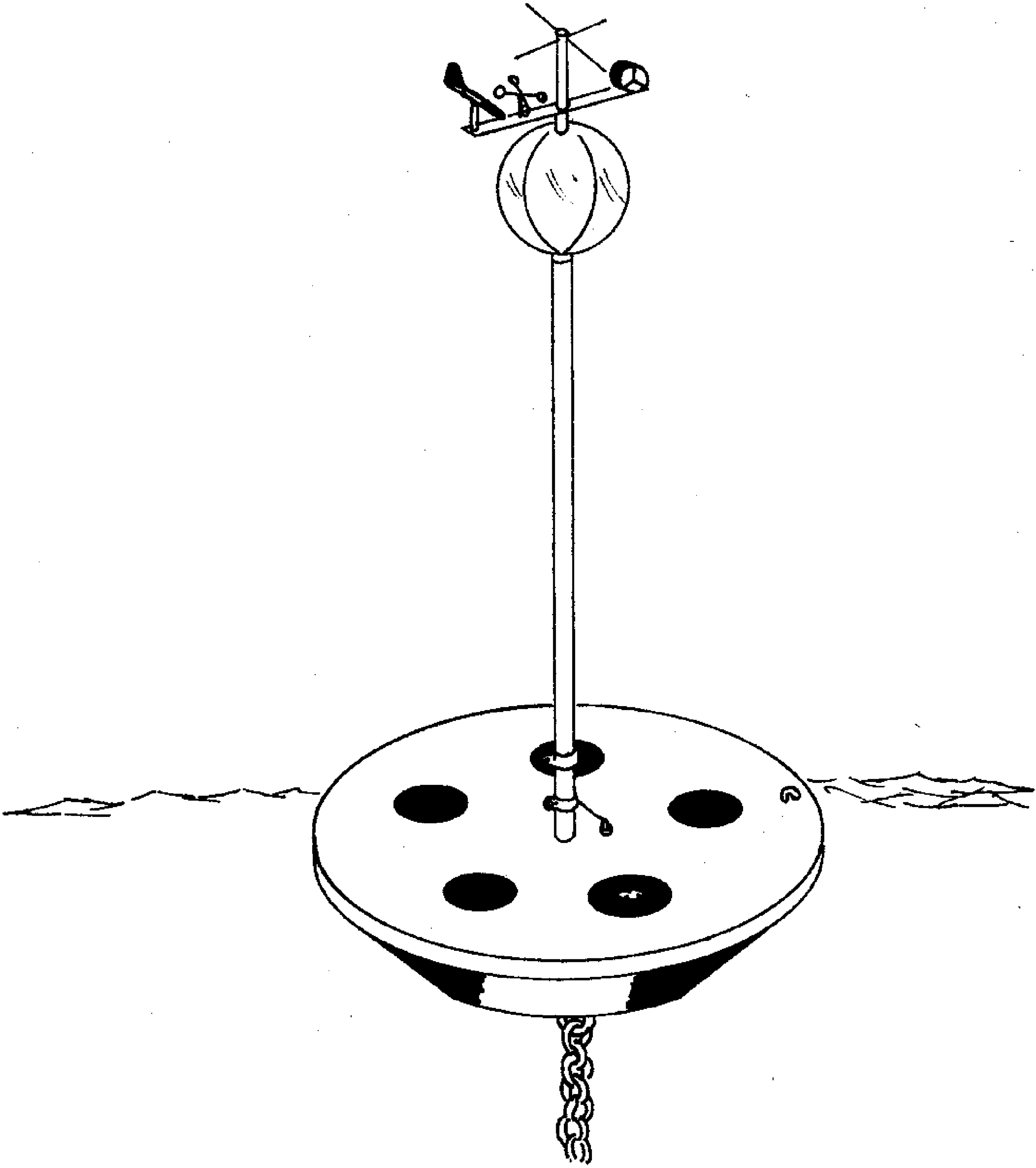


FIGURE 21 BUOY PLATFORM FOR SATELLITE INTERROGATION.
(REF. 187)

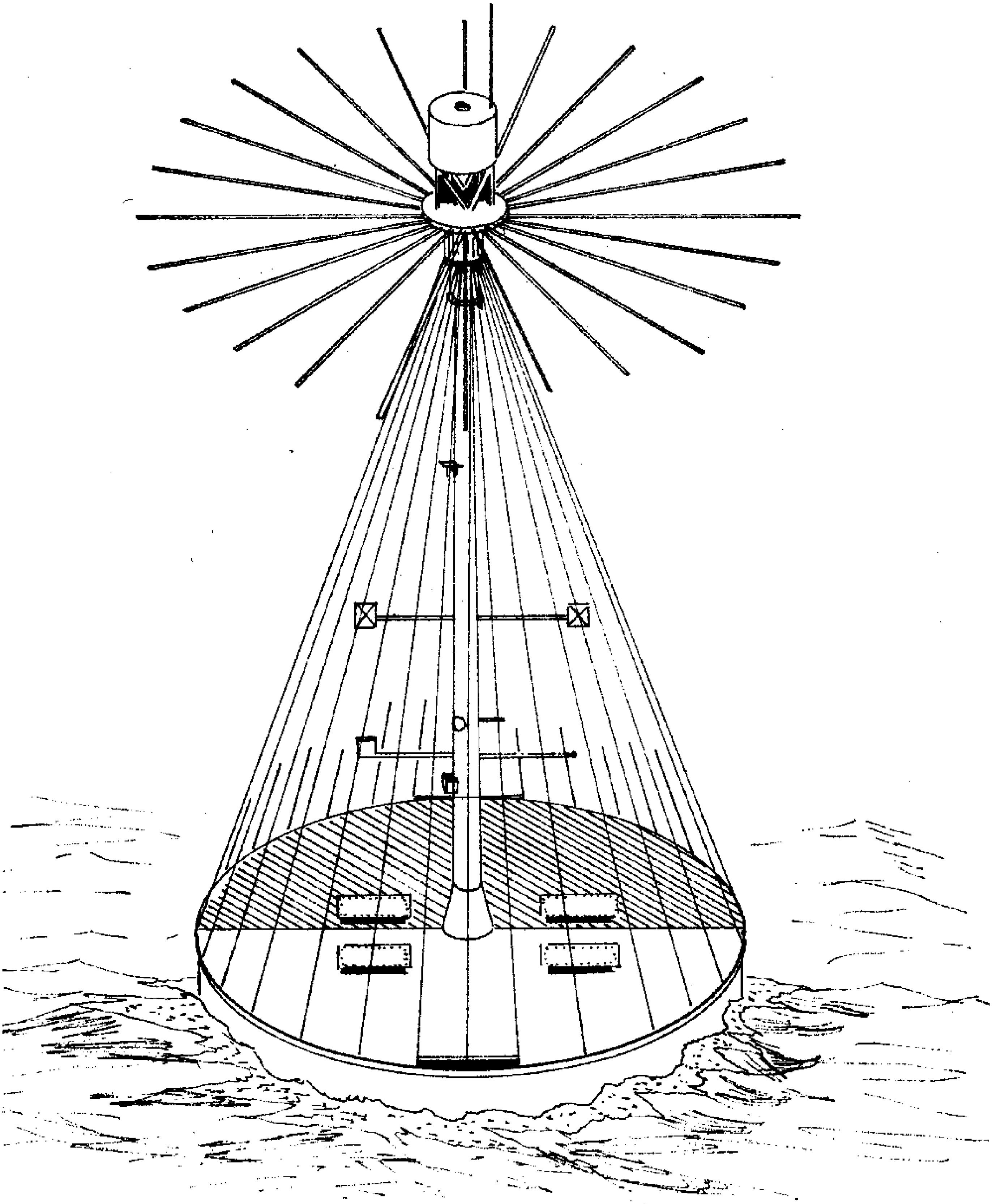


FIGURE 22 OCEAN DATA STATION.
(OCEANOLOGY INTNL., OCT. 1970)

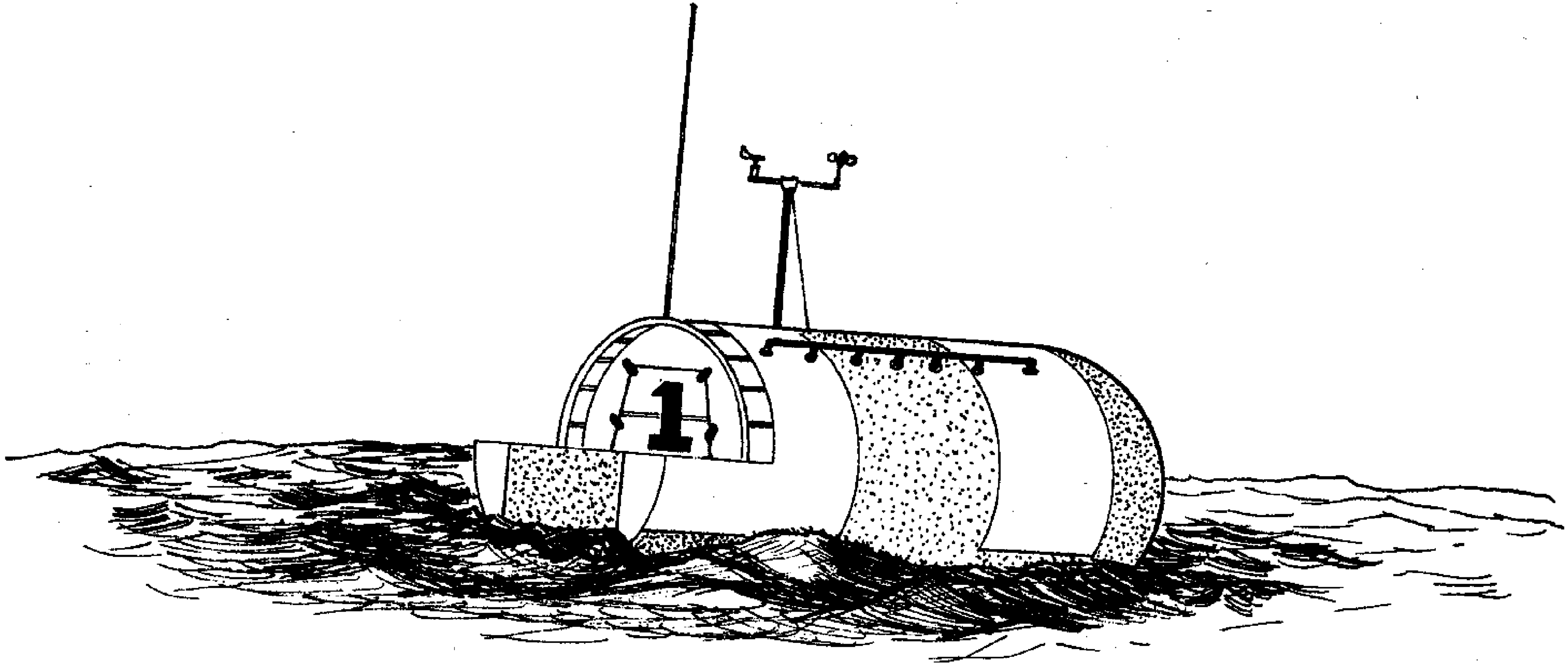


FIGURE 23 UNMANNED/MOORED BUMBLEBEE BUOY COLLECTS ENVIRONMENTAL DATA. (MARINE TECH. CONF., VOL. I, 1970)

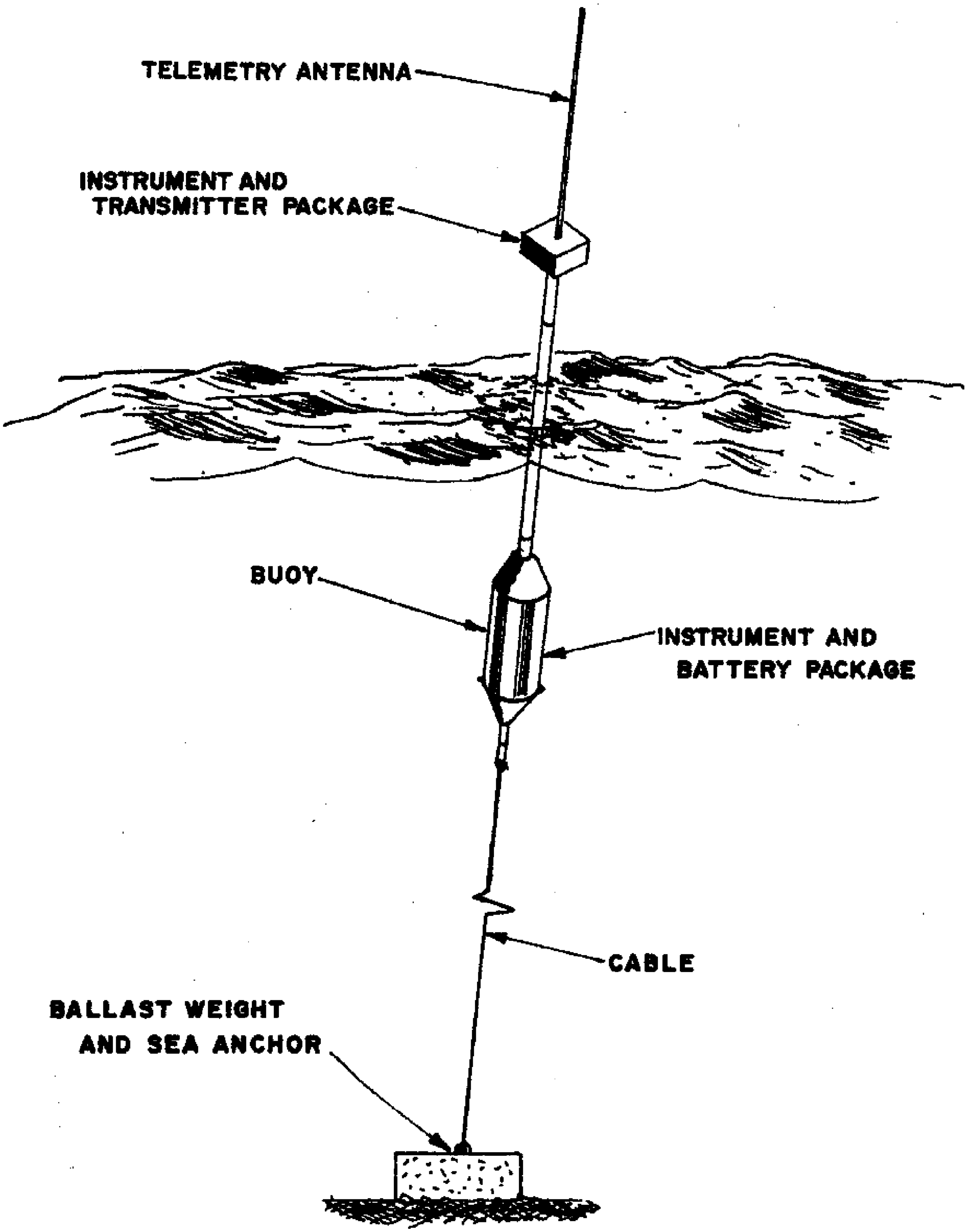
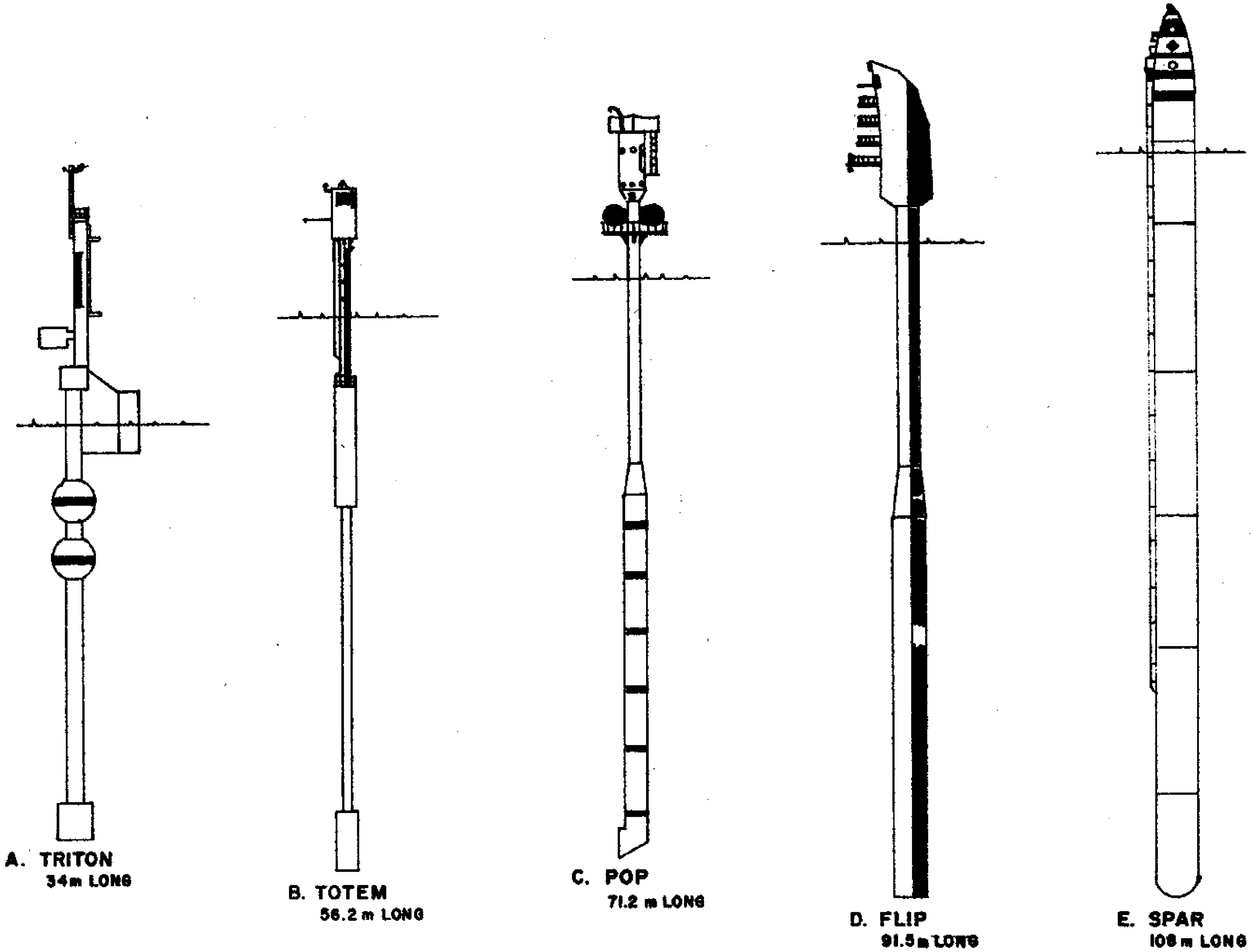


