MARGINAL FIELD (EARLY PRODUCTION): OPTIONS FOR OFFSHORE LOADING

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ABSTRACT

This paper will describe some of the various schemes that have been utilized since the early 1970's and which are available now for direct tanker loading from offshore oil fields to allow economic production from marginal fields and/or to allow revenues to be obtained at an earlier date than would be possible using conventional development.

Particular emphasis will be directed to the types of Single Point Mooring systems that have been accepted by the oil industry as viable elements in the overall production scheme.

INTRODUCTION

While the concept of offshore tanker loading has been around for many years, it was not until the early 1970's that the idea of employing a Single Point Mooring (SPM) terminal as an integral part of an offshore production facility achieved wide industry acceptance. In this application, the SPM provides both a permanent (or semi-permanent) mooring for the tanker and a means for transporting oil from the seafloor to the tanker. The SPM thus eliminates the requirement for a pipeline from the offshore field to the shore which often significantly reduces the overall cost and may allow development of marginal fields which have insufficient recoverable reserves to justify a pipeline system.

A second economic consideration in the election to use offshore loading is that it makes it possible to ship crude and receive income as soon as oil is available for a relatively small investment and in a relatively short time frame. Thus, production from initial wells can be generating cash flow while the drilling program continues with delineation of the reservoir. Even if the economics can support the cost of a pipeline, an offshore loading system ensures income during the sometimes lengthy design and construction period and is often retained subsequent to pipeline completion as a backup system in the event of pipeline outage.

Selection of an offshore loading scenario obviously will often require in-depth analysis of many economic considerations. However, the fact that viable concepts for offshore loading are available is of prime importance and offers a much greater flexibility to the operator in his planning than previously existed.

THE SPM CONCEPT

There are several distinct types of SPM's, all of which share two common features:

1. They all provide a single point which may rotate 360 degrees in the horizontal plane, to which the tanker moors its bow (or stern) via hawsers or structural steel frame.
2. They all employ fluid transfer systems which are capable of 360 degrees rotation in the horizontal plane.

The tanker moored only by connection to its bow or stern is free to "weathervane" about the single point mooring and, thus, stay oriented head-on into the prevailing environment. This attitude reduces the response of the tanker to the environment and, consequently, reduces the forces imposed upon the mooring system. The SPM design must provide sufficient elasticity to minimize mooring forces while controlling vessel excursions within an acceptable scope.

The SPM solves several problems inherent to other types of offshore mooring and loading systems, such as multiple buoy moorings, fixed towers, dolphins or sea islands.

1. It can readily be transported and placed in deep, remote offshore waters.
2. It can operate efficiently in hostile environments because it is not sensitive to directional changes of wind, waves and currents.
3. It reduces operational dependency on support vessels.
4. It is generally less expensive to construct than other types of mooring and loading systems.
5. It reduces vessel turnaround time.
6. For some applications, re-use or salvage value can be appreciable.

The SPM provides a highly reliable mooring (either permanent or temporary) with greater flexibility regarding water depth and environmental conditions and provides a secure facility for safely passing fluids from the seafloor to the moored vessel.

APPLICATIONS IN OFFSHORE PRODUCTION OPERATIONS

There are three basic ways in which SPM's are employed in offshore production operations:

- Shuttle Tanker "Filling Stations"
- Permanent Mooring Systems for a Floating Storage Vessel
- Permanent Mooring Systems for a Floating Process/Storage Vessel

1. Shuttle Tanker "Filling Station"

In this instance, the SPM is used in connection with a platform or semi-submersible type floating production facility (FPF). A short pipeline typically 1.6 - 3.2 km (1 - 2 miles) long is installed from the production facility to the SPM. Oil, following processing operations, is pumped through the pipeline and SPM into the moored shuttle tanker. When loaded, the tanker departs the berth and a second tanker moors. Depending on market logistics, two or three tankers will typically be required. The tankers will usually be modified for bow loading and for mooring via single hawser. "Self-Mooring" traction winches may be employed, especially in some rough weather locations.

The time lost between tankers will depend primarily on sea conditions which may be sufficiently rough to prevent the tanker from mooring for several hours or even days. Delays may also result from inability to perform required maintenance activities.

This type of system has the advantages of low initial cost, short lead time and high system flexibility (for relocation to subsequent locations). This shuttle type "on-off" operation may be undesirable for two principal reasons:

- Potential reservoir damage due to frequent shut-ins during tanker changeouts.
- Excessive downtime and, hence, deferred production waiting on weather to moor the shuttle tanker or to perform maintenance functions.

These problems may be partially solved by adding a second SPM or essentially eliminated by adding storage capacity either as an integral part of the production platform or in the form of floating storage. Downtime is more pronounced in severe environments such as the North Sea where shuttle type operations strive to achieve 80% efficiency. Other areas, such as Southeast Asia and Brazil, enjoy +90% operational efficiencies* with single SPM shuttle tanker operations(1) and, hence, are areas where this concept may warrant detailed investigation.

2. Floating Storage

The application of SPM's for direct tanker loading from an offshore oil field dates back to the mid 1960's with installations in West Africa and the Gulf of Mexico. It was in this period that one of the first permanently moored tankers appeared offshore Qatar. Around 1970 an increasing number of permanently moored tankers and barges began to appear offshore Iran, Saudi Arabia and Indonesia. These early installations all employed hawser-moored storage vessels and, in general, all shared the same operational problems.

- Necessity for frequent hawser replacement
- Frequent hose replacement
- Requirement for thrusters or slow astern running to prevent tanker from hitting buoy during tide changes or slack weather.

Again, certain areas of the world are environmentally suited to successful hawser-moored storage systems and their low initial cost may warrant utilization.

* Efficiency = $\frac{\text{actual crude loaded}}{\text{field production capacity}}$

A design solution to the problems experienced with hawser-moored storage vessels emerged in the form of the "Single Buoy Storage (SBS) (Fig. 6) which is a CALM buoy with an integral steel yoke rigidly linking the storage vessel to the buoy turntable, thus eliminating hawsers and floating hoses. The first such system was installed in the Gulf of Gabes, Tunisia, in 1974 and operated successfully in this relatively quiet water area. Since then, approximately ten SBS-type floating systems have been installed which closely approaches the number of hawser-type permanent mooring systems installed in the same period.

Floating storage will often be considerably cheaper than platform storage and has been proven in many areas of the world. While its viability is still a subject of debate in rough water areas, SHELL-EXXON's Fulmar Field in the North Sea, which utilizes an AL-yoke system (Fig. 8), should provide valuable guidelines for future decision making.

3. Floating Process and Storage

The application of floating production facilities has been around for many years in the oil industry beginning with barge mounted oil and gas separator plants in S. Louisiana and Indonesia. These early facilities were employed in sheltered shallow water and utilized spread-moorings or multiple buoy berths.

The first application of a Single Point Mooring for a floating process plant came in 1977 and involved a single seafloor completion which produced directly to a moored process/storage tanker via a flexible riser.