FIGURE 24 STABILIZED BUOY FOR OCEANOGRAPHIC AND METEOROLOGICAL INSTRUMENTATION (TRANS. MAR. TECH. SOC. SYMP., 1964)



A. TRITON
34m LONG

B. TOTEM
56.2 m LONG

C. POP
71.2 m LONG

D. FLIP
91.5 m LONG

E. SPAR
108 m LONG

FIGURE 25 MOORED SPAR BUOYS. (REF. 178)

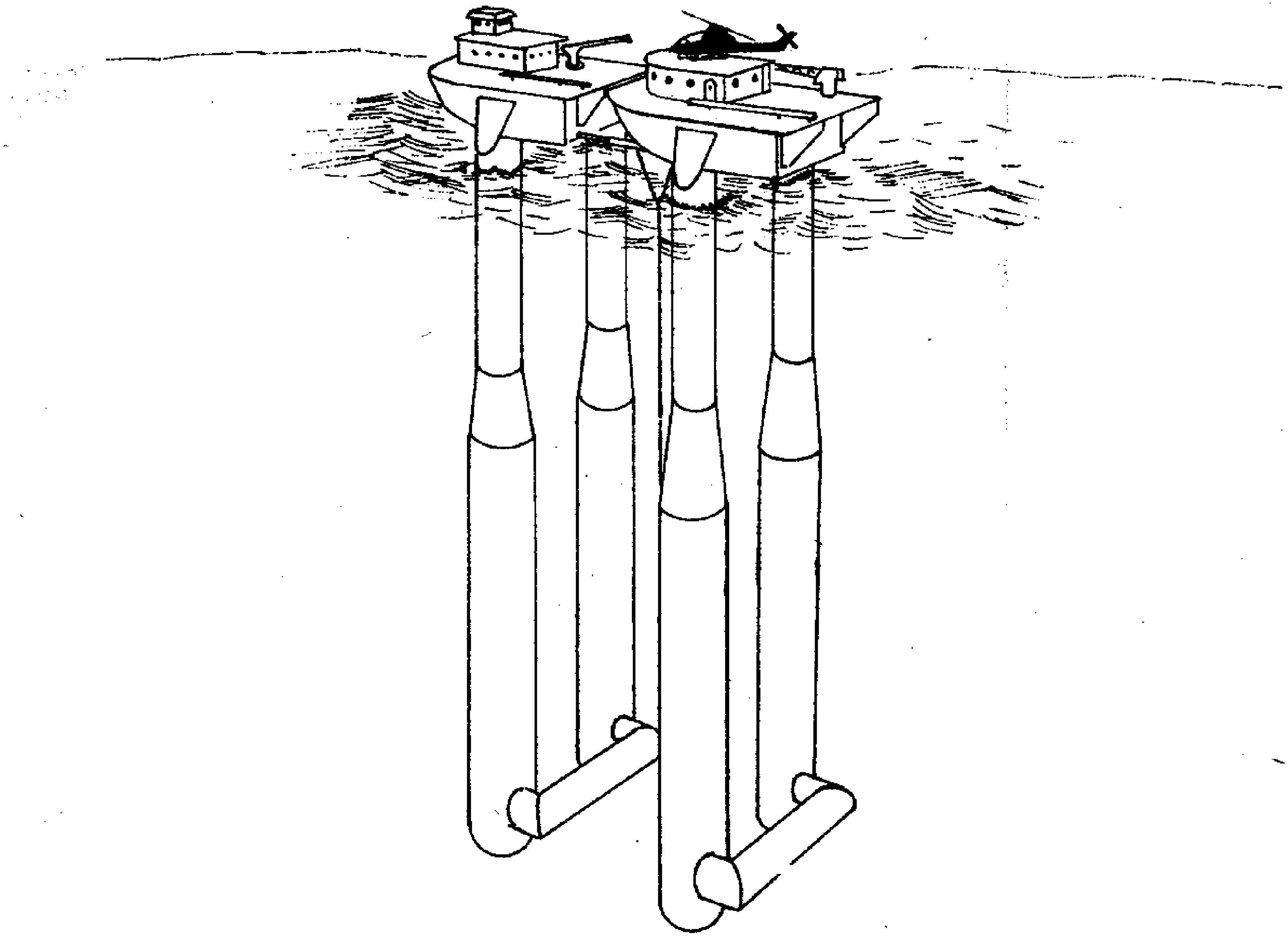


FIGURE 26 SUPER-STABLE PLATFORM FOR OCEANOGRAPHIC RESEARCH. (REF.184)

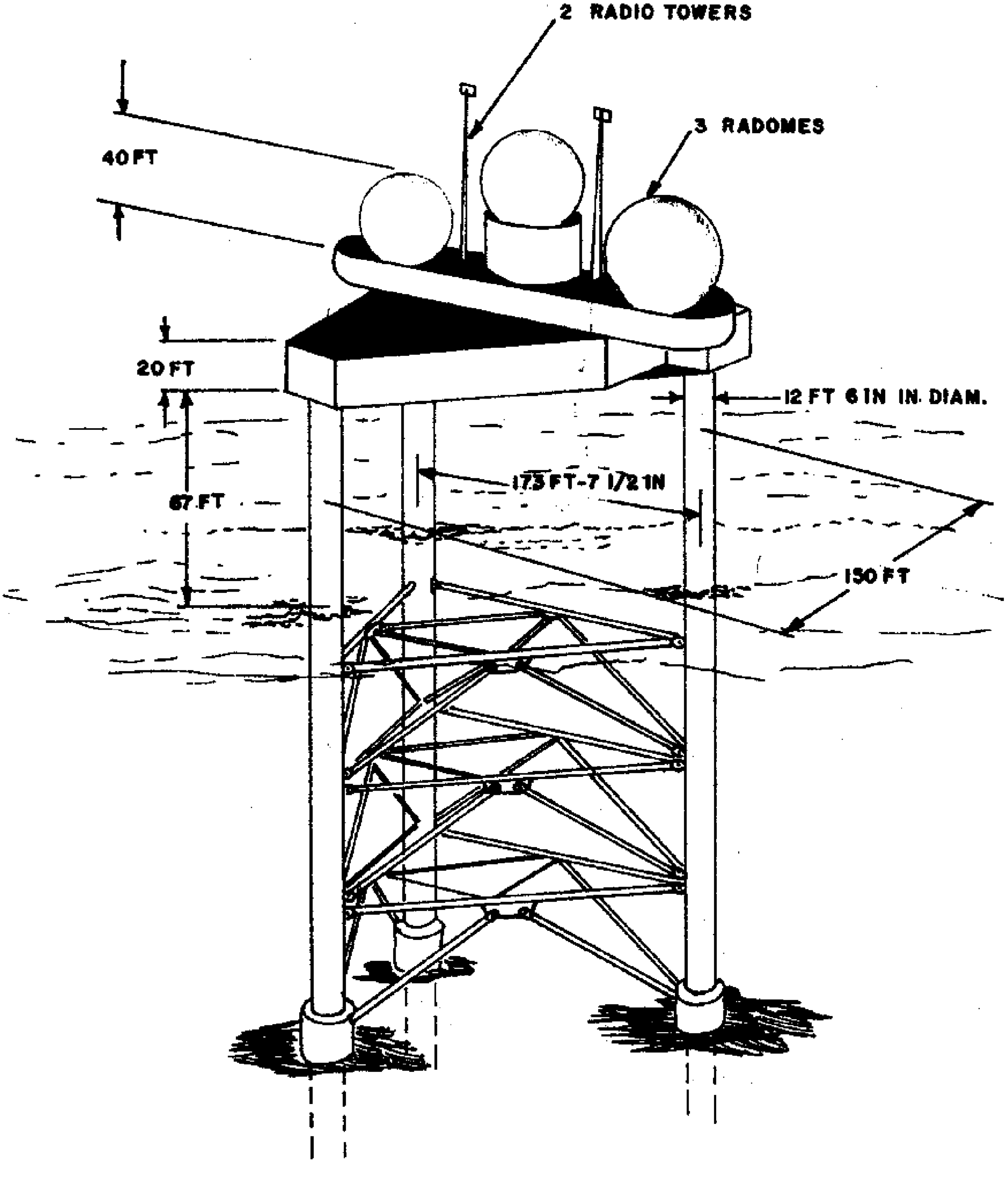


FIGURE 27 "TEXAS TOWER" TYPE RADAR PLATFORM.
(REF. 15, 189)

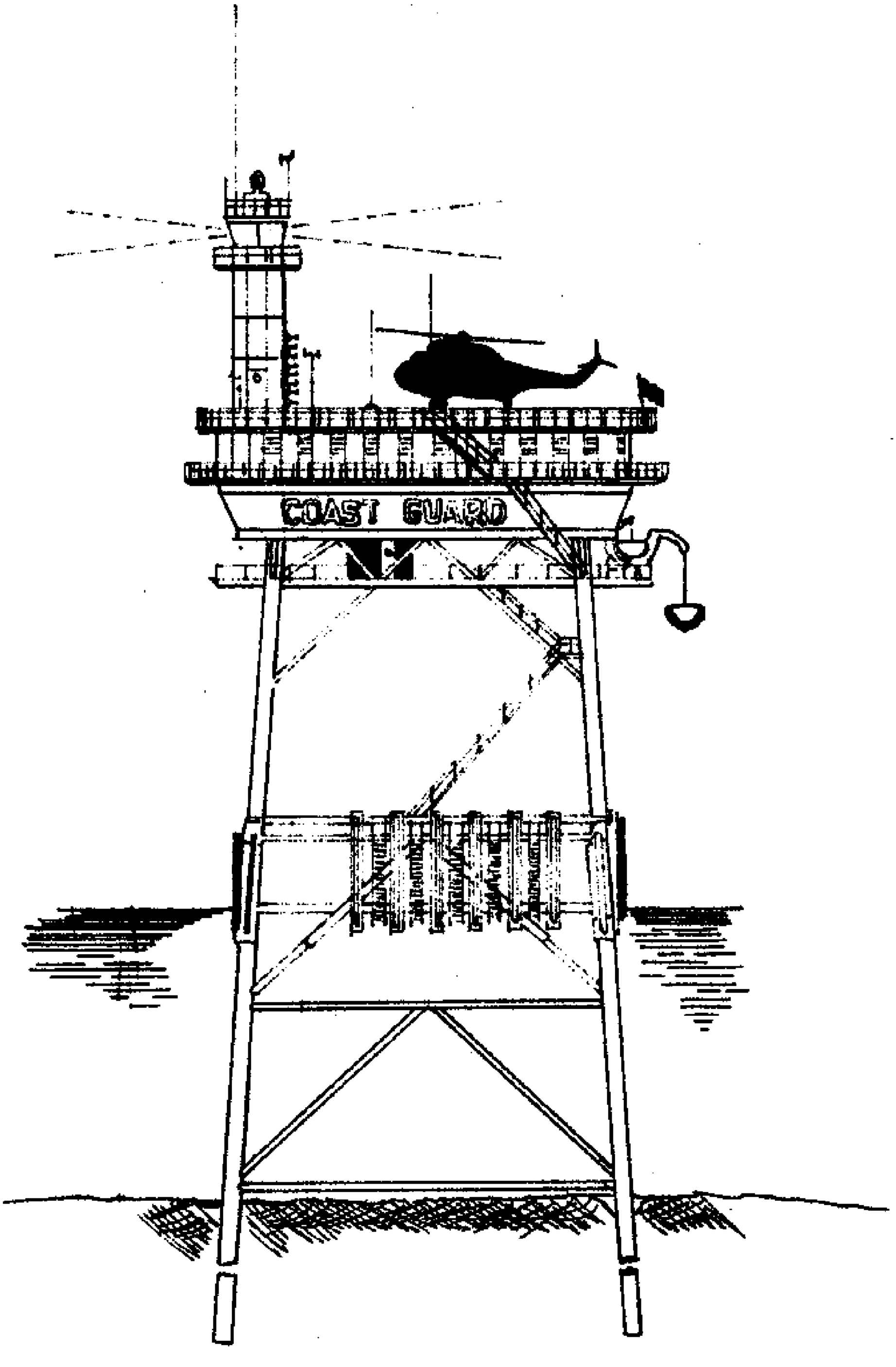


FIGURE 28 U.S.C.G. TEMPLATE TYPE PLATFORM.
(REF. 15)

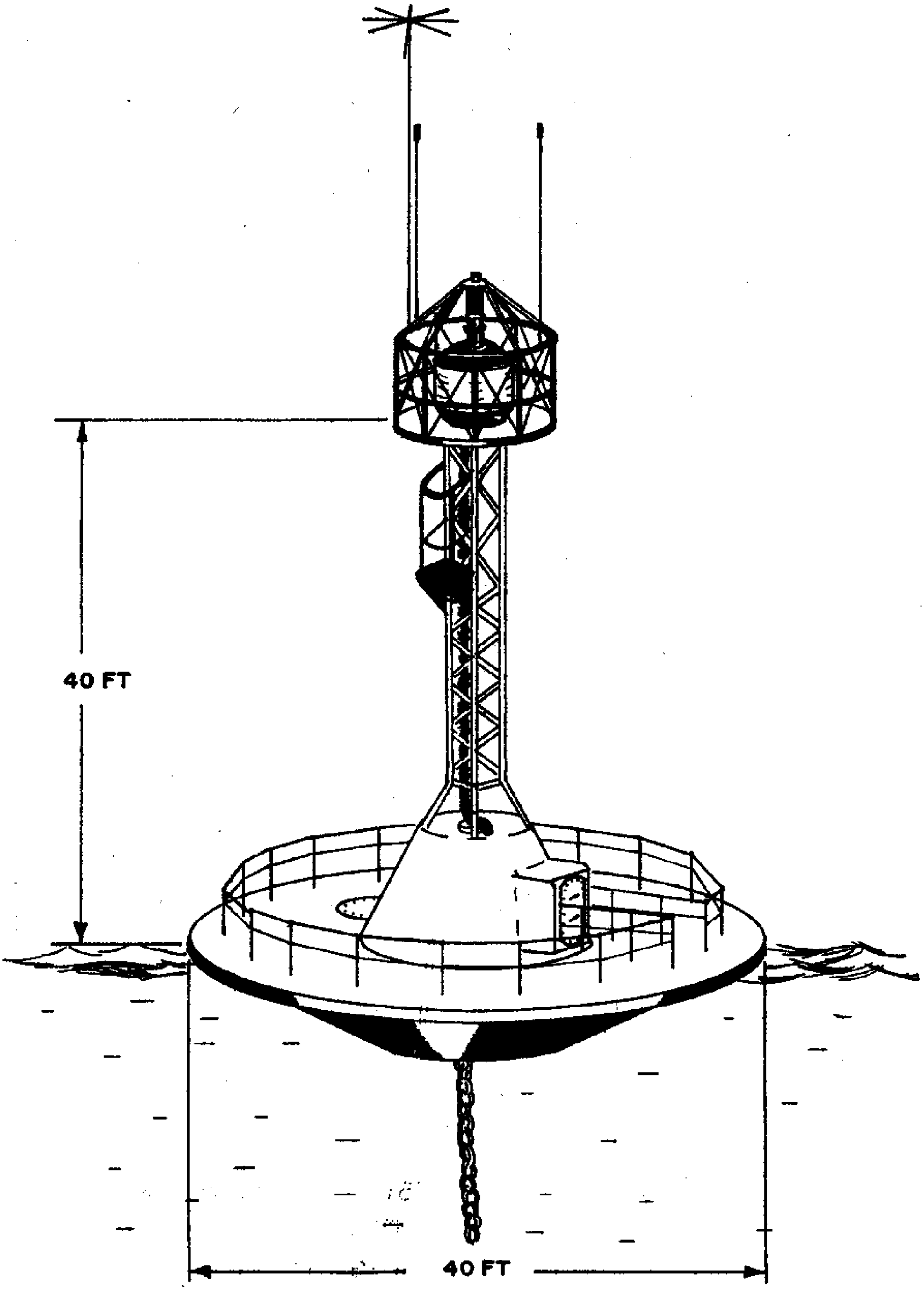


FIGURE 29 LANBY BUOY, LIGHTSHIP REPLACEMENT. (REF. 201)

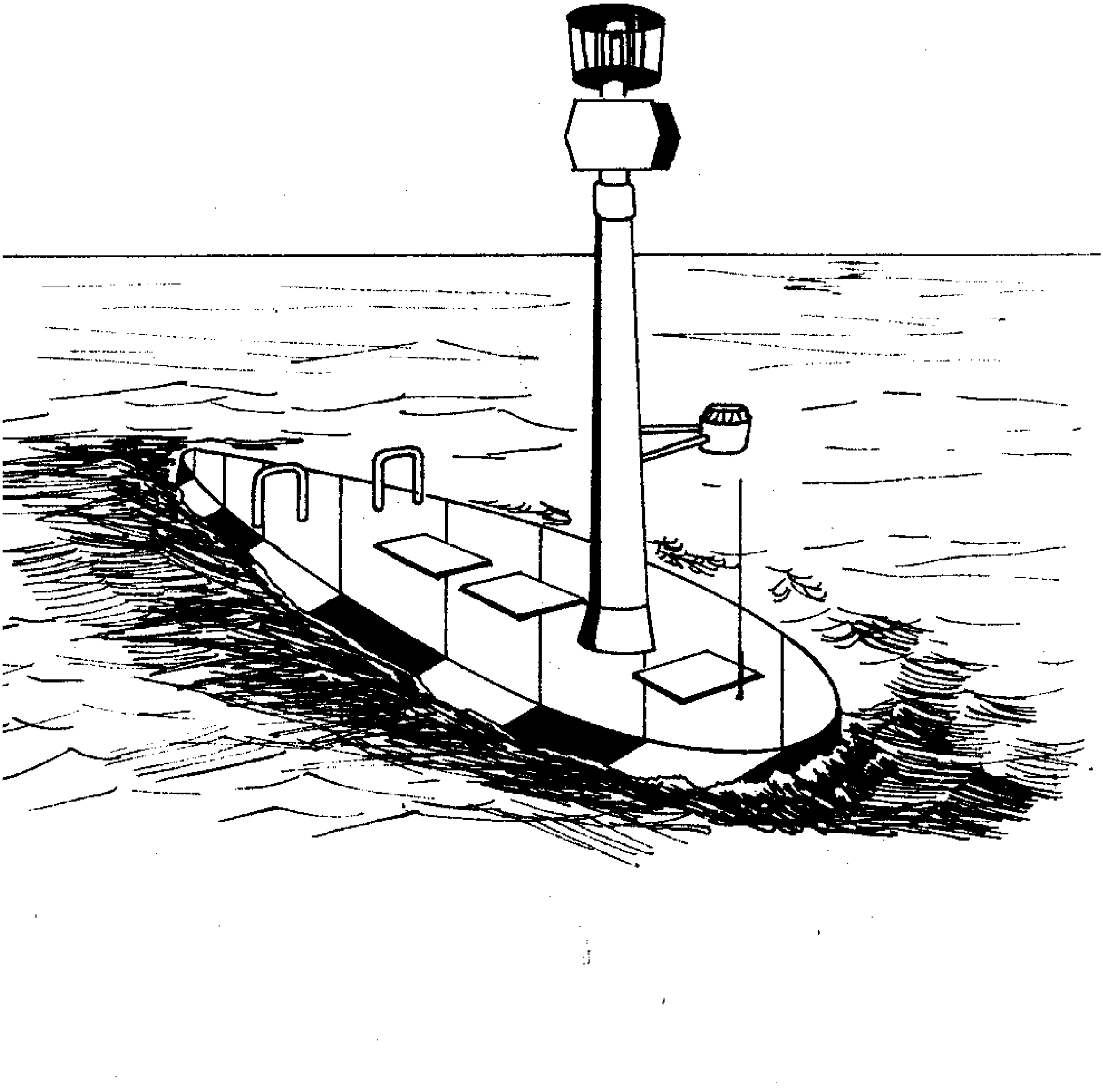


FIGURE 30 SHIP-SHAPE-BUOY, DESIGNED FOR GREATER SURVIVABILITY. (OCEAN INDUSTRY, AUG. 1971)

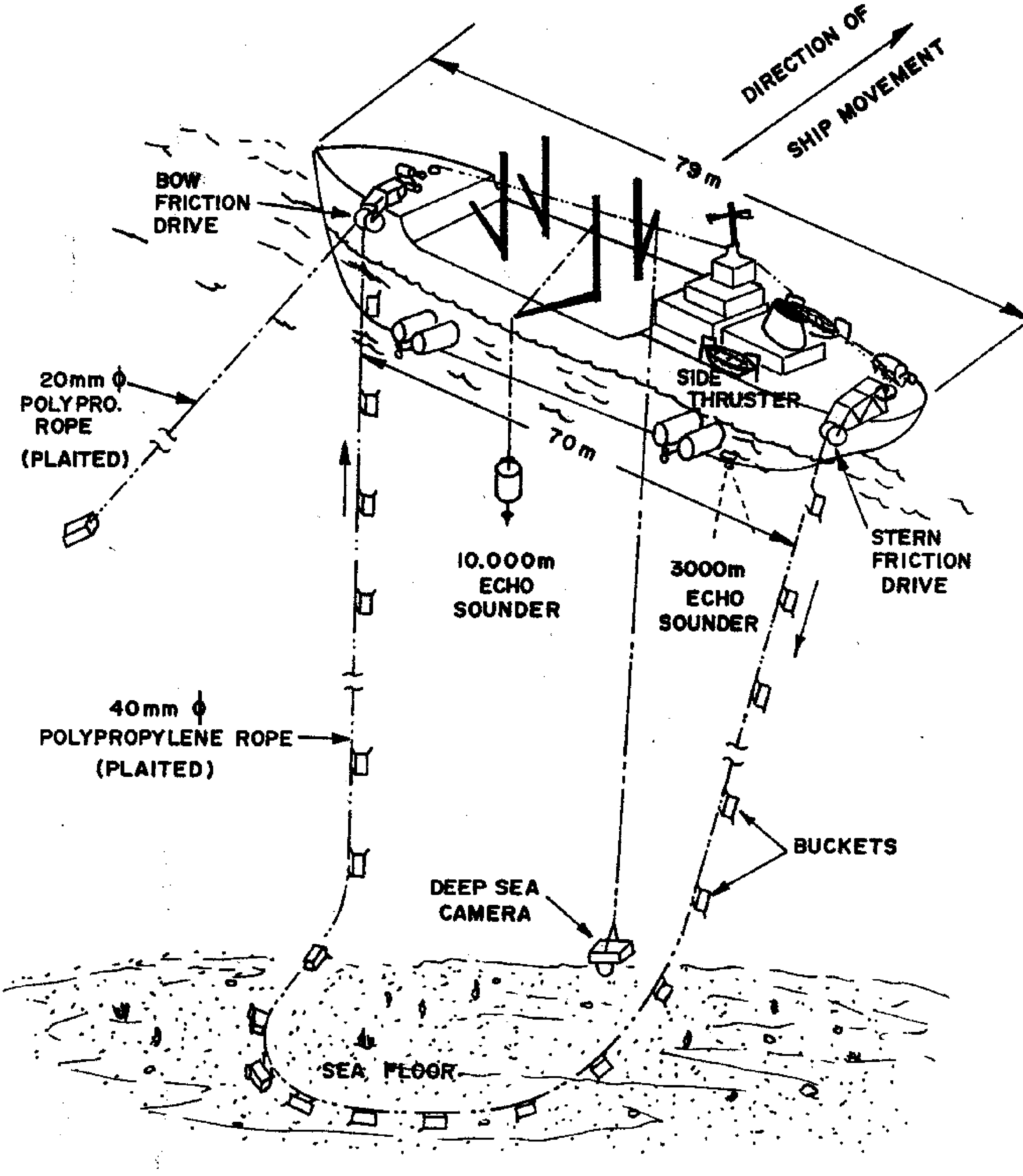


FIGURE 31 THE CONTINUOUS BUCKET-LINE DREDGE SYSTEM. (REF. 212)

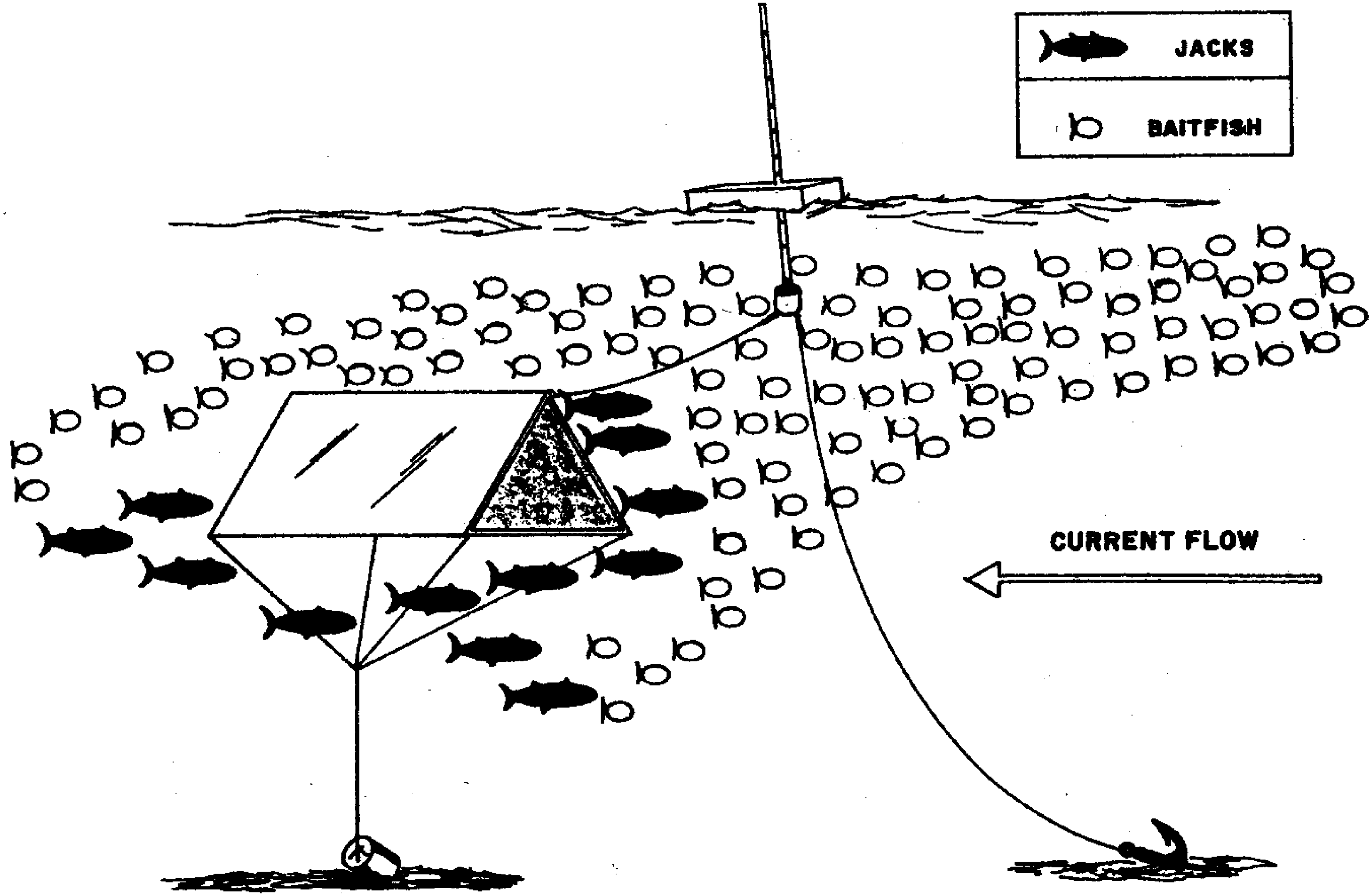


FIGURE 32 POSITION OF BAITFISH AND JACKS IN RELATION TO A SUBMERGED STRUCTURE. (REFS. 218, 222)

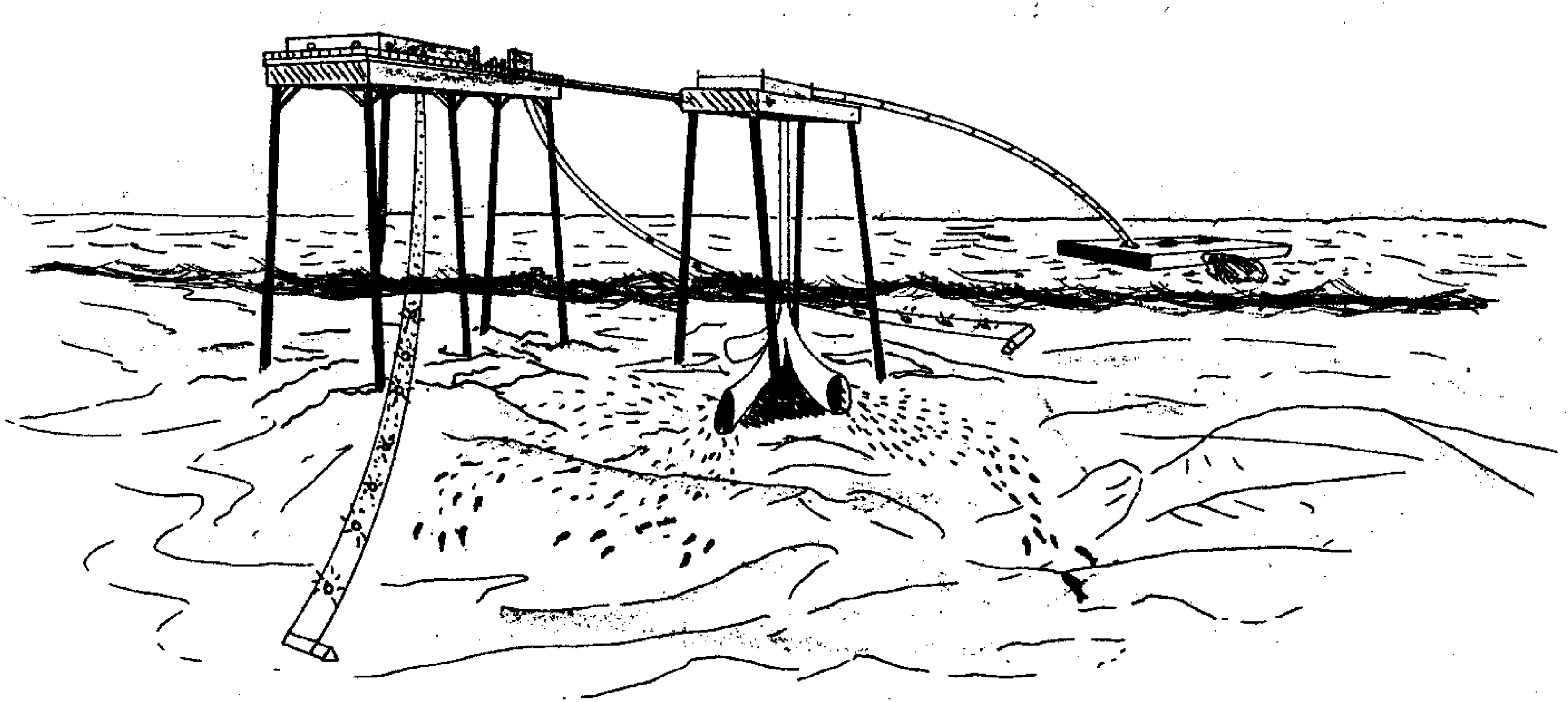


FIGURE 33 PROPOSED FISHING PLATFORM CONCEPT.
(REF. 220)