Industry acceptance of floating process for deep water open ocean applications has been rather slow but is growing rapidly because of the attractive economics. The definition of floating process in this paper is any operation in which oil and/or gas is transferred from the well head to moored process vessel via SPM, i.e. the SPM serves as a "live" production riser. This type system eliminates the necessity for the process platform, semi-submersible, TLP, jack-up, etc.

Developing an offshore oilfield via floating process offers several possibilities:

- Elimination of platform, jack-up or semi-submersible; seafloor completions are piped directly to permanently moored vessel either through individual risers or via central seafloor gathering manifold.
- If surface completions are preferred, these may be accomplished on a platform of reduced size as all process equipment is located on the moored vessel.
- The floating production system may be readily transported and re-used at another location.
- The floating system, in many instances, may be leased.
- Extended production testing for reservoir evaluation prior to full field development.
- Early generation of revenue.

Floating production and storage systems in hostile environments have, to date, accommodated simple one or two well developments, but an upcoming installation offshore Tunisia will allow production from eight wells which will considerably extend the potential applications.

As field complexity increases, subsea well control systems must become increasingly more sophisticated. Control power and communication circuitry must be passed through the SPM in a reliable manner. The technology to allow monitoring and control of several individual wells is definitely state-of-art today.

Other possible areas for floating process will be the development of marginal offshore gas fields. Several plans have been proposed for direct offshore production of methanol, LPG and even LNG, as well as the manufacture of products such as urea.

BASIC DESIGN REQUIREMENTS AND CONSIDERATIONS

There are several general types of questions that must be addressed during the formulation of a field development plan. Most of these, like many engineering problems, have no absolute right or wrong aswers and will in fact be determined by both the projected economics and the operators preference.

The following are typical major decision areas to be investigated once offshore loading has been elected. Areas involving questions such as satellite vs. cluster wells, wet vs. dry trees and TFL vs. wireline control are intentionally omitted from this discussion.

1. Storage or No Storage

If reservoir characteristics permit intermittent production, then direct offloading to shuttle tanker(s) probably represents the quickest way to get on-stream. In this approach, process is supported on a fixed platform, jackup rig, semi-submersible or TLP. A major area of study will be directed toward the type and number of export SPM to be employed and the number (and outfitting) of the shuttle tankers.

If floating storage is elected, some key questions will be:

- Yoke or Hawser Mooring
- Type of SPM
- Export Method
  - (a) alongside offloading
  - (b) tandem offloading
  - (c) separate export SPM
- Tanker selection

Table 1 lists some typical installations which will provide insight into the variety of solutions utilized in various geographical areas. Floating storage and field (production) terminals have been combined because they are often similar in application, i.e. a tanker loading directly from field production (not from field storage) may remain on the SPM for periods ranging from several days up to several months, essentially "floating storage" even though the tanker will eventually depart and no alongside or tandem export is required.

2. Floating Process

The decision to use floating process will produce a complex series of options, some of which are listed below:

(a) Platform or sub-sea well heads
(b) If sub-sea wellheads, will live risers be routed directly to "dry" manifold on tanker or SPM structure or via a central sub-sea gathering manifold?
(c) Yoke or hawser mooring
(d) Type of SPM
(e) Export method
(f) Gas disposal method
(g) Water disposal method
(h) Re-injection requirements
(i) Control systems
(j) Safety systems - sub-sea
(k) Safety systems - tanker
(l) Tanker selection
(m) Process/Production Facilities
(n) Purchase or Lease

Table 2 lists some floating process applications which have been employed in recent years.

The following is a summary of the types of questions that must be answered prior to calculation of realistic cost estimates involving the SPM/Tanker/Process/Export operation for oil field application.

General Information

- Location - this may affect fabrication costs and transportation, installation costs.
- Water Depth at proposed site

Environmental Data

What is really required is a complete environmental study which shows statistical occurrence and direction of wind, waves and currents. Initially, maximum wave, wind and current will suffice for estimation purposes. Other potential design factors, such as earthquake, mud-slide or ice should also be assessed.

Tanker Data

- Size of permanently moored vessel
- Size range of shuttle vessel(s)
- Anticipated export method i.e. alongside, tandem offloading or separate export SPM.

Product Data

- Maximum (total) daily production rate
- Number of wells
- Sub-sea wells or platform well heads
- Shut-in pressure
- Operating pressure
- Operating temperature
- GOR
- Salt Water
- Aromatics (%)
- H_2S, CO_2
- Paraffin, Wax
- Pour point
- Anticipated economic life
- Other pertinent crude characteristics

Pressure Maintenance

Gas or water injection requirements

Well Control

Control requirements
Manifold Location
TFL or Wireline Workover

Soil Data

Ultimately a complete bathymetric survey and soil report will be required. For initial estimates, a general description of the seafloor conditions will suffice.

SPM cost is particularly sensitive to water depth and environment. A major early decision will be selection of the design wave, i.e. will the vessel remain moored in the 100 year storm or will it depart. This is an especially interesting subject in locations subject to possible, if infrequent, hurricanes or typhoons. In such situations, system design (and cost) may vary significantly depending on this decision point. Advances in weather data acquisition, analysis, forecasting and the rapid dissemination of this information made possible by satellite observation and communication will allow on-site weather predictions and, therefore, this design decision may be executed with far greater confidence than has previously been possible.

TYPES OF SINGLE POINT MOORINGS

While more than twenty distinct SPM's have been proposed, industry has accepted but a few. SPM's for offshore production applications may be divided into two (2) general categories.

Hawser type SPM's

Catenary Anchor Leg Mooring (CALM)	Fig. 1
Single Anchor Leg Mooring (SALM) Shallow Water	Fig. 2
Single Anchor Leg Mooring (SALM) Deep Water	Fig. 3
Articulated Loading Tower (ALT)	Fig. 4

Rigid Yoke type SPM's

CALM - Yoke	Fig. 5
SALM - Yoke Deep Water	Fig. 6
ALT - Yoke	Fig. 7
Single Anchor Leg Storage (SALS)	Fig. 8
SALM - Very Deep Water	Fig. 9

The following discusses each of these designs in greater detail.

HAWSER TYPE SPM'S

CALM: The Catenary Anchor Leg Mooring obtains its compliance and restoring force from gravity, i.e. the weight of chains that anchor the system to the seafloor and must be lifted in order for the buoy to be displaced laterally or vertically. CALM's normally employ four, six or eight legs.

Oil flows into the rotary fluid system contained within the buoy via submarine hoses which connect at the seafloor with the pipeline end manifold (PLEM) and to the tanker through floating hoses.

This design is generally attributed to SHELL (SIPM) and the oldest type of SPM dating back to around 1959. About 220 CALM's have been installed which represent eighty percent of all SPM's.