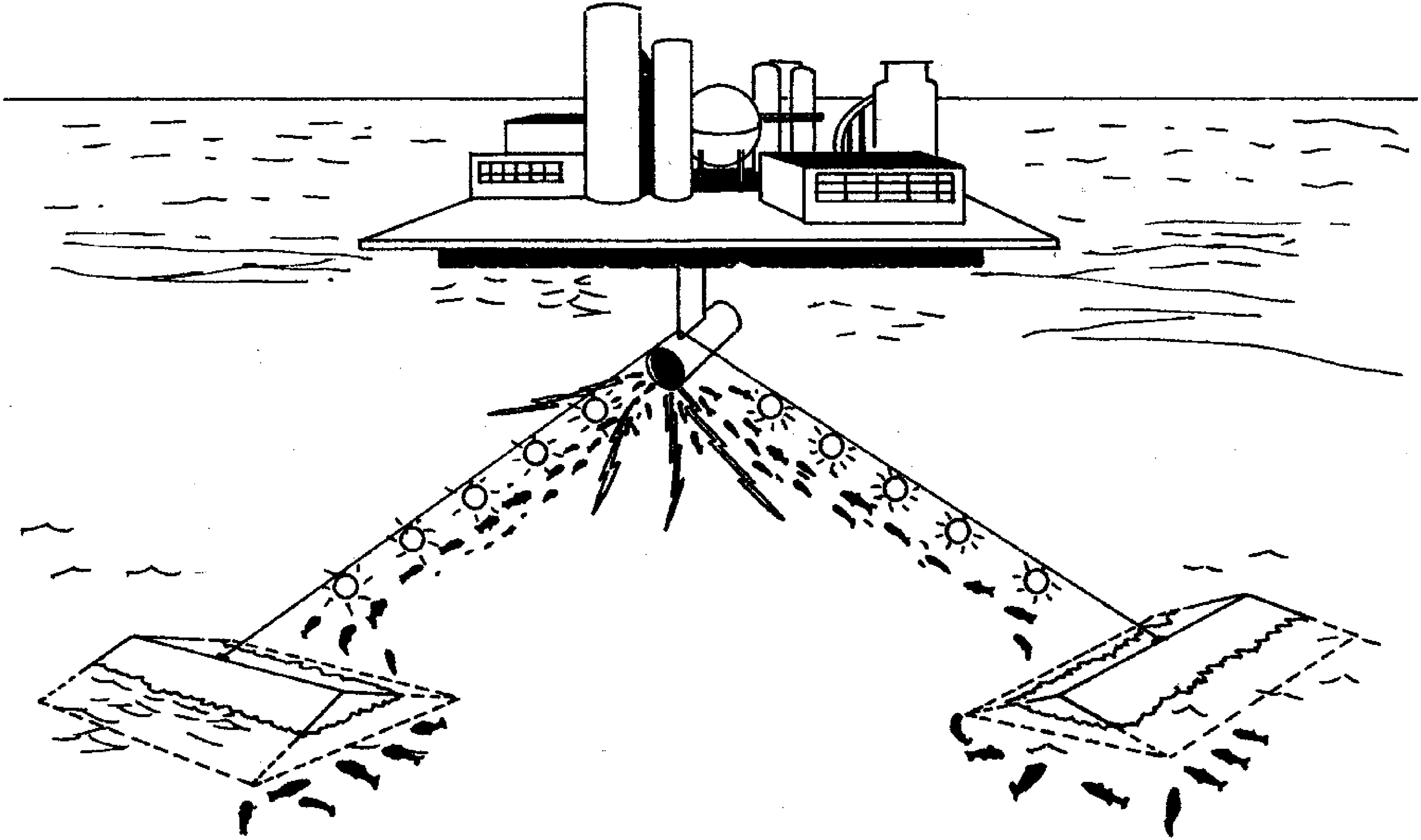


FIGURE 34 AUTOMATIC FISHING AND PROCESSING PLATFORM. (REFS 221,225)

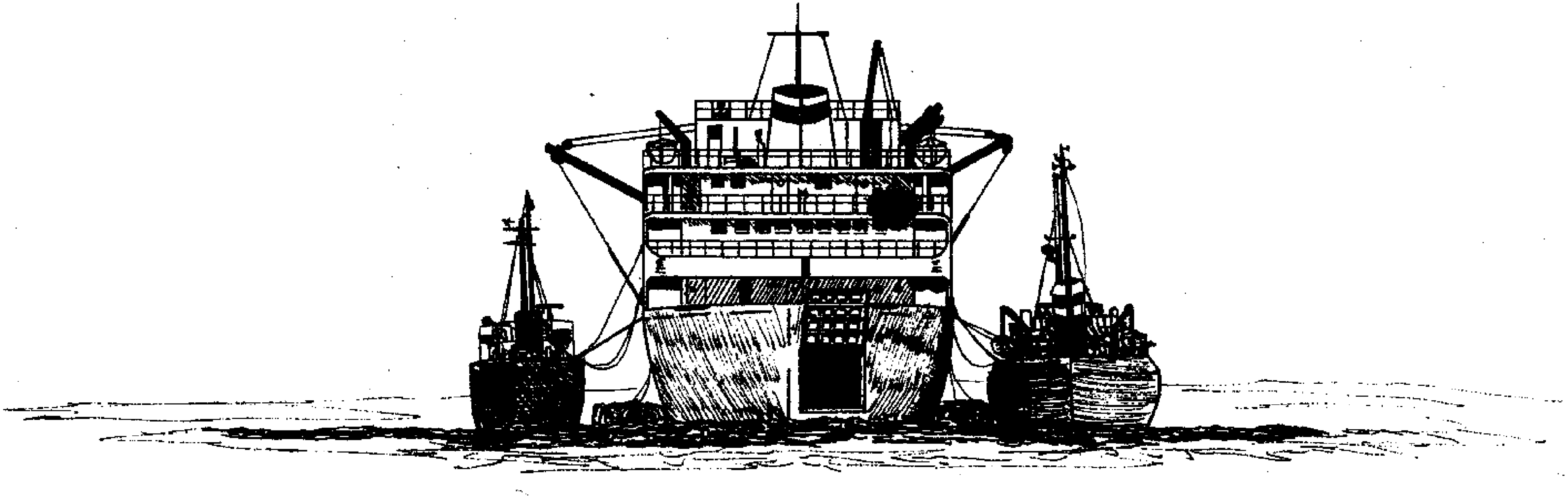


FIGURE 35 FISH-PROCESSING FACTORY SHIP. (RUSSIAN)-(REF. 217)

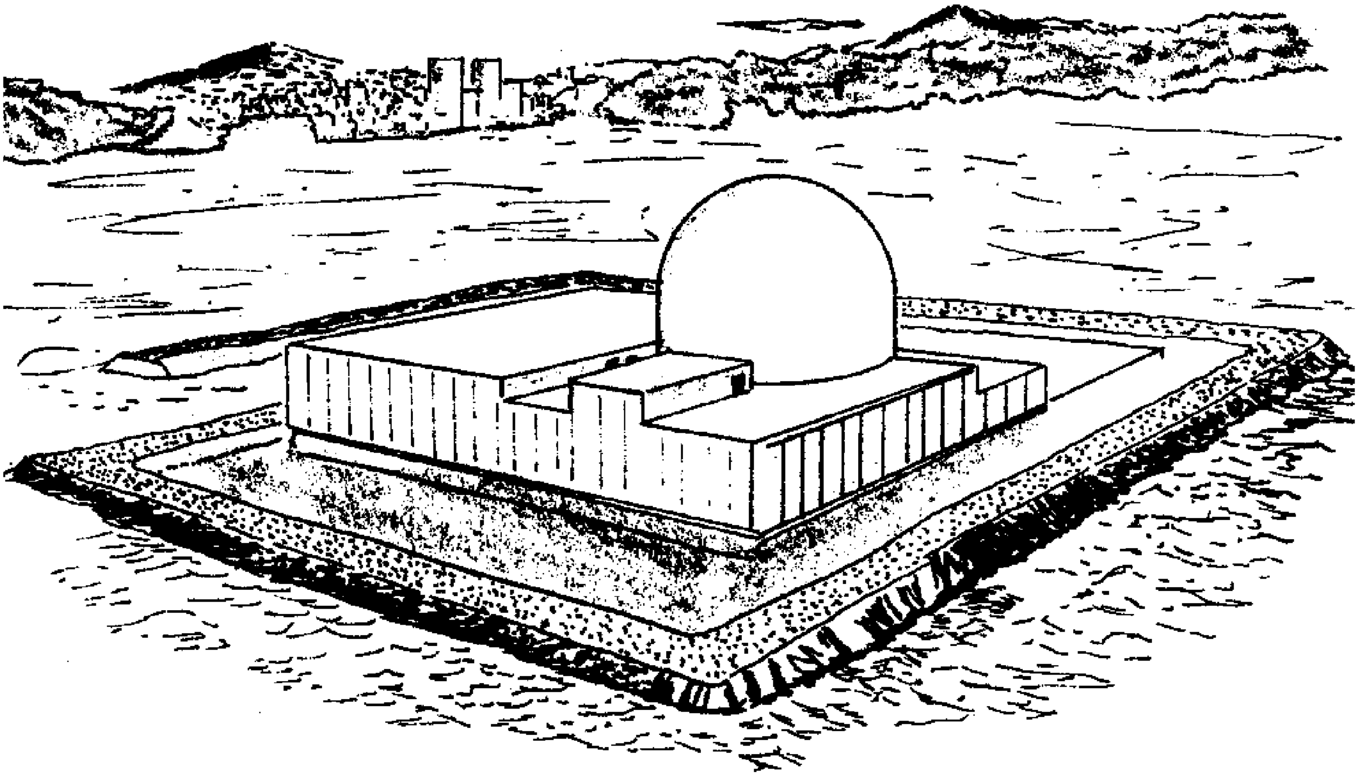


FIGURE 36 OFFSHORE NUCLEAR POWER PLANT. (REF. 230)

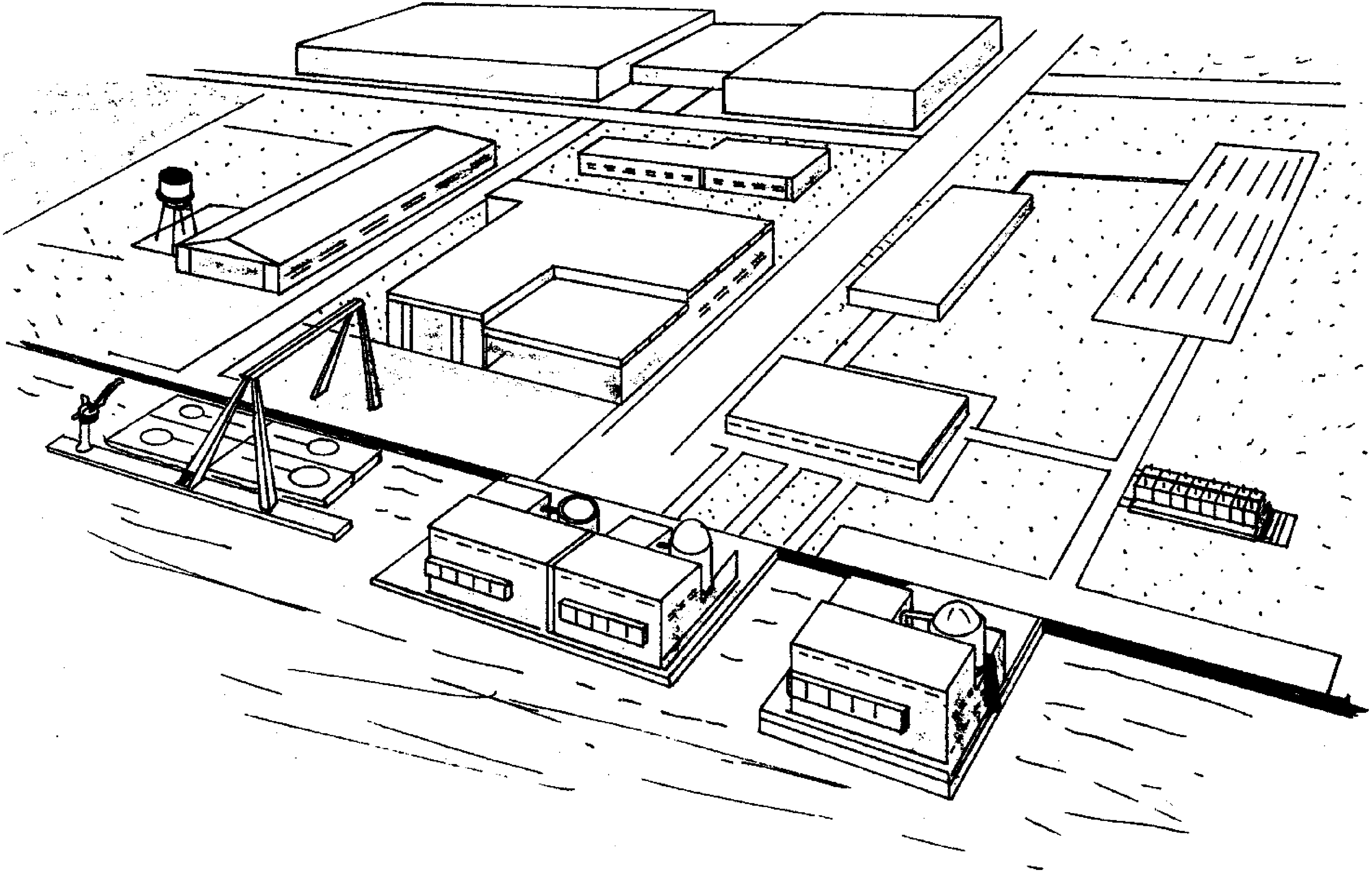


FIGURE 37 OFFSHORE NUCLEAR POWER-GENERATING PLANTS.
(MARITIME REPORTER, 9/1/71, P.21)

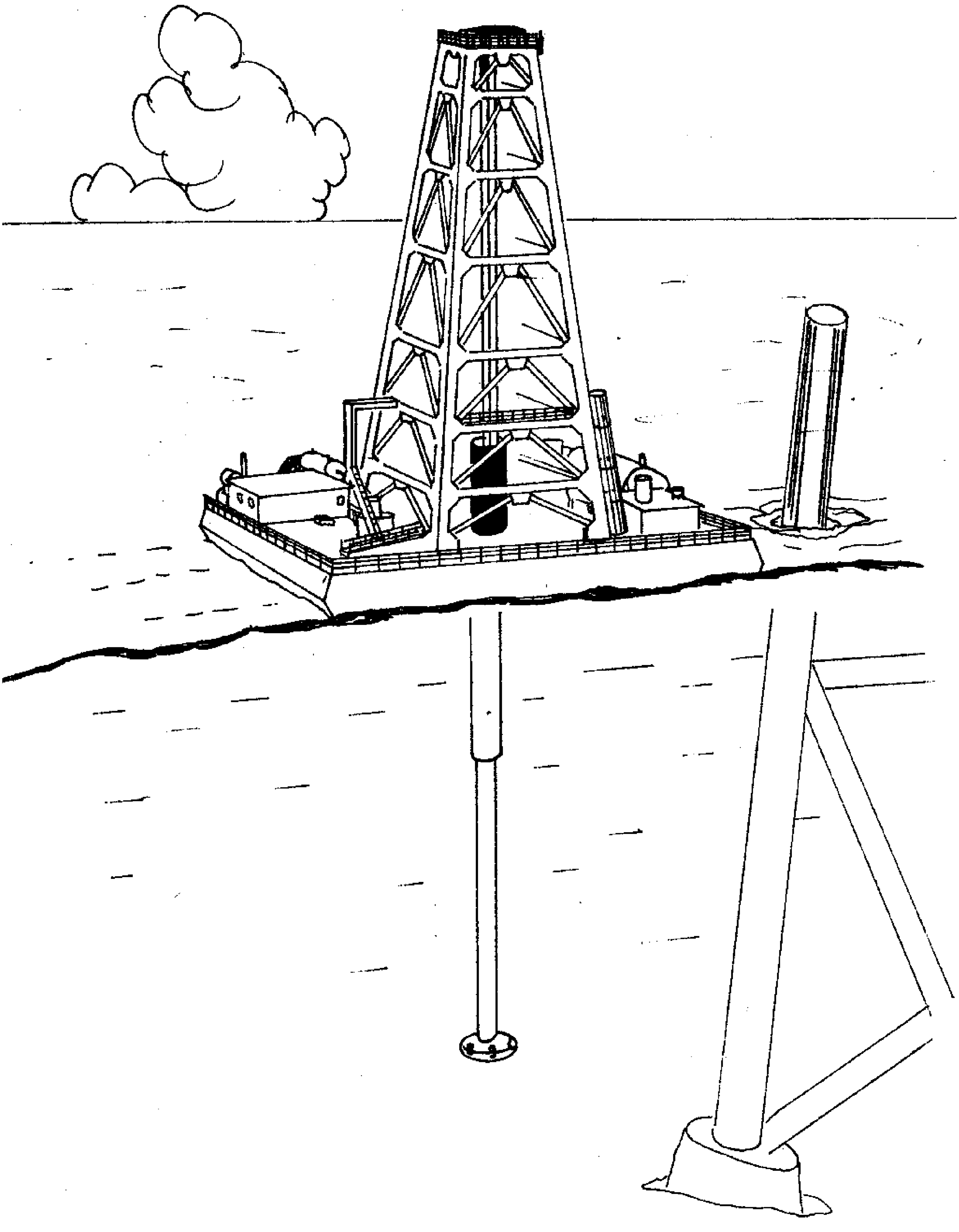


FIGURE 38 UNDERWATER CONSTRUCTION BARGE.(REF.245)

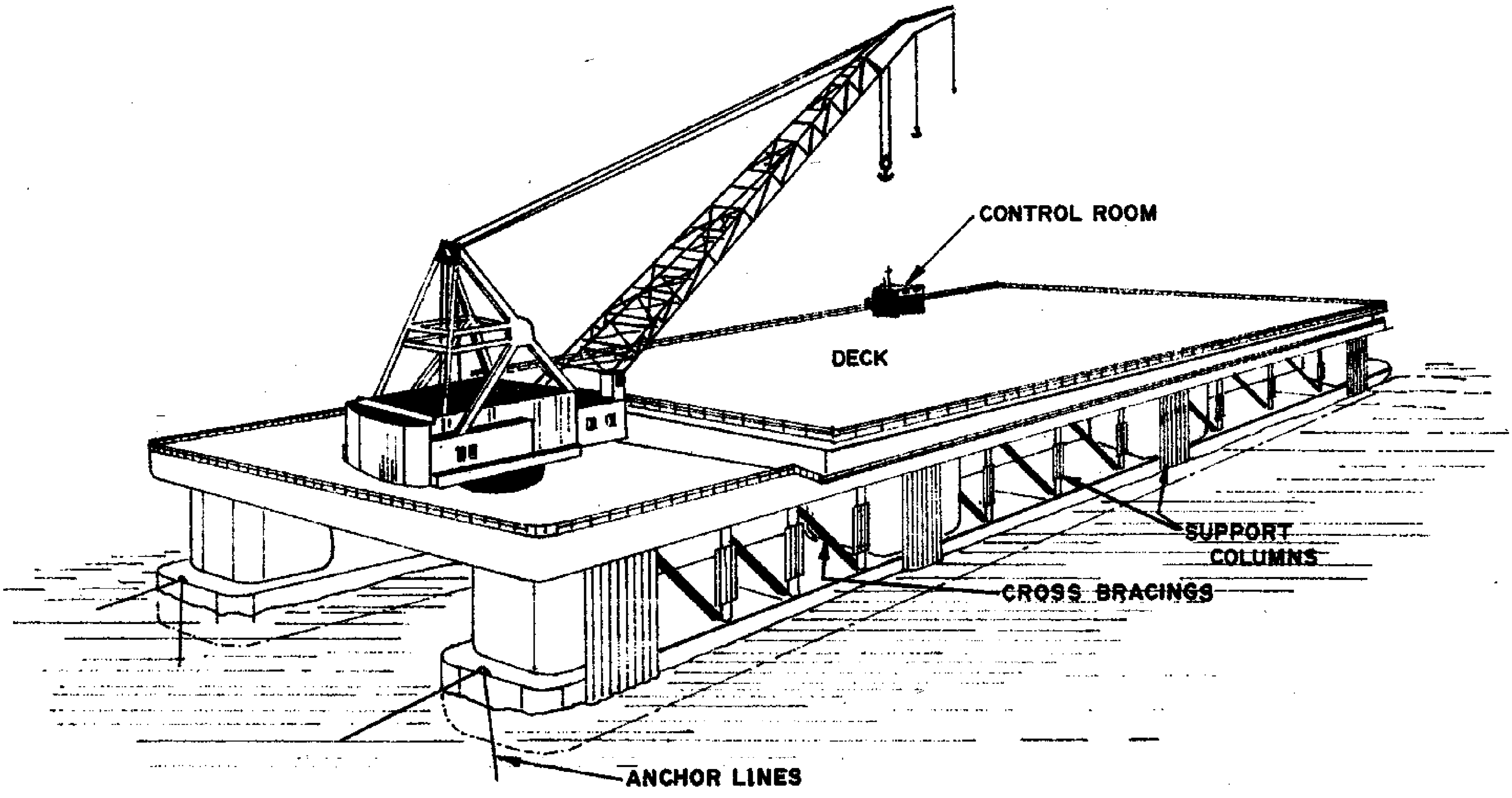


FIGURE 39 SEMISUBMERSIBLE WORK BARGE.
(UNDERWATER INFORMATION BULL. APRIL, 1971)

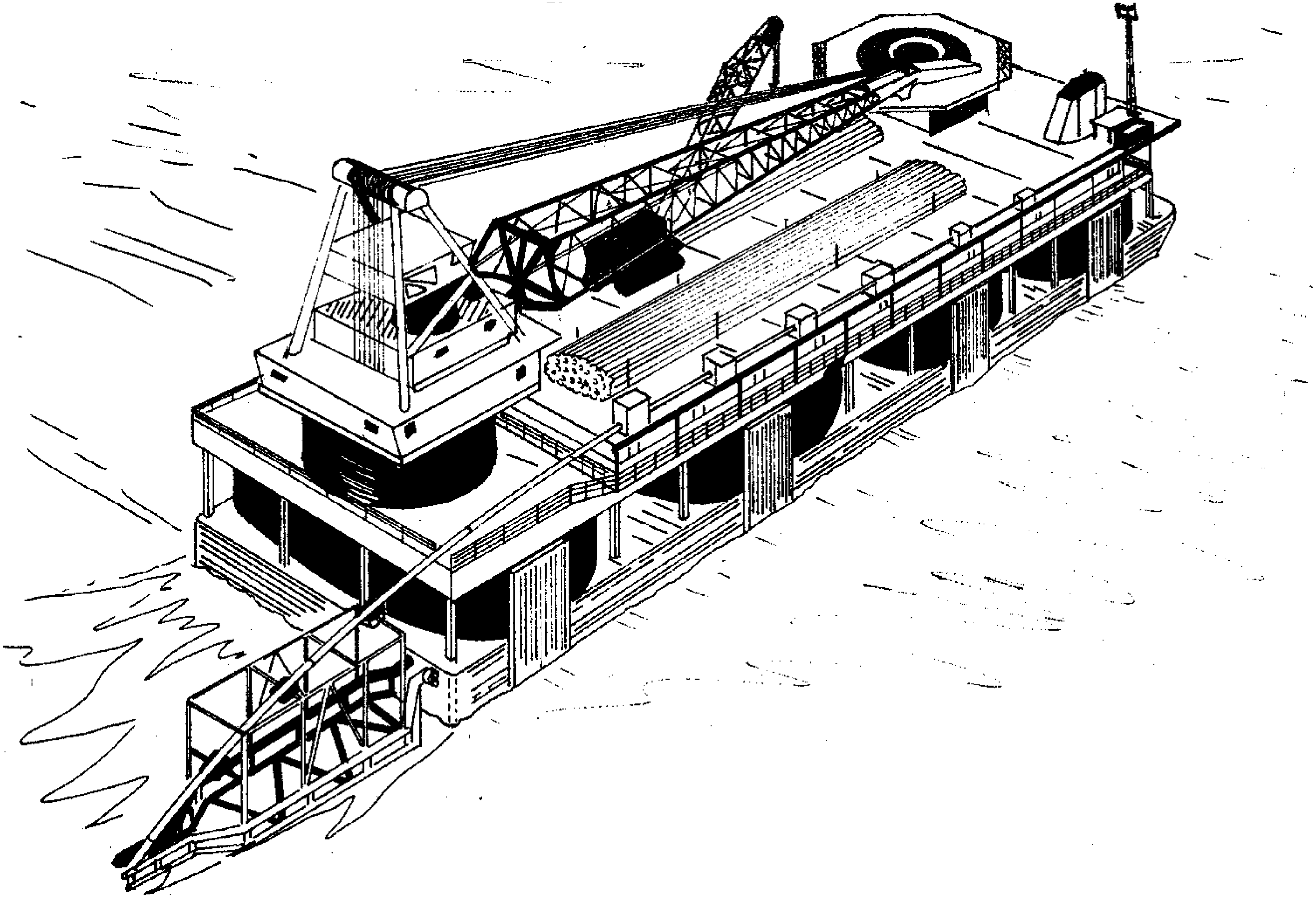


FIGURE 40 PIPE-LAYING BARGE. (REF.241)

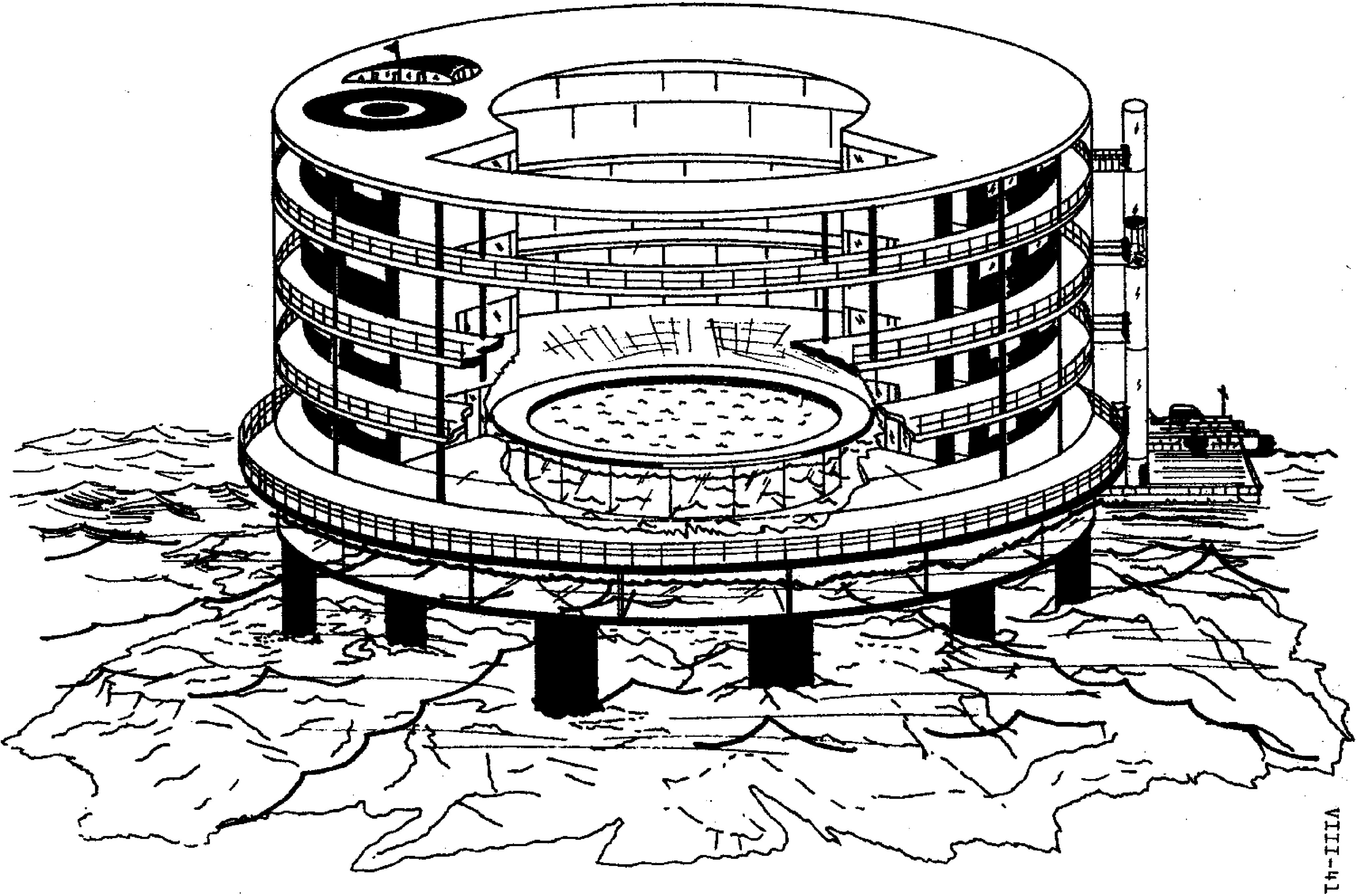


FIGURE 41 CONCEPT OF RESORT HOTEL FIXED TO REEF. (REF. 255)

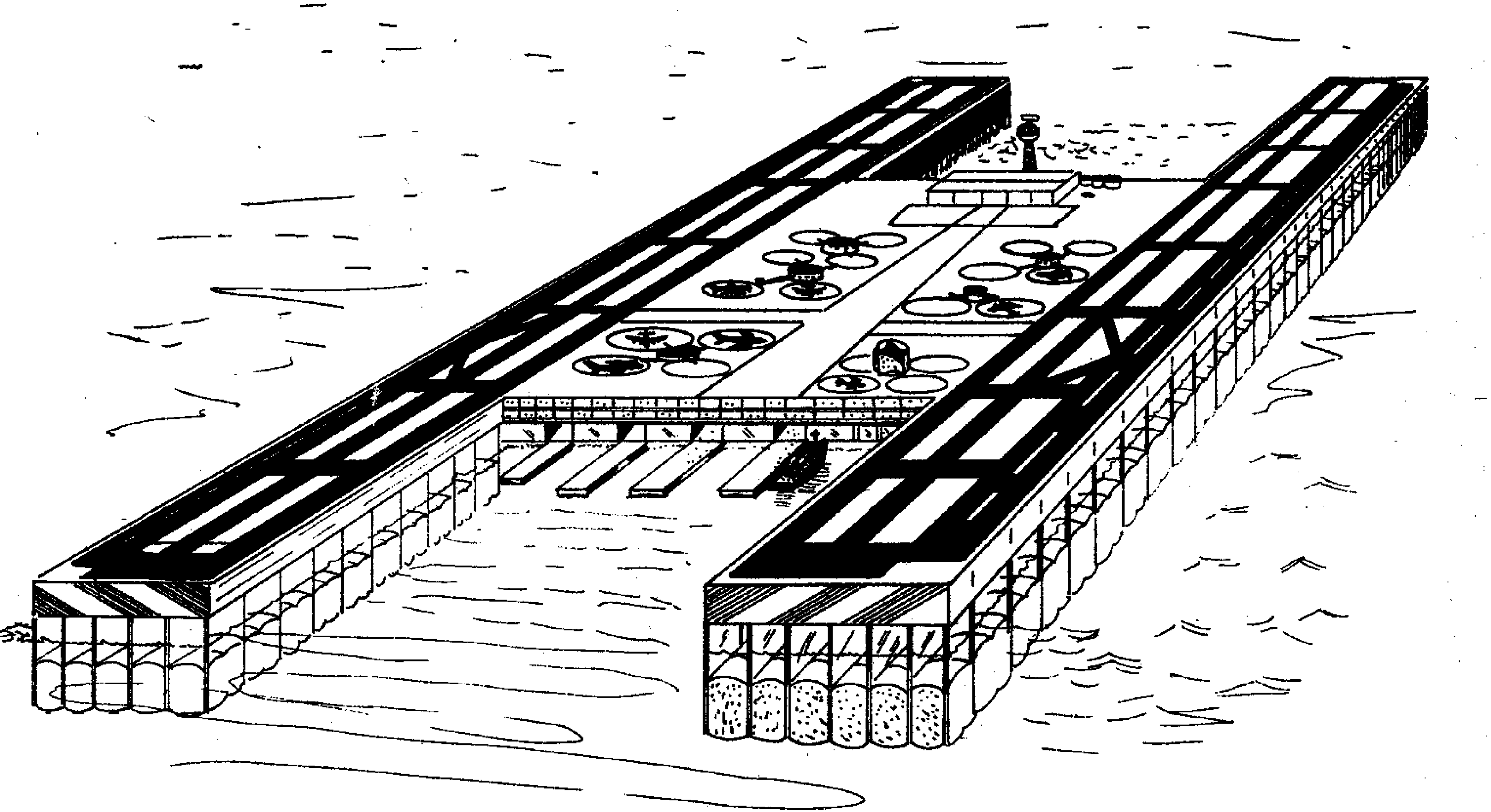


FIGURE 42 FLOATING AIRPORT CONCEPT. (REF. 252)