The CALM is a simple, proven system which offers low first cost, as well as high mobility, as it can be readily recovered and relocated in a different water depth. The CALM, originally conceived as primarily a shallow water system - less than 150 ft (50 m) - has in fact been installed in water depths of 400 ft (122 m) and, in some locations (notably offshore Brazil) is performing very effectively. The primary design difference between deep and shallow water CALM's is the underbuoy hose profile.

Figure 1 shows a "Chinese Lantern" suitable for relatively shallow water. For deep water, the hose is suspended vertically below the buoy in a J-curve which terminates in a sub-surface buoy. From this buoy a short length of hose extends vertically to the PLEM. This system is commonly called a "Steep S".

A Calm will generally require more maintenance than SALM or ALT in exposed locations, especially regarding hoses and turntable. It is also vulnerable to damage from tanker impact[2].

SALM: The Single Anchor Leg Mooring for shallow water up to 160 ft (50 m) obtains its elasticity from buoyancy.

Oil flows from the PLEM into the subsea swivel unit and then via the submerged and floating hose system to the tanker. The PLEM is totally isolated from buoy excursions and the hose system is not subjected to continual flexing from buoy motions.

The SALM was developed by Exxon Research and Engineering in the mid 1960's and the prototype installation was in 1969. Eighteen SALM's have been installed to date.

The SALM is a simple, proven and extremely rugged system which offers low first cost, low maintenance and reasonable mobility in water depths from about 50 ft (15 m) to 160 ft (50 m). It will survive in extremely severe environmental conditions and is intrinsically safe from damage by tanker overrun.[2]

Originally conceived as a primarily deep water terminal, the majority of SALM applications to date have been in water depths around 100 ft (30 m).

SALM - Deepwater: In water depths beyond about 160 ft (50 m), the submerged hose system from the seafloor becomes impractical. Thus, the fluid swivel is elevated by means of a structural riser to a position near the surface but below wave action and tanker keel.

The deepwater SALM is characterized by two articulation points, one at the seafloor and one at an intermediate point typically 100 ft (30 m) - 150 ft (46 m) below the surface. This feature relieves bending moments and allows for a small diameter riser and highly compliant fast response system, a SALM characteristic which helps to reduce snatching loads on the mooring hawser.

Oil flows from the PLEM into piping located inside or outside the riser through short jumper hoses or through swivels incorporated in the lower universal joint. Hoses from the fluid swivel to the tanker may be suspended in a catenary or left floating on the surface.

The deepwater SALM is cost effective relative to the CALM and is substantially cheaper than the ALT. For field export in water depths beyond 500 ft (150 m) the SALM is probably the only viable system. Designs based on this concept have been developed for water depths of 5,000 ft (915 m)[3] and a SALM in the North Sea is the deepest SPM in the world today at 530 ft (162 m). Present day technology may be considered viable to about 1,200 ft (366 m).

This design offers low maintenance, safety from collision and reasonable mobility for use at other sites in water depths which vary from design depth (typically) + 100 ft (30 m) - 50 ft (15 m).

ALT: The Articulated Loading Tower obtains its restoring force from buoyancy. It is a heavy, large diameter column with a single articulation at the seafloor. It is characterized by a very long natural period and may require a hawser tensioning system to prevent high peak "snatching" loads.

The ALT is a proven system whose primary advantages are that the fluid swivel and turntable are well above the wave zone and are accessible without divers. Additionly, the loading hose may be suspended from a boom which eliminates problems of hose-hawser entanglement and may simplify hose retrievel onto the tanker (relative to designs for which the hose must be retrieved directly from the water).

The ALT has several disadvantages, among which are high installation cost and substantial risk with respect to fire and collision damage.

This system has found primary application in deep North Sea locations 350 ft - 400 ft (100 m - 120 m) as a loading terminal for platform supported storage. The very high efficiencies associated with North Sea ALT's may be attributed to substantial platform storage capacity and high loading rates which reduce the tankers time on station.

The ALT may, at great expense, conceivably be extended to 600 ft (183 m), but beyond this a SALM-type double articulated structure will be required.[4]

RIGID YOKE TYPE SPM'S

CALM - Yoke: The CALM yoke operates identically to the Hawser CALM with the major exception that the tanker is attached to the buoy by a rigid steel structure (yoke) rather than a flexible hawser.

The yoke is connected to the tanker by horizontal pins (to allow the tanker to pitch and heave). Depending on the specific design, the yoke may be attached rigidly to the CALM turntable (SBS)[5] or it may be connected to the turntable by pins which uncouple the buoy from the tanker with respect to pitch and heave.

Due to the added weight of the yoke and the loss of elasticity provided by the hawser, the CALM yoke will experience somewhat greater loads than the hawser system and will, therefore, require greater buoyancy (larger buoy) and a stronger anchorage (larger, longer anchor chains).

As with the hawser system, product flows from the seafloor to the buoy fluid swivel via submarine hoses. From the buoy, product is routed along the yoke, eliminating the need for floating hoses. Hydraulic/Electric Control lines can follow the same path.

Utilization of these flexible conduits between buoy and seafloor imposes a practical limit as to the number of individual wells which can be serviced with this type of system.

In water depths less than approximately 150 ft (45 m) the CALM Yoke provides a cost effective permanent mooring facility in nominal environments.

Certain CALM Yoke designs do not allow for on-site disconnection of the yoke from the buoy. This can pose an operational disadvantage in that the entire mooring system must be decommissioned if the tanker needs to be taken (even temporarily) from the field.

ALT-Yoke: The articulated tower-yoke system consists of a large, buoyant tower, as previously described, but which is connected to the tanker through a rigid steel yoke in lieu of a hawser. The yoke is connected to the tanker through vertical hinges and to the tower in a manner which will accommodate pitch (heave) and roll while permitting weathervaning.

Product and control lines are routed from the seafloor to the vessel along (or inside) the tower and through the swivel assembly. The universal joint on the seafloor, the connection of yoke to tower and the hinges at the vessel may be bridged either with flexible loops or through co-axial swivel elements.

This concept has the advantage of being able to accommodate a greater number of flowlines (hence, wellheads) with greater integrity than the CALM.

Disadvantages include large buoyancy requirements in order to obtain the required restoring force and a high initial cost, relative to the CALM, particularly in shallow water.

Deepwater SALM-Yoke: The SALM-Yoke is similar to the SALM previously described, but with the SALM-Tanker connections being a rigid yoke instead of a hawser. As water depth increases beyond 350 ft - 400 ft (106 m - 122 m), bending forces in the articulated tower become so large as to mandate a secondary articulation point.(6) This is accomplished by connecting the mooring buoy to the riser shaft through a universal joint which allows X-Y articulation. This joint relieves bending stresses and allows the riser to be of relatively light construction.

As on the tower, the yoke-tanker connection is a horizontal hinge and the yoke-buoy connection provides three degrees of freedom. Product routing is similar to what might be used on a tower.

In relatively deep water 400 ft - 800 ft (122 m - 244 m), the SALM-Yoke should provide an efficient, economical solution for permanent moorings with no undue restrictions regarding the number of wells which can be serviced.

In the event that the storage/process vessel needs to be removed from the field, the yoke may be disconnected from the buoy and removed along with the vessel. The SALM will remain functional and can be used for mooring other vessels via hawser, in the interim period.

<u>S</u>ingle <u>A</u>nchor <u>L</u>eg <u>S</u>torage <u>S</u>ystem (<u>SALS</u>): The SALS consists of a slender riser connected by a universal joint to a seafloor mooring base and to the storage vessel by a rigid yoke incorporating a large buoyancy tank located between the riser and the vessel. The system obtains its restoring force from this offset buoyancy chamber which provides an especially effective method for concentrating buoyancy near the surface. This increases system efficiency, particularly in shallow water.

Connection of yoke to riser and yoke to vessel is accomplished in essentially the same manner as with the tower and the SALM. Product and control lines are also routed in a similar manner with the same advantages with regard to multiplicity of lines.

The SALS provides an efficient mooring in a wide range of water depths. However, in particularly deep water where buoyancy requirements are high, or in particularly severe environments, the large buoyancy chamber located in the wave zone will result in escalated system forces.

The SALS has the disadvantage that, with the storage vessel off location, the system will not function in a temporary mode as will the SALM and the Tower.

SALM - Very Deep Water: In very deep water below 800 ft (244 m) a modified SALM offers excellent potential. The system will be essentially the same as the deepwater SALM, except that the riser section will consist of a series of joints (to facilitate installation using a drilling rig) and the riser section will be purely a tension member, deriving its resistance to large deflections by the tension applied.(7)

In addition to tension supplied by the buoy, riser support may be achieved with buoyancy added to each section of the riser with flotation (buoyancy) chambers.

This concept offers a good solution to very deep water locations utilizing proven technology and should be viable in water depths of up to about 1,200 ft (366 m) without any new technical breakthroughs.

Offtake Systems: From a permanent storage/process facility, after the oil is stored aboard the vessel, it must be discharged to another ship for transport to market. In general, there are three methods which may be employed:

- Discharge through adjacent mooring terminal
- Discharge to vessel tied "along-side"
- Discharge to vessel moored "astern"

1. <u>Adjacent Mooring Terminal</u>

Depending on offtake frequency and environmental conditions, a second SPM may be installed nearby and connected by seafloor pipeline to the storage facility. Shuttle vessels will then moor to the SPM and receive cargo from storage.

This concept has the advantage of high utilization, even in adverse environments, safety and adaptability to receive "ships of opportunity". Disadvantages are mainly related to high initial cost.

2. <u>Along-side Mooring</u>

By installing proper fendering and cargo transfer systems on the storage vessel, it is practical to bring "shuttle vessels" alongside and discharge product. This method of ship-to-ship transfer is well practiced in sea lightering operations worldwide.

This method of offtake offers low initial cost and certain flexibilities regarding the servicing of ships of varying characteristics. Unfortunately, environmental conditions (swell perpendicular to current) and ship size incompatabilities often pose severe restrictions onto this concept.

3. Astern (Tandem) Mooring

Installation of specialized mooring and hose facilities on the stern of the storage vessel provides a facility whereby "shuttle" tankers can moor by a single point to the storage vessel and receive product through a floating hose. In essence, the storage vessel becomes an auxiliary SPM.

This system offers greater flexibility with regard to environment and ship compatibility than alongside mooring and represents significantly less investment than an auxiliary SPM.

Disadvantages are that the specialized equipment will be expensive. Also, mooring availability will not be as high (during adverse weather) as with a second SPM and safety is not as secure.

The Ultradeep Challenge

Present SPM technology, especially the SALM and the SALS, can certainly be extended to beyond 1,000 ft (300 m). How far beyond will be determined by economics and OWNER/OPERATOR experience and preference.

Since the classic 1975 FPF of Hamilton Brothers "ARGYL" Field in the North Sea, a great number of ideas have appeared in the market place. Many of these "early production systems" are in fact oriented about a single specialized concept or piece of equipment, such as a sub-sea manifold center, a marine riser design, a tanker stabilization system or an available semi-submersible drilling rig. Others have gone a step further to incorporate a special riser support system, and some have addressed methods for floating process, storage and offloading. While it is obvious that huge semi-submersible FPF's can operate in water depths greater than 2,000 ft (600 m), it is also expensive and often represents a viable avenue only when the semi does not have a drilling contract on the horizon.

Historically, the oil industry has pushed "conventional" marine technology far beyond the limits originally conceived (witness the "COGNAC", "CERVEZA" and "HONDO" platforms). Thus, it is reasonable to expect SPM's to be pushed to some yet-to-be-defined depth, but it is difficult to imagine that this will be very much beyond about 1,500 ft (457 m). At this point, segregation of the flowline support system from the mooring requirement may provide attractive operational flexibility and economy. In this approach, flowlines are supported by a surface (or sub-surface) buoy or by a series of buoys. The production/storage vessel is moored nearby via separate device and linked to the riser assembly by means of a flexible flowline and control system bundle.

This type of idea has been proposed for significantly deepwater 2,500 ft (762 m) by ASTANO with the "ALGA" (Fig. 10) system and Global Marine Development, Inc. with the Buoyant Tower Concept (Fig. 11).

Others, such as ACB and CANOCEAN, have developed deep water production risers and some prototype equipment has already been built.

This segregated approach is distinctly different from Exxon Production Research Company's integrated deep water riser which is an extension of SALM technology designed around an installation procedure using a floating drilling vessel. This concept (Fig. 9) utilizes the flowline support system as a structural element directly responsible for mooring the process-storage vessel. Mobility with respect to water depth is achieved by adding (or deleting) sections to the riser.

Segregated flowline support and floating process-storage concepts have not clearly defined the means by which vessel station-keeping is accomplished. It is conceivable that spread mooring, or dynamic positioning or some combination will be employed. Spread mooring has been successfully demonstrated in the drilling industry for many years where it provided excursion control of typically 5% - 6% of water depths and could weather 50 ft (15 m) waves. New super-strong fibers such as KEVLAR may extend the feasible water depths for spread moorings and improvements in acoustic positioning coupled with satellite position reference capabilities make DP a competent station-keeping option.

The spread-mooring/DP approach, however well it moors the slave vessel, have the problem of offloading, i.e. neither provides a secure offloading base for shuttle tankers. A separate field export SPM or, perhaps, DP controlled shuttle tankers may provide the answer.

For marginal field development in some areas of the world, the segregated flowline support system and spread-moored process-storage vessel may well provide acceptable operational efficiency and will certainly offer attractive economics relative to advanced SPM technology, especially in water depths beyond 1200 ft (370 m).