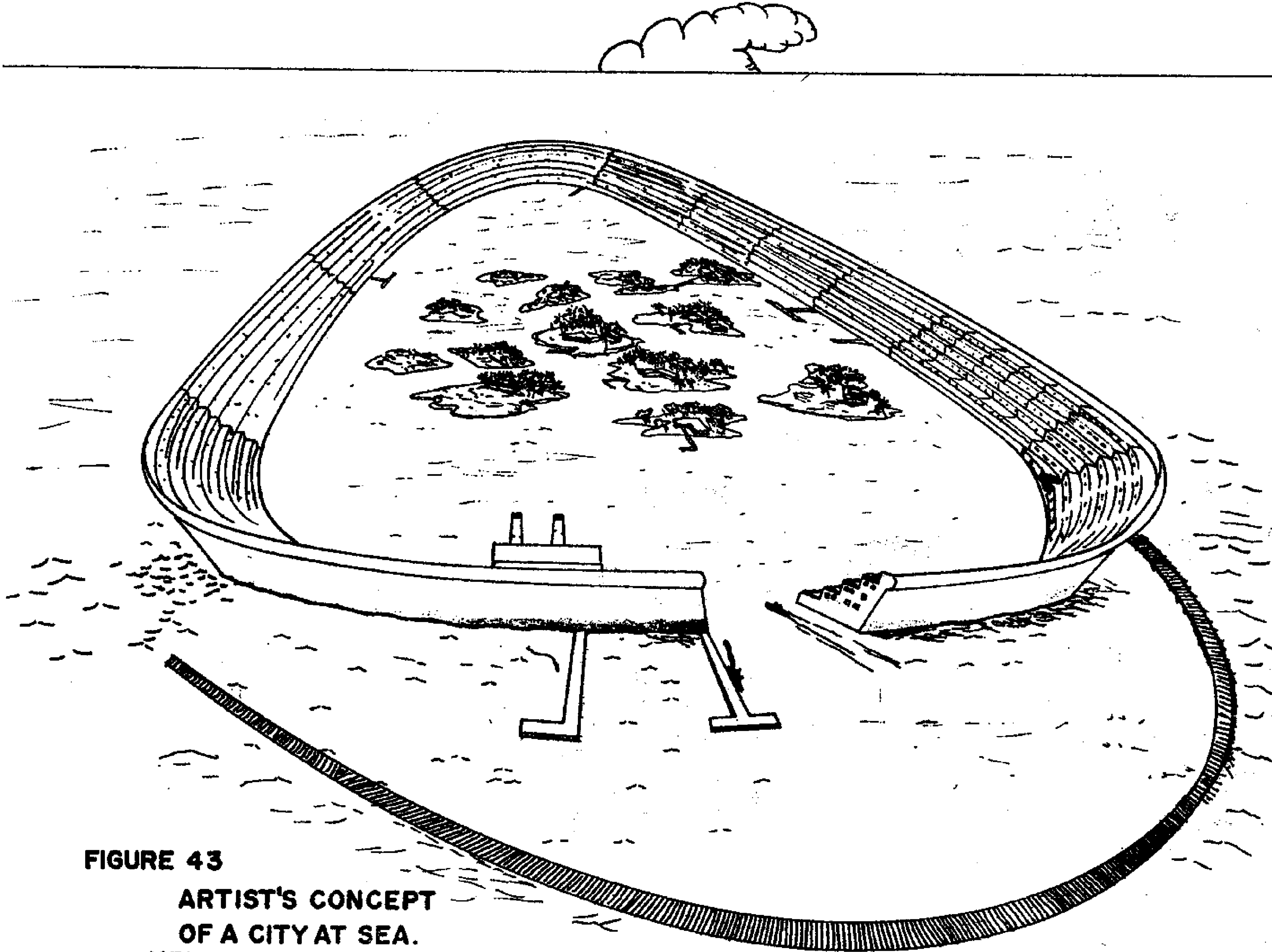
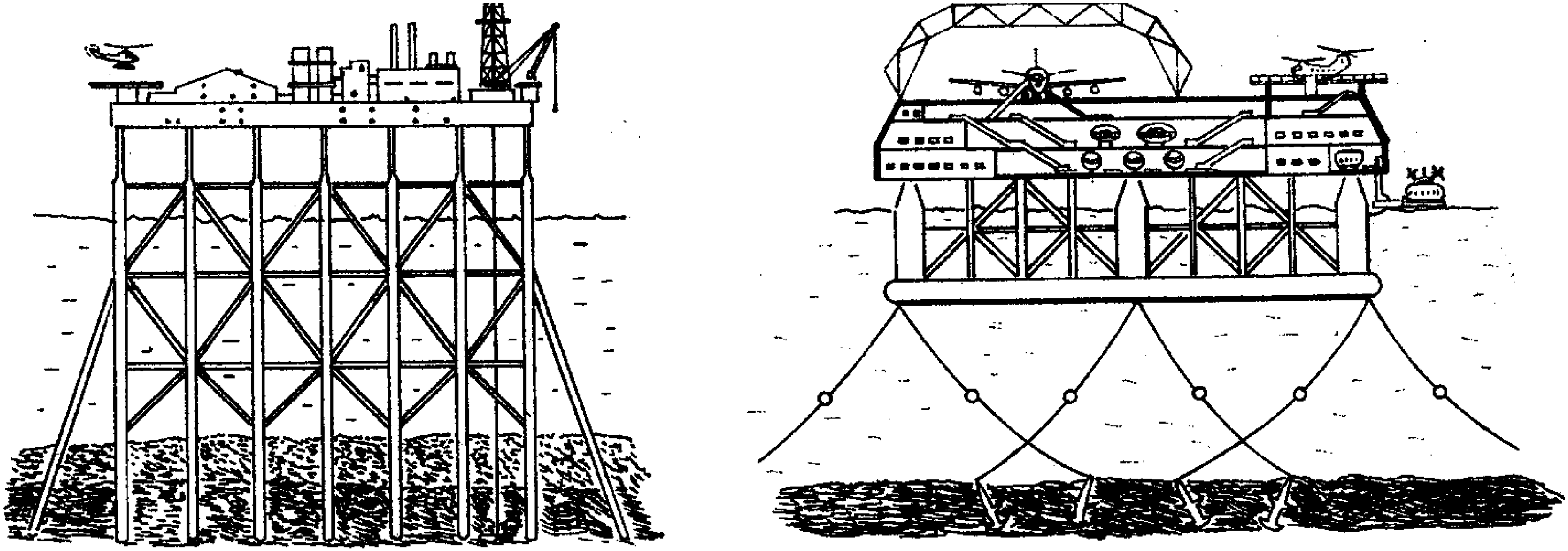


FIGURE 43

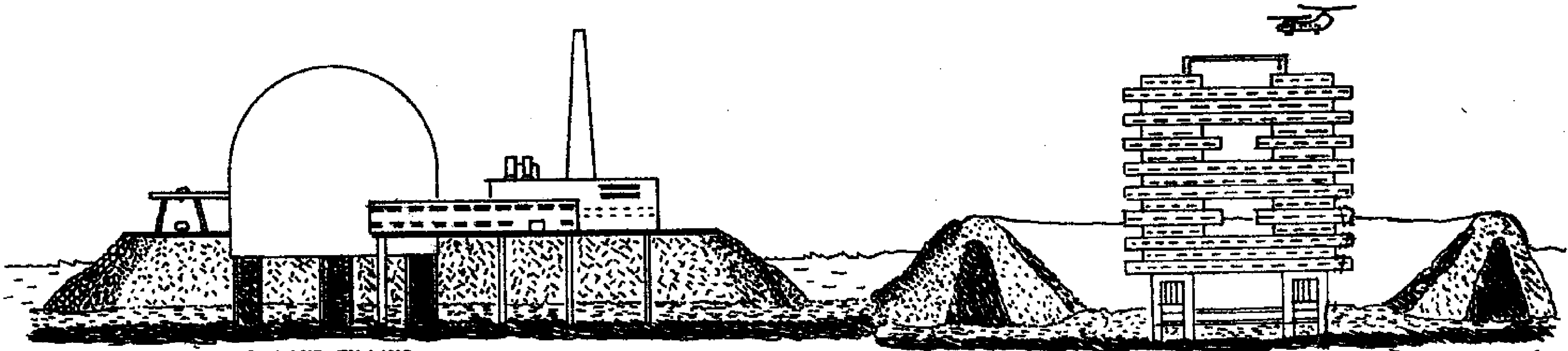
ARTIST'S CONCEPT OF A CITY AT SEA.

(SEA FRONTIERS SEPT.-OCT. 1968)



A. FIXED STRUCTURES.

B. FLOATING STRUCTURES.



C. LAND FILLING.

D. DIKES AND POLDERS.

FIGURE 44 FOUR WAYS TO BUILD IN WATER. (FORTUNE, SEPT. 1969, P. 131)

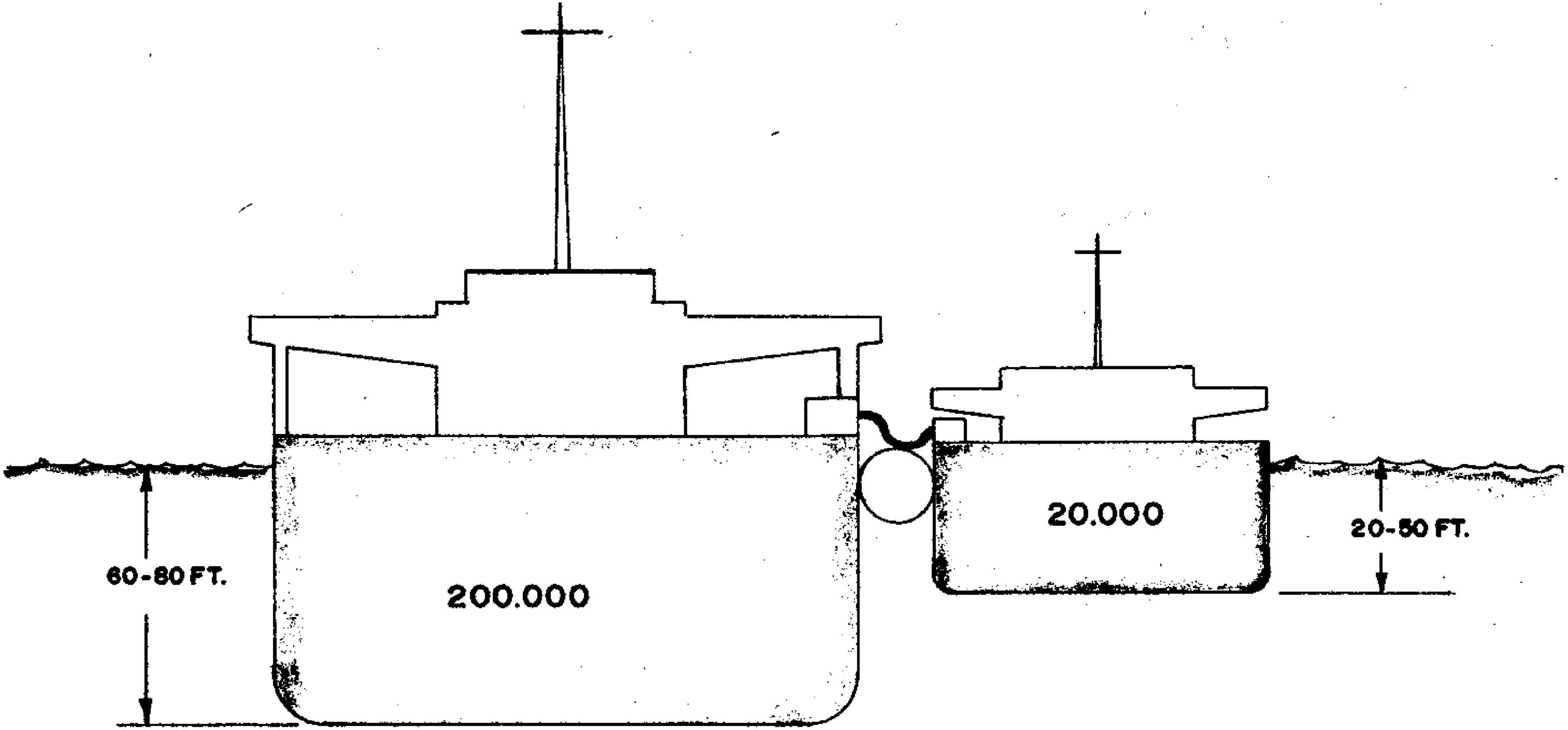


FIGURE 45 LIGHTERING AT SEA. (REF. 261)

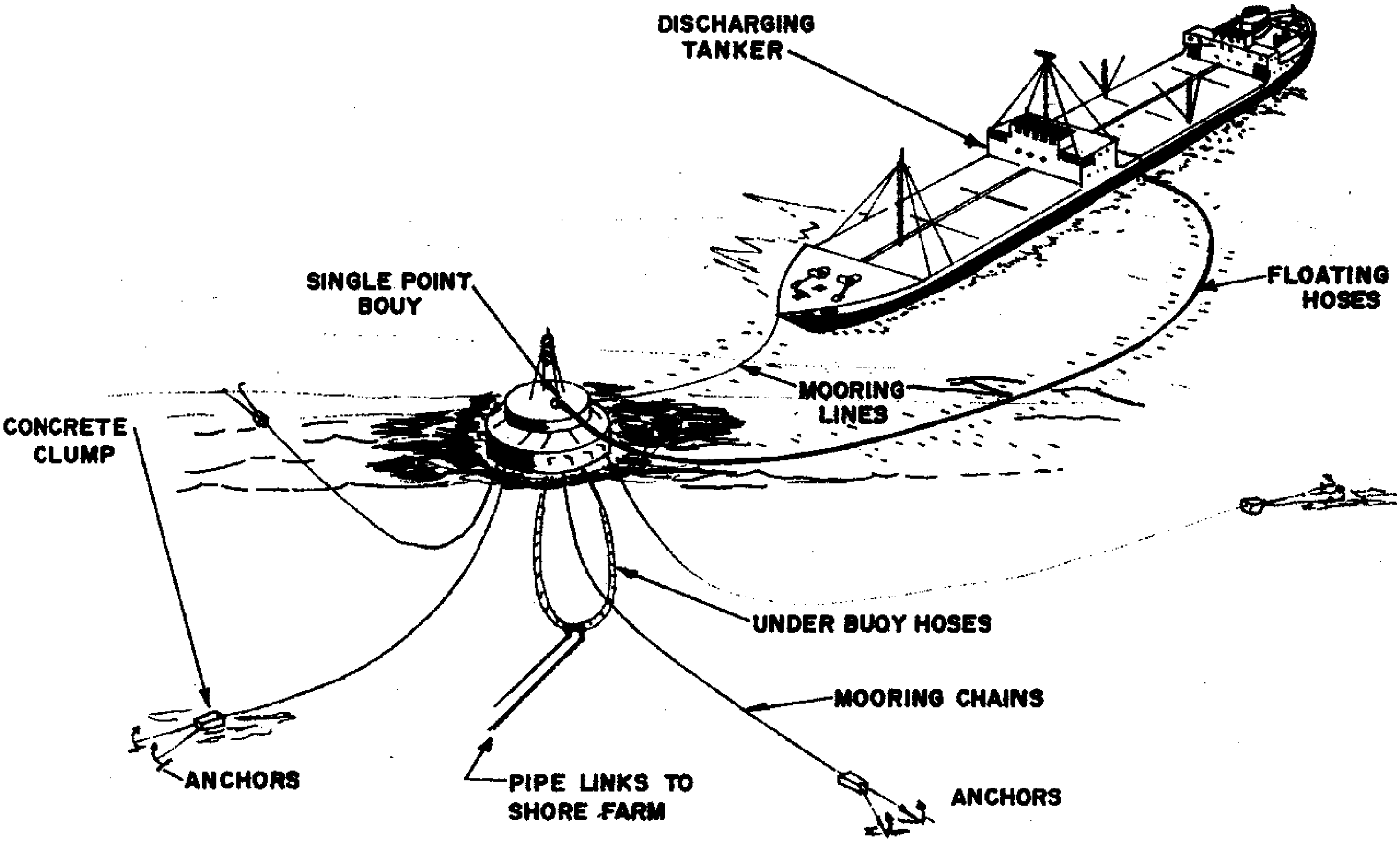


FIGURE 46 SINGLE-POINT MOORING SYSTEM. (REF. 261)

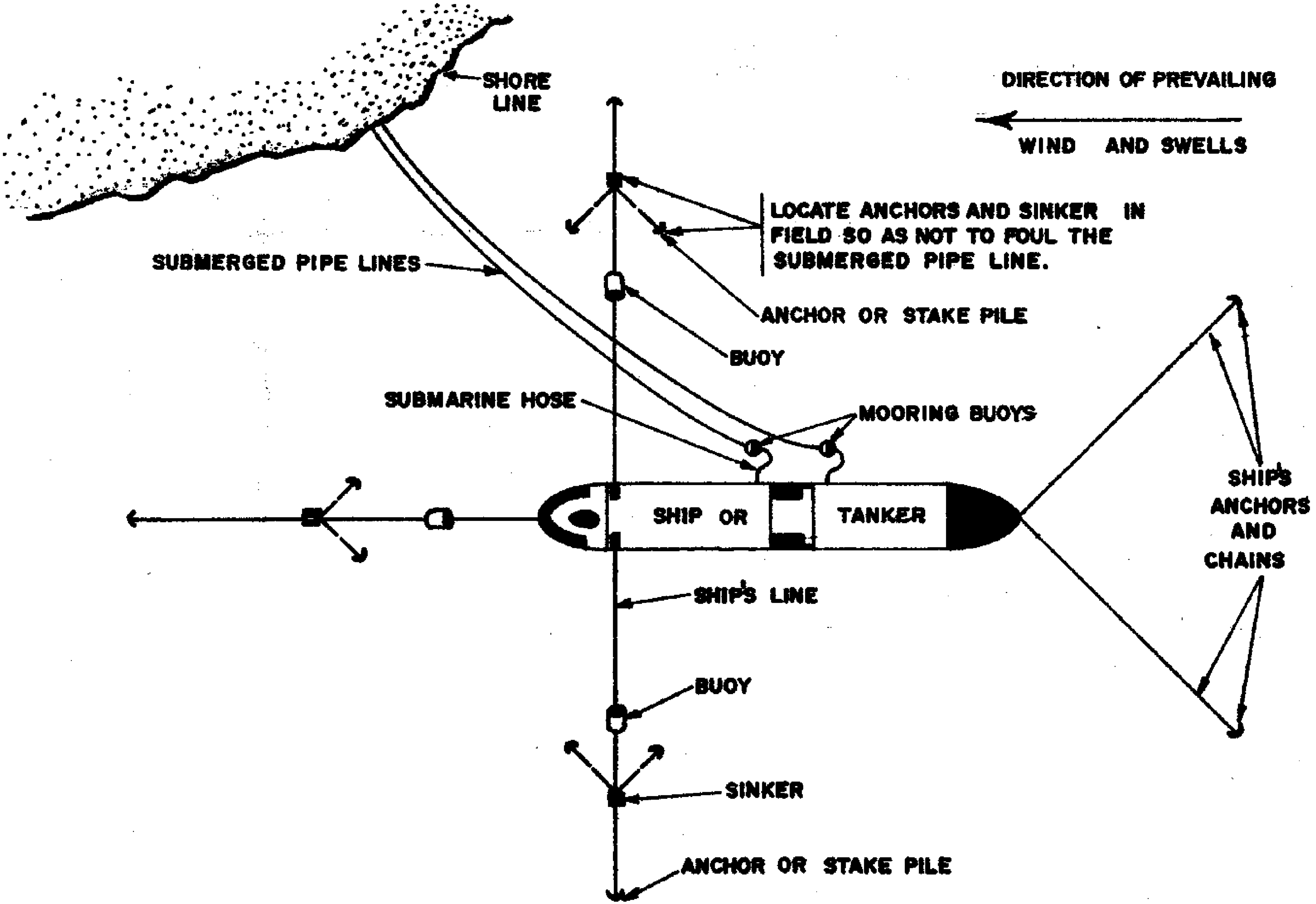


FIGURE 47 TYPICAL SEA BERTH- OIL TRANSFER (REF. 261)