CONCLUSIONS

- The utilization of Single Point Mooring Systems as an integral component in an offshore production complex is occurring with increasing frequency. Industry is accepting the concept as an excellent economic and technical solution and the equipment presently being produced is continuously proving its adequacy for the application. Systems are presently in service on 2 well fields in water depths of 300 feet (92 m) and state-of-the-art technology is available today to extend these capabilities to 8-10 well fields in locations in water depths up to about 1200 ft. (370 m).
- For water depths beyond 1200 ft (336 m) the "segregated riser" approach with spread moored or DP tankers may offer a cost effective solution for direct offshore field production.
- Regardless of the basic approach, the "macroscopic" questions remain and must be determined on a case-by-case basis in view of the Operator's preference and experience:
  - Cluster (template) or Satellite Walls
  - Submarine or Surface Trees
  - Wet or Dry (atomospheric) Trees
  - Flexible Risers or Rigid Risers
  - Wireline or TFL Maintenance

The SPM designer with specific expertise in analyzing wave effects on the vessel mooring system, predicting the resultant forces and motions and performing the detailed structural design and project-construction management, is not equipped to answer all of these questions, but may certainly provide valuable guidance based on his experience with other operators.

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TABLE 1
FIELD EXPORT AND FLOATING STORAGE TERMINALS

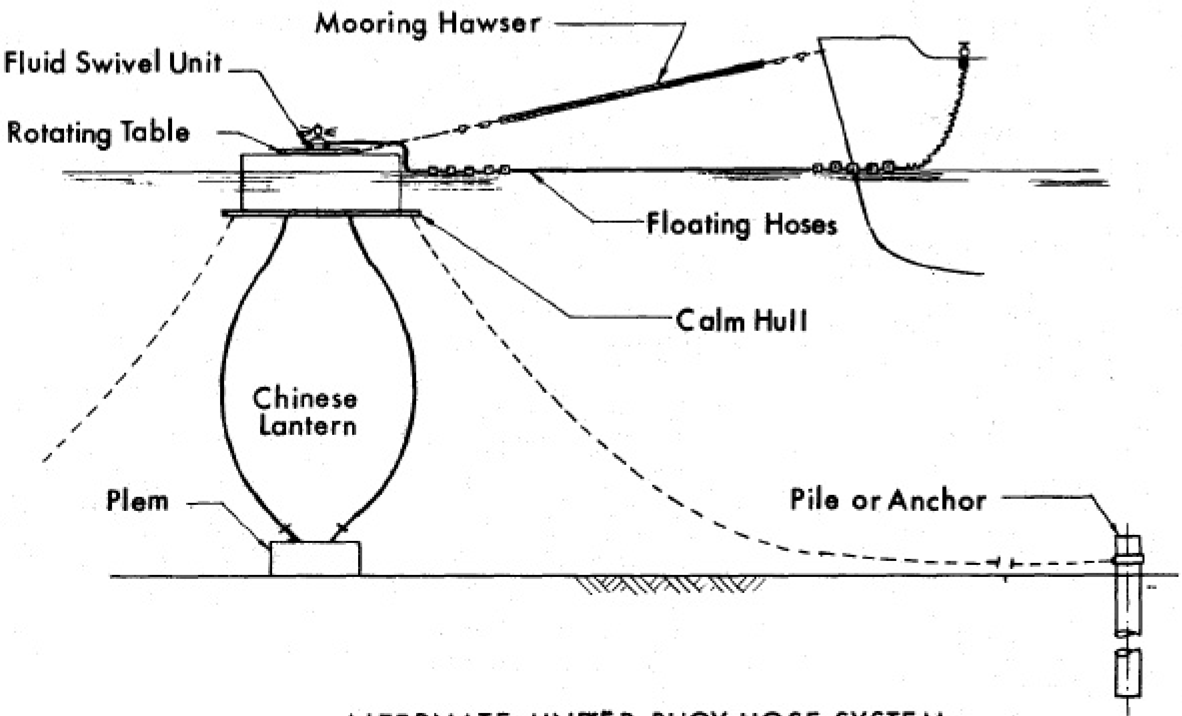
COUNTRY	OWNER	WATER DEPTH	TANKER SIZE (DWT)	TYPE OF SYSTEM	REMARKS
Gabon	SHELL	63 ft (19 m)	100,000	CALM	Installed 1965. Field Export
Qatar	SHELL	100 ft (30 m)	38,000	CALM	Hawser Moored Permanent Storage Installed 1965
Gabon	SHELL	112 ft (34 m)	165,000	CALM	Installed 1967. Field Export
Dubai	CONOCO	103 ft (31 m)	150,000	CALM	Field Export
Saudi Arabia	ARAMCO	111 ft (34 m)	250,000	CALM	Hawser Moored Permanent Storage (1970)
Saudi Arabia	ARAMCO	129 ft (39 m)	450,000	CALM	Export from Floating Storage
Norway	PHILLIPS	208 ft (63 m)	150,000	CALM	Field Export
Norway	PHILLIPS	232 ft (71 m)	60,000	CALM	Field Export
Denmark	DANBOR	150 ft (46 m)	70,000	CALM	Field Export
Indonesia	ARCO	135 ft (41 m)	1,000,000 barrel barge	CALM	Hawser Moored Permanent Storage Barge (1972)
Indonesia	IIAPCO	130 ft (39 m)	1,000,000 barrel barge	CALM	Hawser Moored Permanent Storage Barge (1972)
United Kingdom	HAMILTON BROS.	252 ft (77 m)	100,000	CALM	Field Export (1973) from FPF
Abu Dhabi	TOTAL/ABK	97 ft (29 m)	100,000	CALM	Hawser Moored Permanent Storage
Sharjah	CRESCENT	160 ft (49 m)	350,000	CALM	Field Export
Indonesia	ARCO	138 ft (42 m)	150,000	CALM	Hawser Moored Permanent Storage
Indonesia	ARCO	126 ft (38 m)	200,000	CALM	Export from Floating Storage
Indonesia	TOTAL	123 ft (37 m)	100,000	CALM	Hawser Moored Permanent Storage
Malaysia	EPMI	296 ft (90 m)	140,000	SALM	Hawser Moored Permanent Storage Installed 1974
United Kingdom	AMOCO	304 ft (93 m)	50,000	CALM	Field Export
United Kingdom	AMOCO	304 ft (93 m)	50,000	CALM	Field Export
Tunisia	AQUITAINE	220 ft (67 m)	70,000	SBS	Installed 1974. First Rigid Yoke
Nigeria	TEXACO	87 ft (26 m)	50,000	CALM	Hawser Moored Permanent Storage
Nigeria	TEXACO	93 ft (28 m)	250,000	CALM	Export from Floating Storage

TABLE 1 (Continued)
FIELD EXPORT AND FLOATING STORAGE TERMINALS

COUNTRY	OWNER	WATER DEPTH	TANKER SIZE (DWT)	TYPE OF SYSTEM	REMARKS
Indonesia	ARCO	140 ft (43 m)	Concrete barge for LPG (30,000)	SBS	Permanent Floating Storage
Tunisia	ACQUITAINE	220 ft (67 m)	100,000	CALM	Export from Floating Storage
Indonesia	CITIES SERVICE	180 ft (55 m)	55,000	SBS	Permanent Floating Storage
India	ONGC	240 ft (73 m)	100,000	CALM	Hawser Moored Permanent Storage
India	ONGC	240 ft (73 m)	100,000	CALM	Export from Floating Storage
United Kingdom	BNOC	535 ft (163 m)	80,000	SALM	Field Export. World's Deepest SPM. Installed 1976
United Kingdom	MOBIL	380 ft (116 m)	100,000	ALT	Field Export from Platform Storage
Malaysia	EPMI	240 ft (73 m)	190,000	SALS	First SALS for Floating Storage
Cameroon	SNEA	75 ft (23 m)	120,000	CALM	Field Export from Spread-Moored Storage Vessel
Qatar	HOLCAR	88 ft (27 m)	65,000	CALM	Hawser Moored Permanent Storage
Abu Dhabi	AMERADA HESS	107 ft (33 m)	252,000	SBS	Permanent Floating Storage
Zaire	GULF	79 ft (24 m)	79,000	CALM	Hawser Moored Permanent Storage
Ghana	AGRI PETCO	79 ft (24 m)	64,000	SALM	Hawser Moored Permanent Storage
Brazil	PETROBRAS	410 ft (125 m)	53,000	CALM	Field Export from FPF
Philippines	CITIES SERVICE	200 ft (61 m)	90,000	SBS	Installed 1979
Indonesia	CONOCO	302 ft (92 m)	100,000	SBS	Permanent Floating Storage
Tunisia	SEREPT	220 ft (67 m)	120,000	SBS	Permanent Floating Storage
United Kingdom	BP	369 ft (112 m)	107,000	CALM	Field Export from FPF
Norway	STATOIL	480 ft (146 m)	150,000	ALT	Field Export from Platform Storage. There are two ALT's currently in service with a third scheduled for Installation in 1985
Cameroon	SNEA	95 ft (29 m)	250,000	CALM	Field Export from spread moored Storage Vessel
Gabon	SNEA	90 ft (27 m)	70,000	CALM	Hawser Moored Permanent Storage
Angola	TEXACO	115 ft (35 m)	250,000	CALM	Hawser Moored Permanent Storage
USA	EXXON	494 ft (151 m)	50,000	SALM	First SALM-YOKE System. Installed 1981
Angola	GULF	118 ft (36 m)	55,000	CALM	Hawser Moored LPG Tanker
Angola	GULF	200 ft (61 m)	300,000	CALM	Hawser Moored Permanent Storage
Indonesia	ARCO	135 ft (41 m)	56,000	CALM	Hawser Moored Butane Tanker
Brazil	PETROBRAS	460 ft (140 m)	53,000	CALM	Field Export
Brazil	PETROBRAS	395 ft (120 m)	53,000	CALM	Field Export
Thailand	UNION	240 ft (73 m)	105,000	CALM-YOKE	Condensate Storage with Tandem Offloading
United Kingdom	SHELL EXPRO	265 ft (81 m)	220,000	SALM-YOKE	First Permanent Floating Storage in North Sea. Installed 1981
India	ONGC	133 ft (40 m)	115,000	CALM	Hawser Moored Permanent Storage
Ivory Coast	PHILLIPS	300 ft (91 m)		CALM-YOKE	Permanent Floating Storage

TABLE 2
FLOATING PROCESS SPM TERMINALS

COUNTRY	OWNER	WATER DEPTH	TANKER SIZE (DWT)	TYPE OF SYSTEM	REMARKS
Spain	SHELL	383 ft (117 m)	60,000	SALS	Single Well Seafloor Completion (wet) producing directly to a permanently moored process tanker via 4" flexible riser. Installed 1977
Italy	AGIP-SHELL	312 ft (95 m)	80,000	SALS	
Philippines	AMOCO	300 ft (92 m)	120,000	SBS	Dual well system with wet seafloor completion producing directly to permanently moored process tanker via flexible high pressure risers.
Brazil	PETROBRAS	400 ft (122 m)	53,000	CALM	Hawser moored vessel receives production from dry sub-sea manifold center. Process tanker will be replaced by GAROUPA Platform and SPM retained for Field Export.
Tunisia	SHELL	470 ft (143 m)	200,000	SALS	Multiwell system which will produce from subsea trees directly to permanelty moored tanker which will process crude, flare gas, store stabilized crude and control wells.