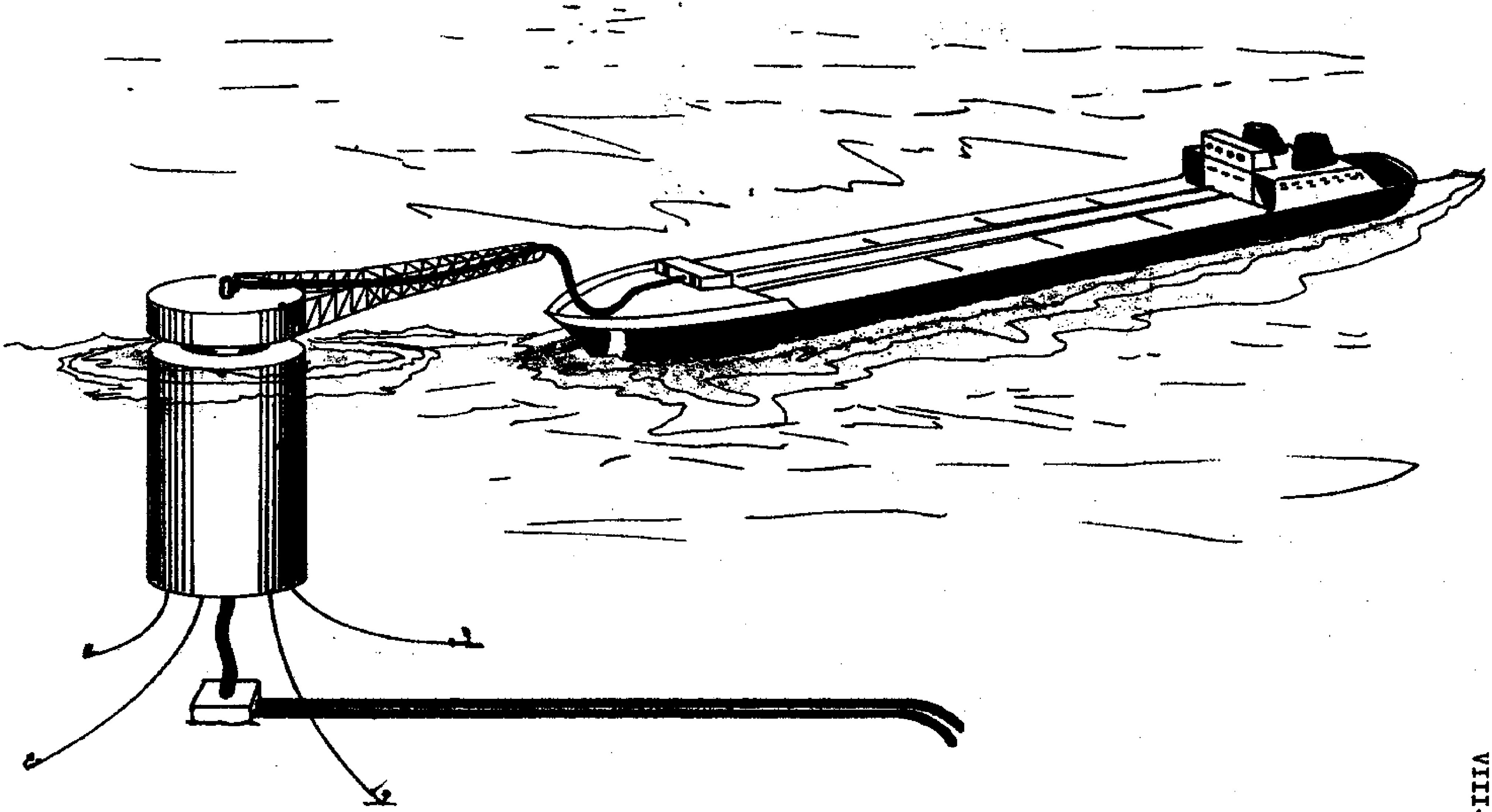


FIGURE 48 OFFSHORE STORAGE AND PETROLEUM TRANSFER SYSTEM.

(OIL & GAS JOURNAL, 9/20/71, P. 67)

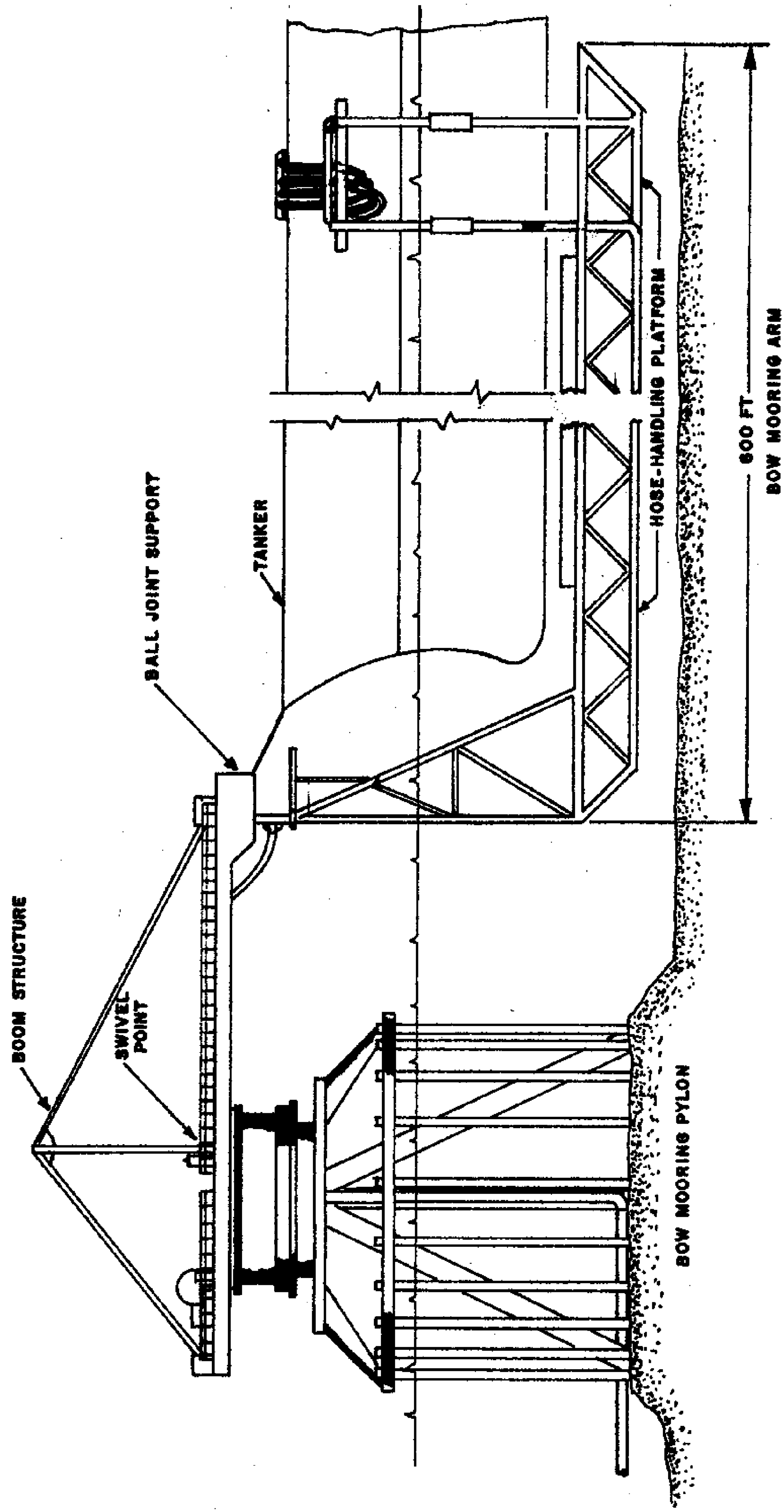


FIGURE 49 BOW MOORING ARM (REF. 261)

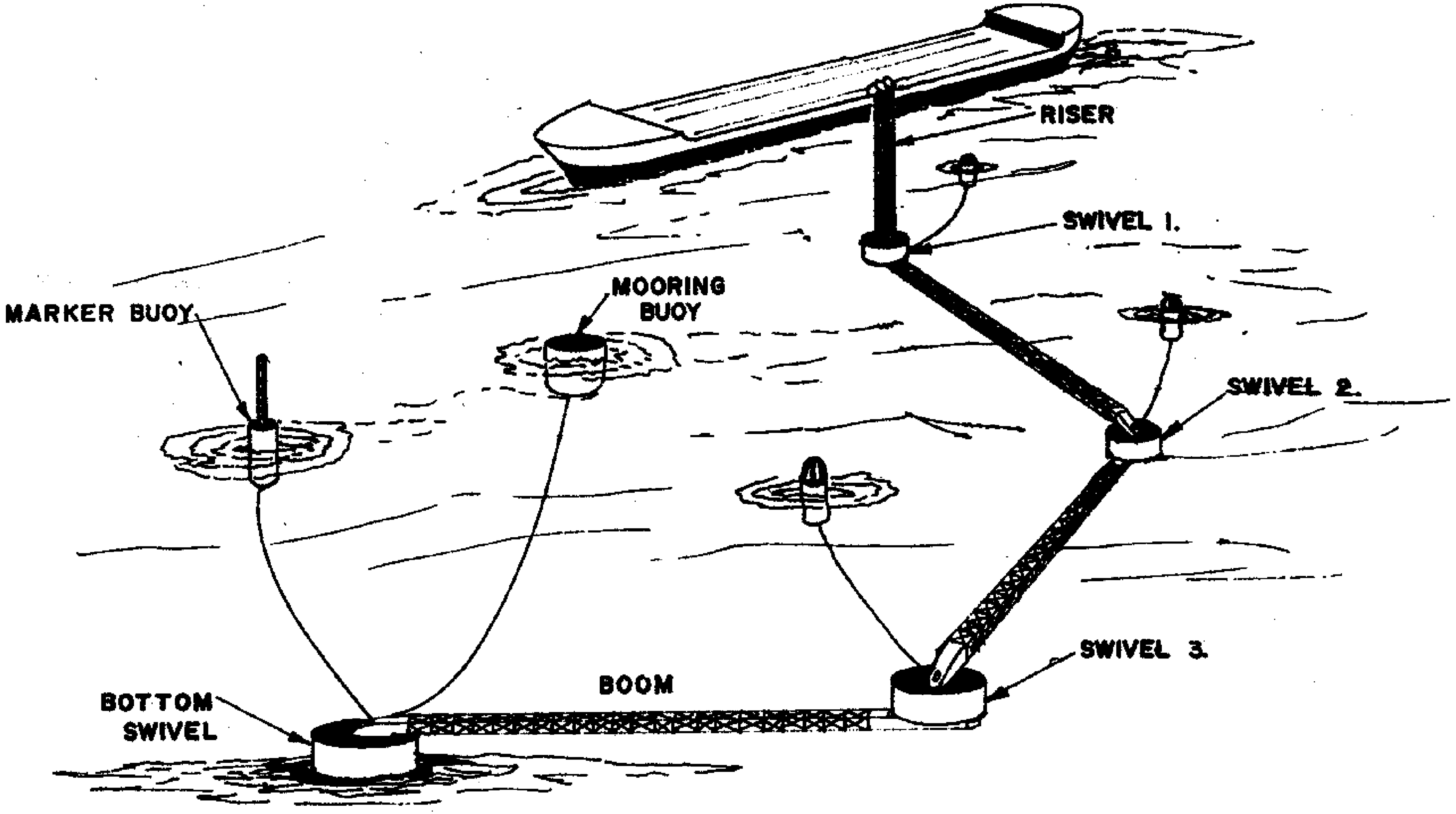


FIGURE 50 FLOATING TERMINAL CONCEPT (PANTAGRAPH DESIGN)
(REF. 261)

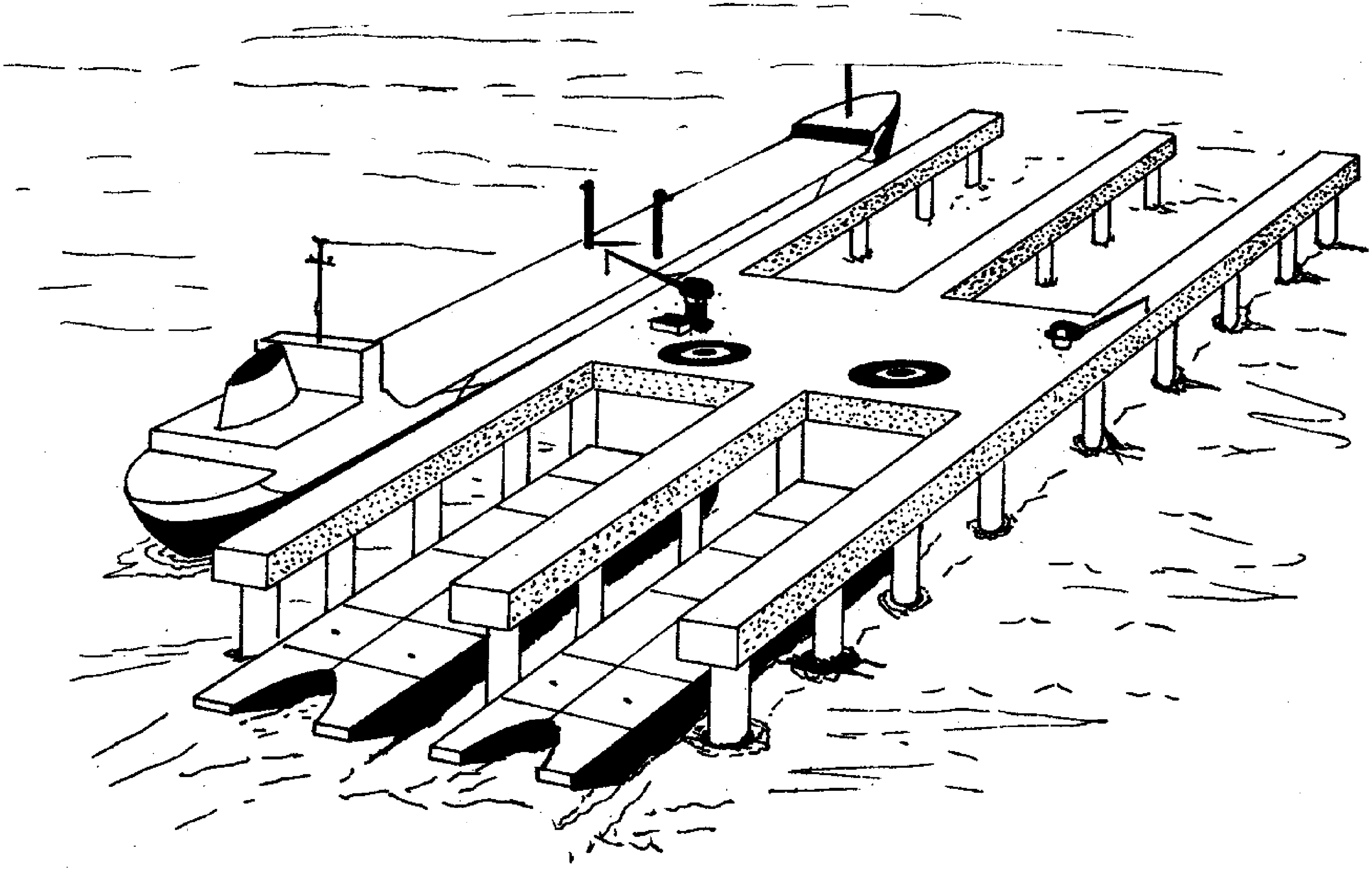


FIGURE 51 FLOATING STABLE PLATFORM TANKER TERMINAL. (REF. 262)