ALTERNATE UNDER BUOY HOSE SYSTEM

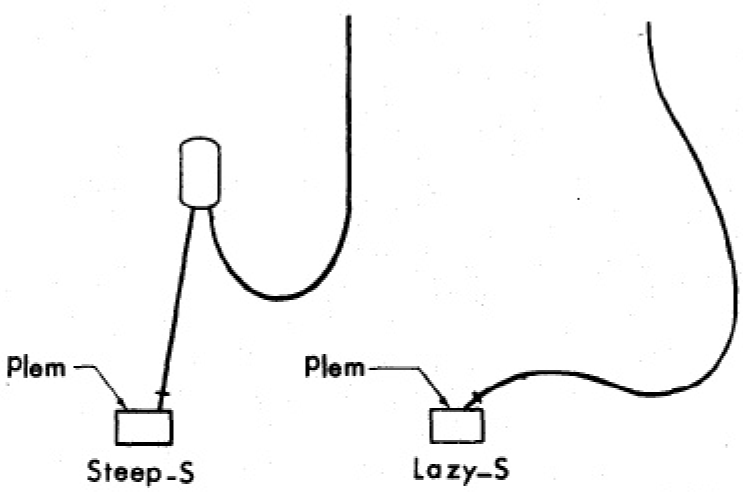


FIG. 1 CALM

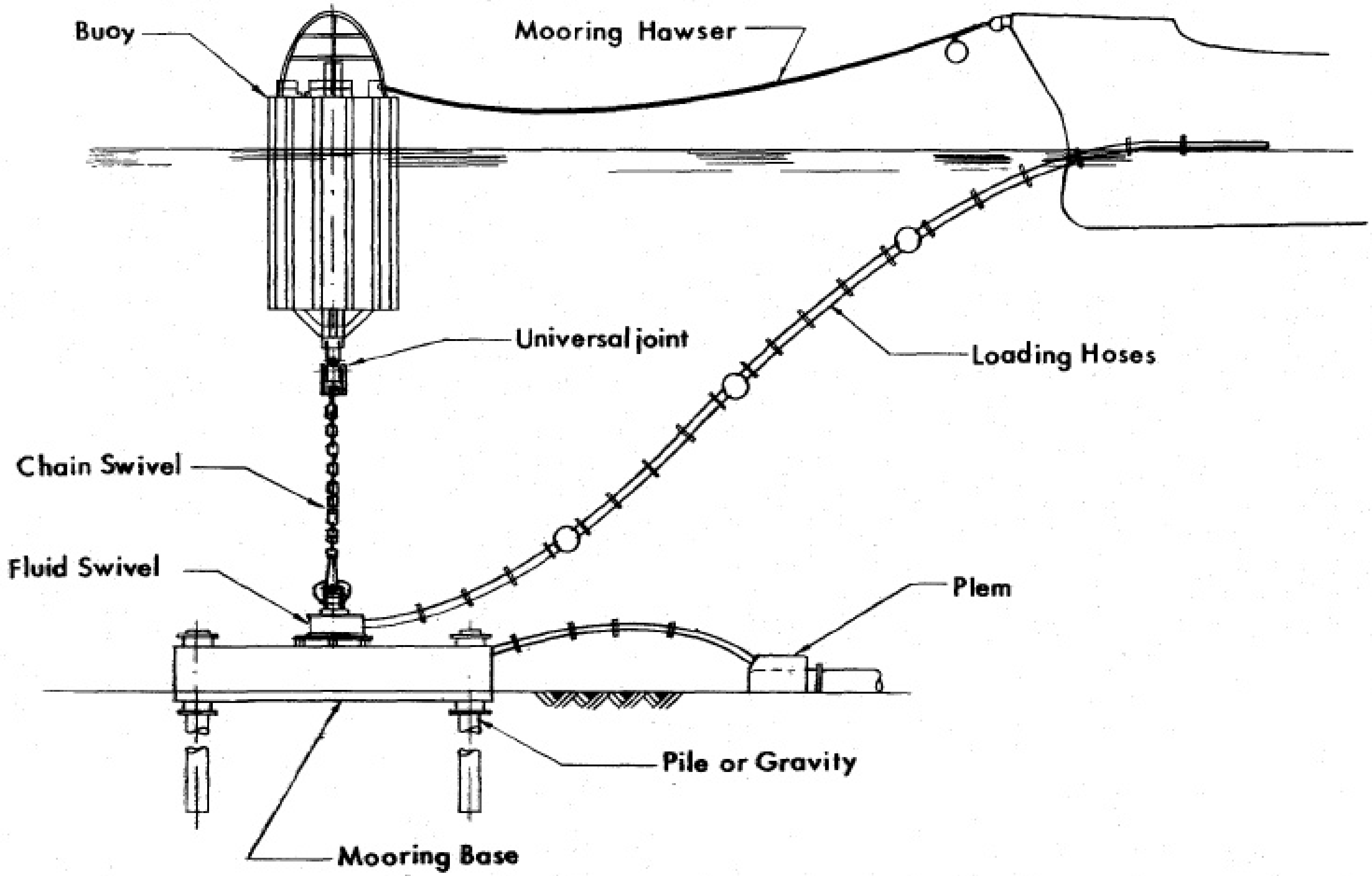


FIG-2 SHALLOW WATER SALM

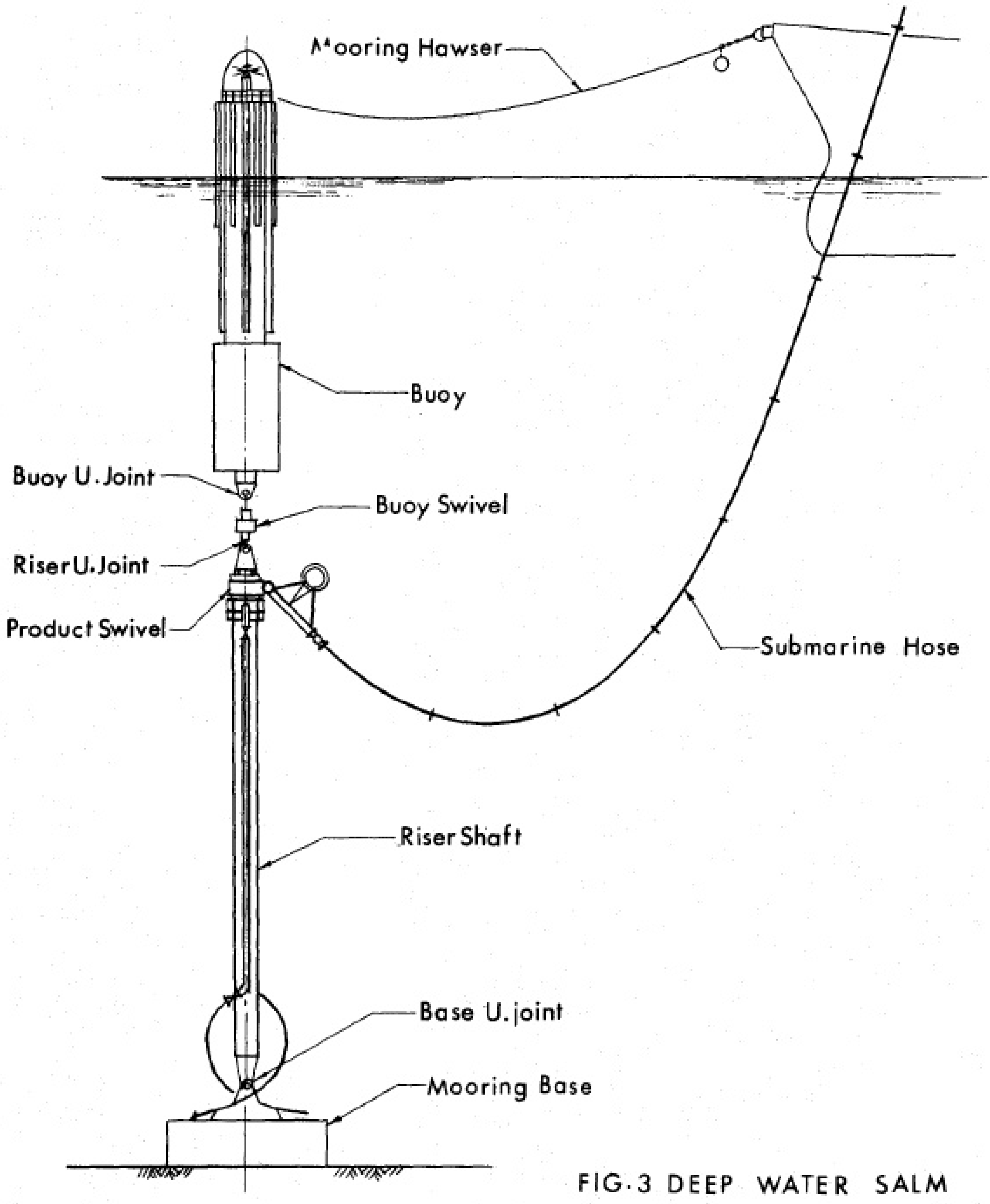