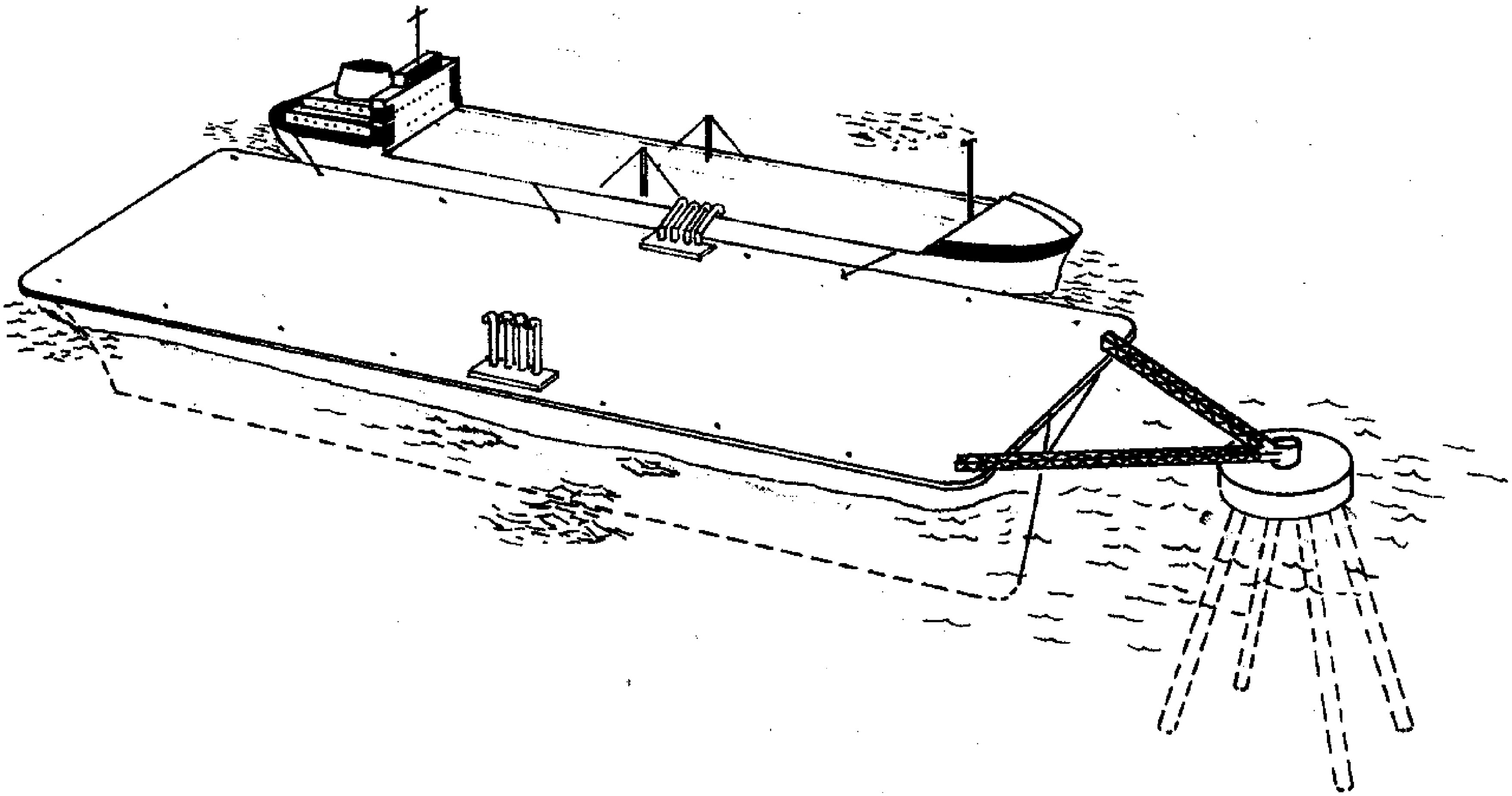


FIGURE 52 FLOATING WHARF CONCEPT. (REF. 258)

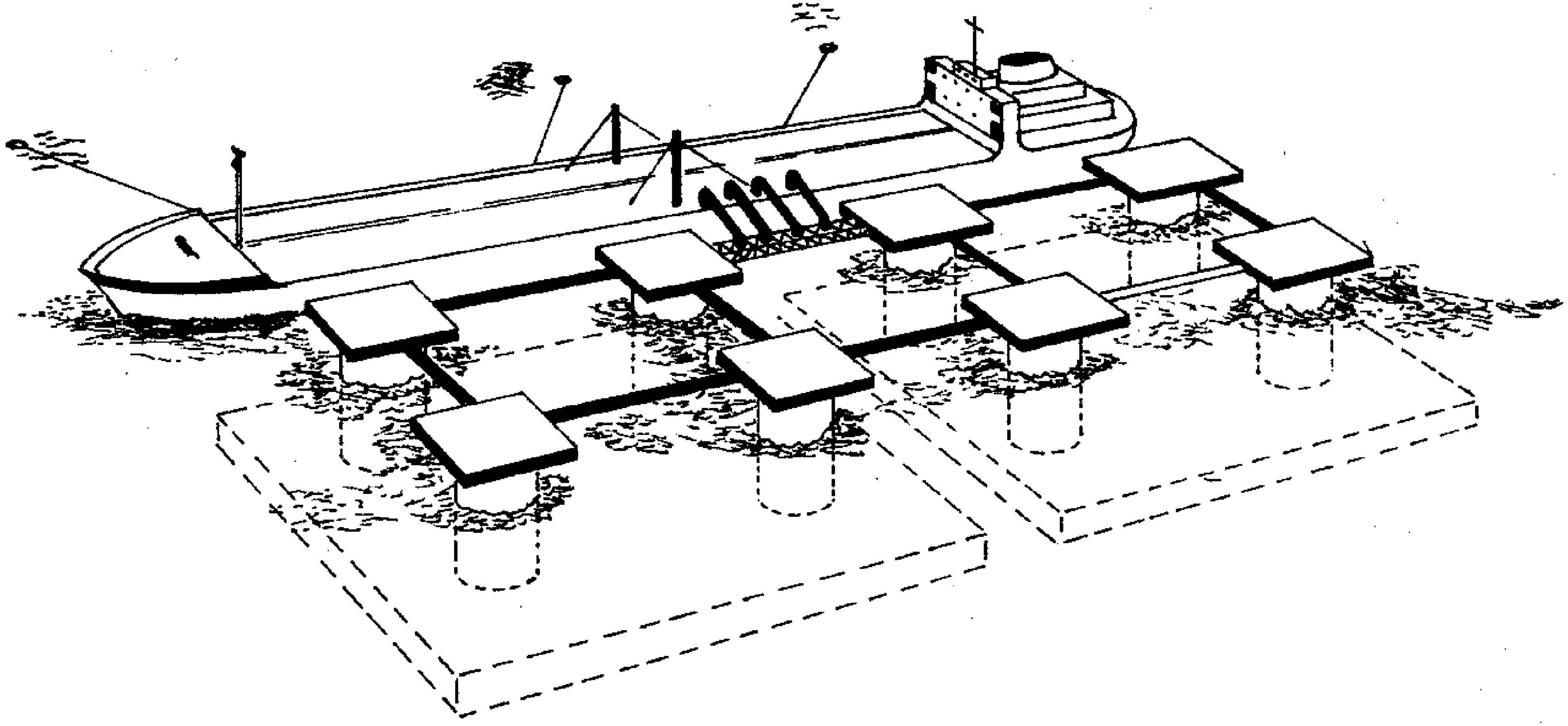


FIGURE 53 CONCEPT FOR OFFSHORE BERTHING WITH SUBSEA STORAGE FACILITY. (REF. 258)

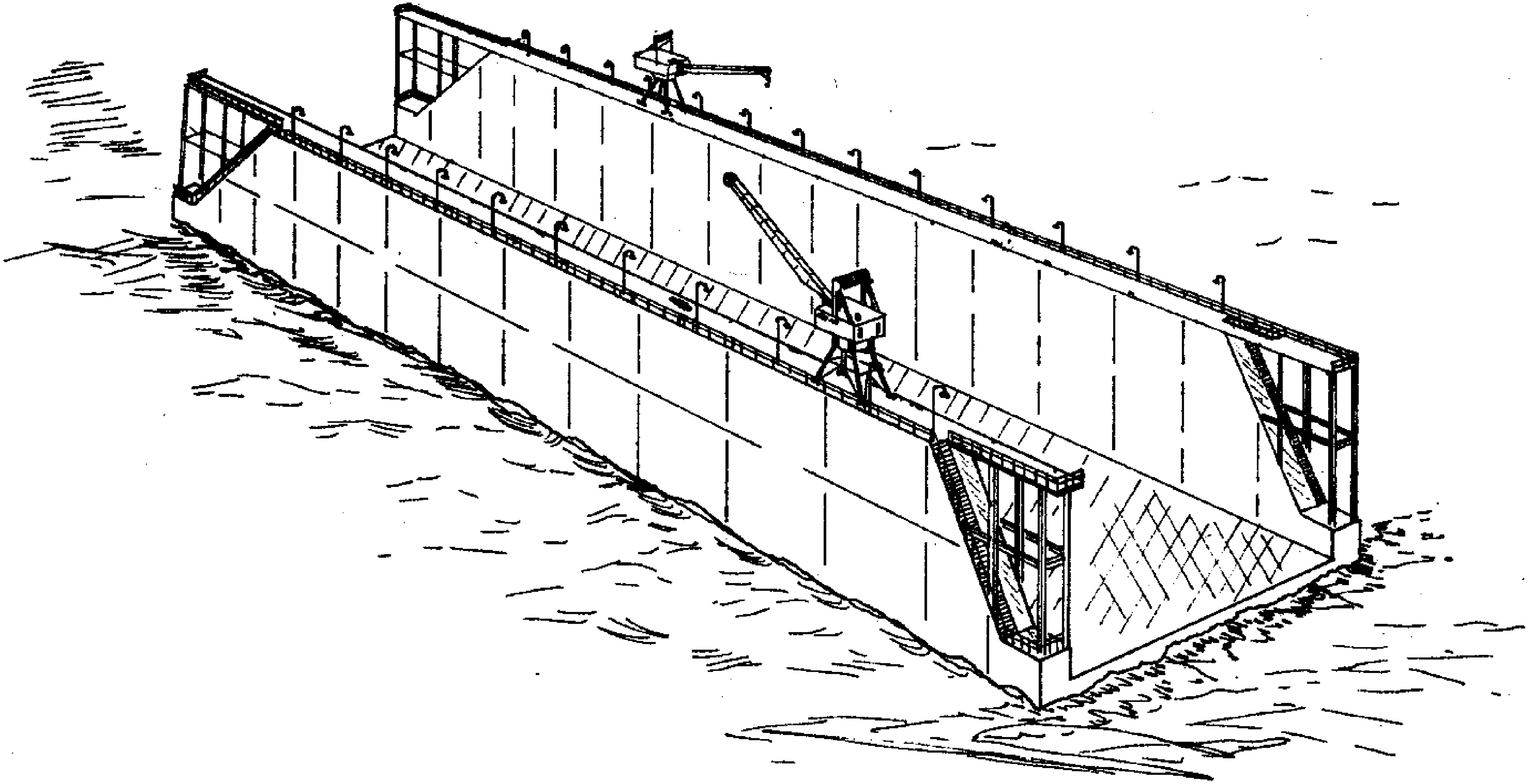


FIGURE 54 8000-TON FLOATING DOCK. (SHIPBUILDING PROGRESS, APRIL 1964, PP. 179-189)

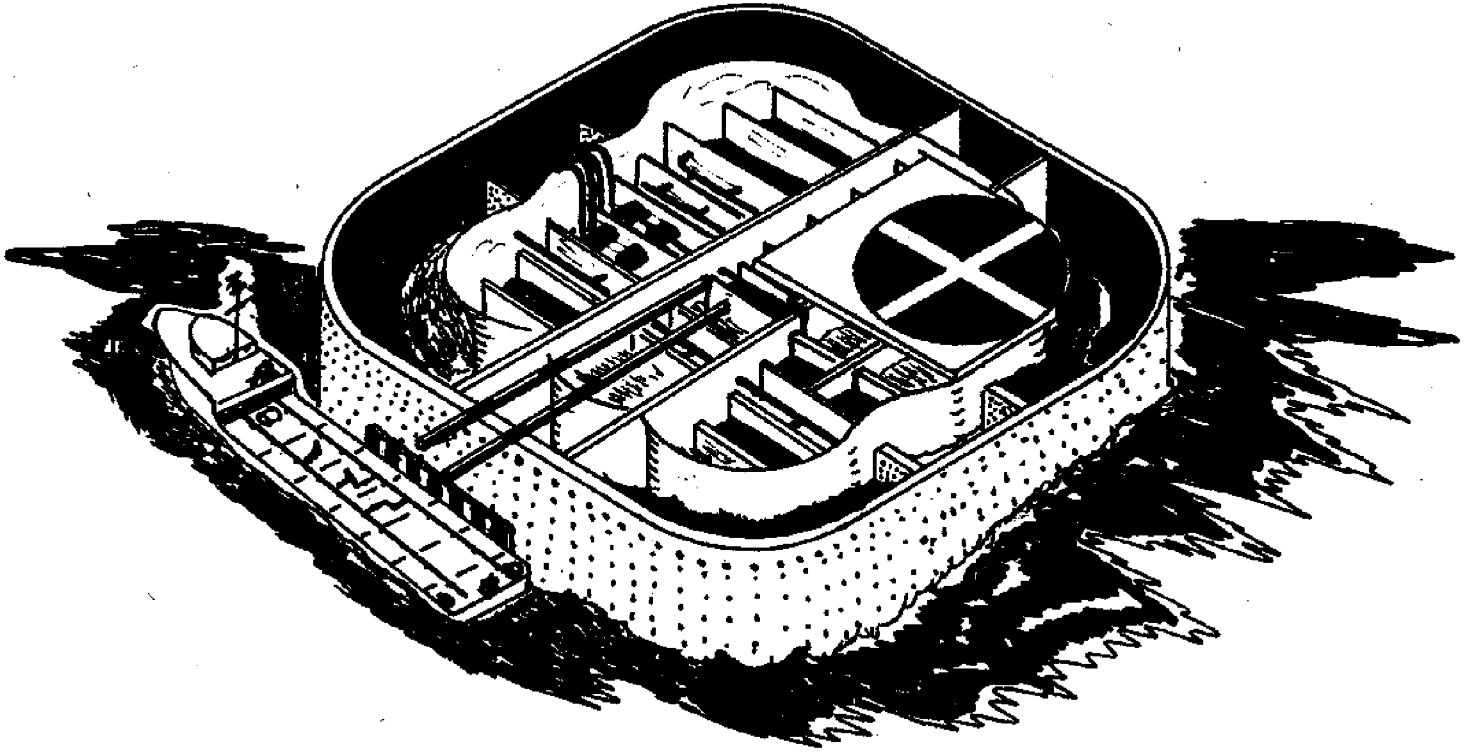


FIGURE 55 OFFSHORE OIL STORAGE FACILITY. (REF. 257)

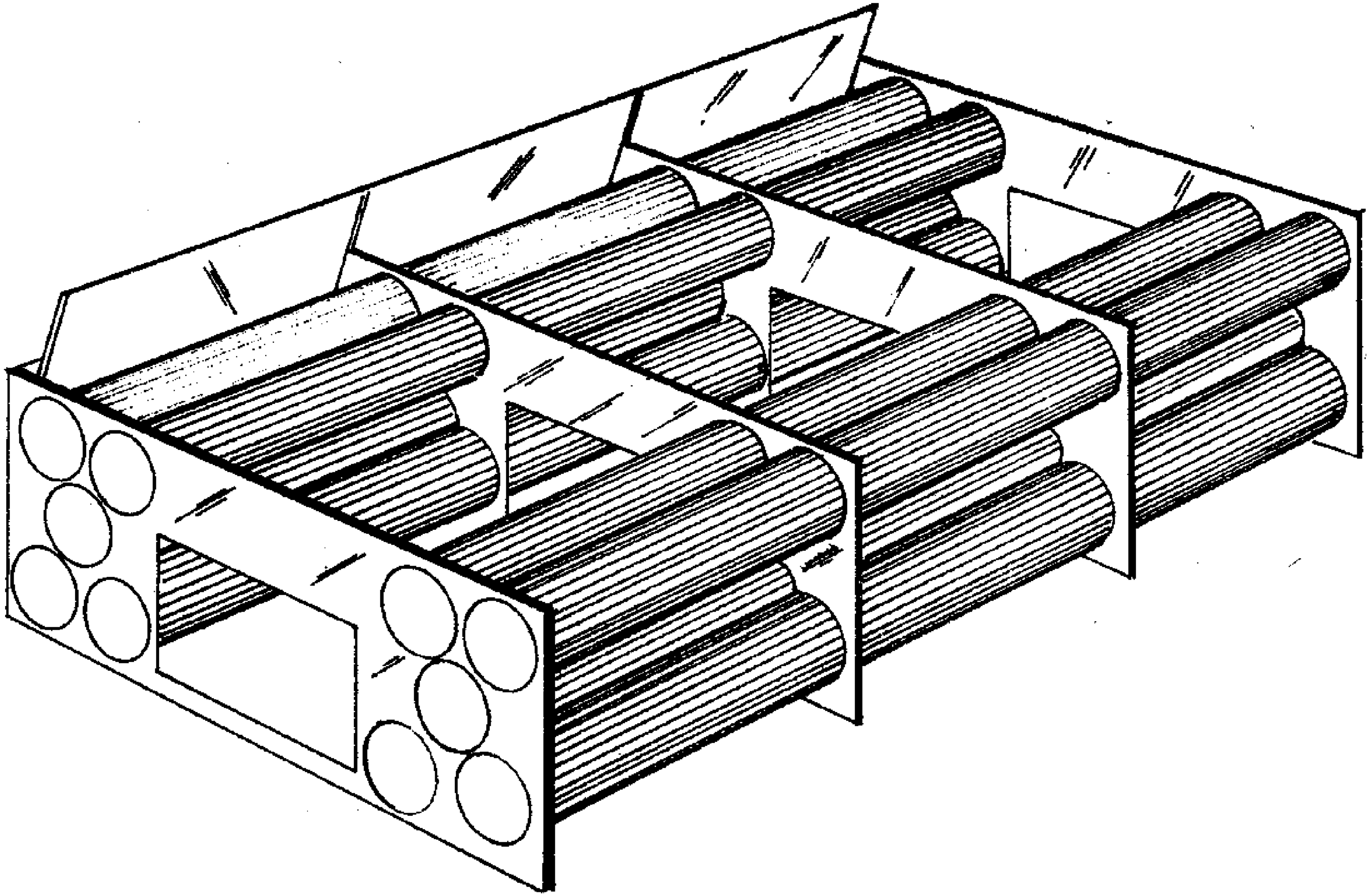


FIGURE 56 TUBULAR FLOATING BREAKWATER DISSIPATES WAVE ENERGY. (REF. 267)