FIG. 3 DEEP WATER SALM

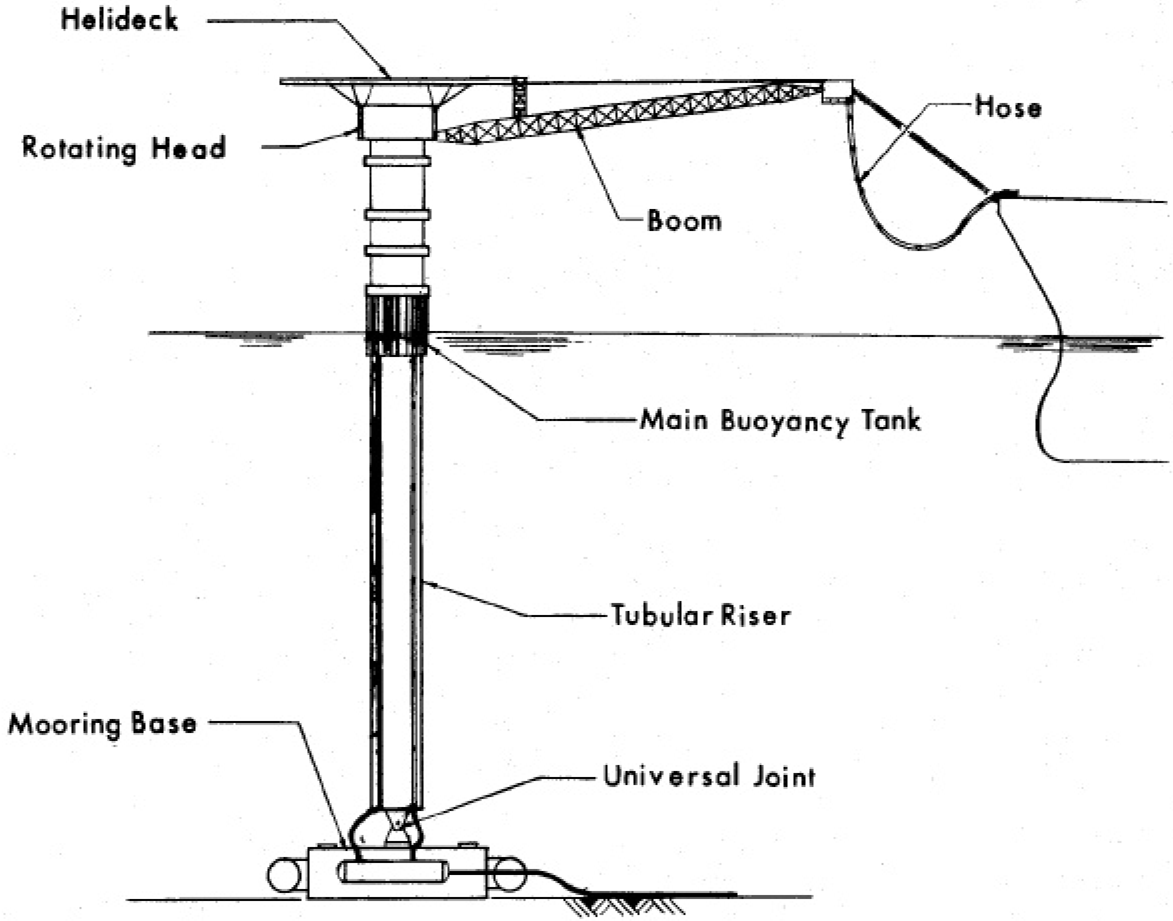


FIG.4 ARTICULATED LOADING TOWER

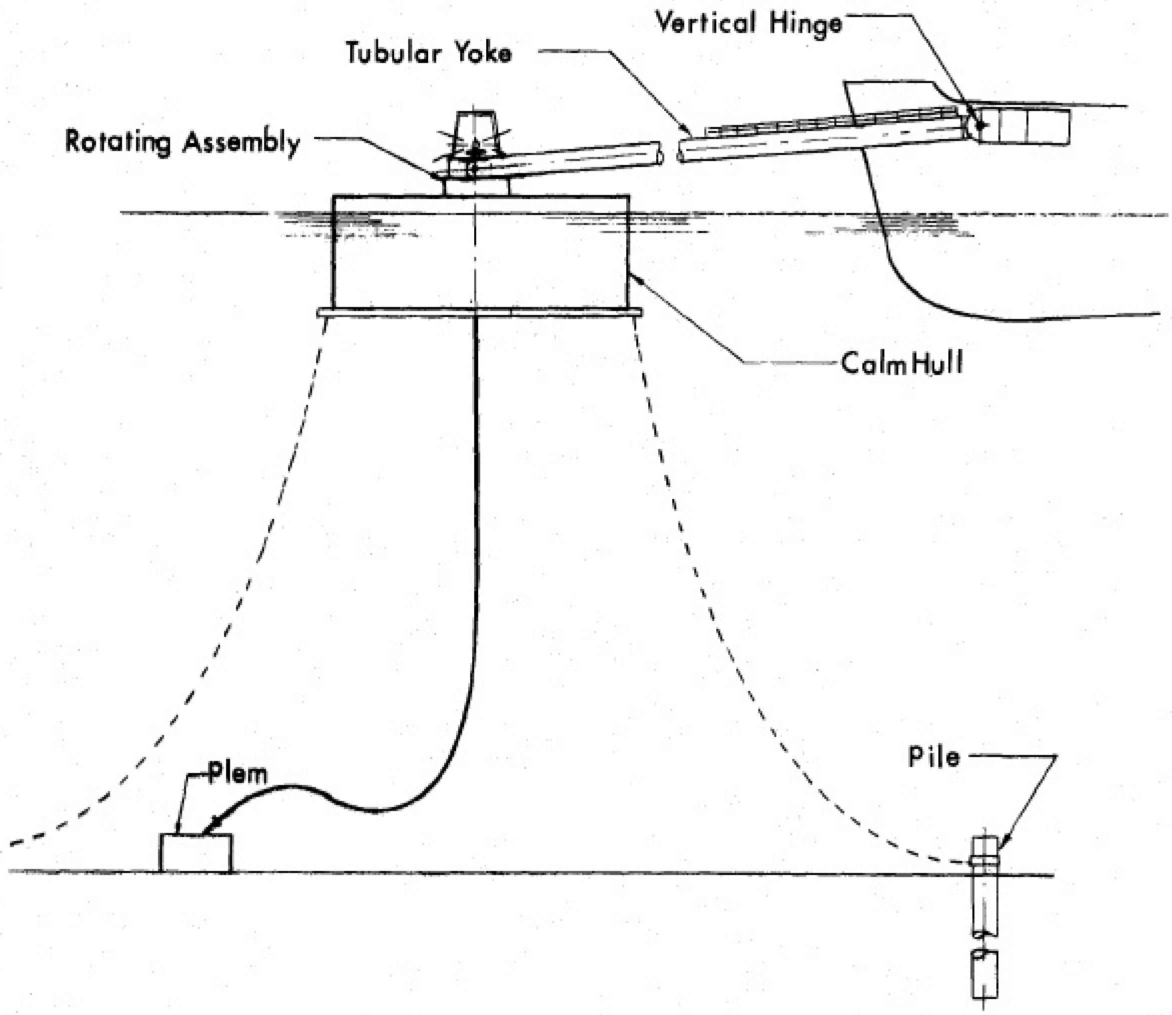


FIG.5 CALM — YOKE

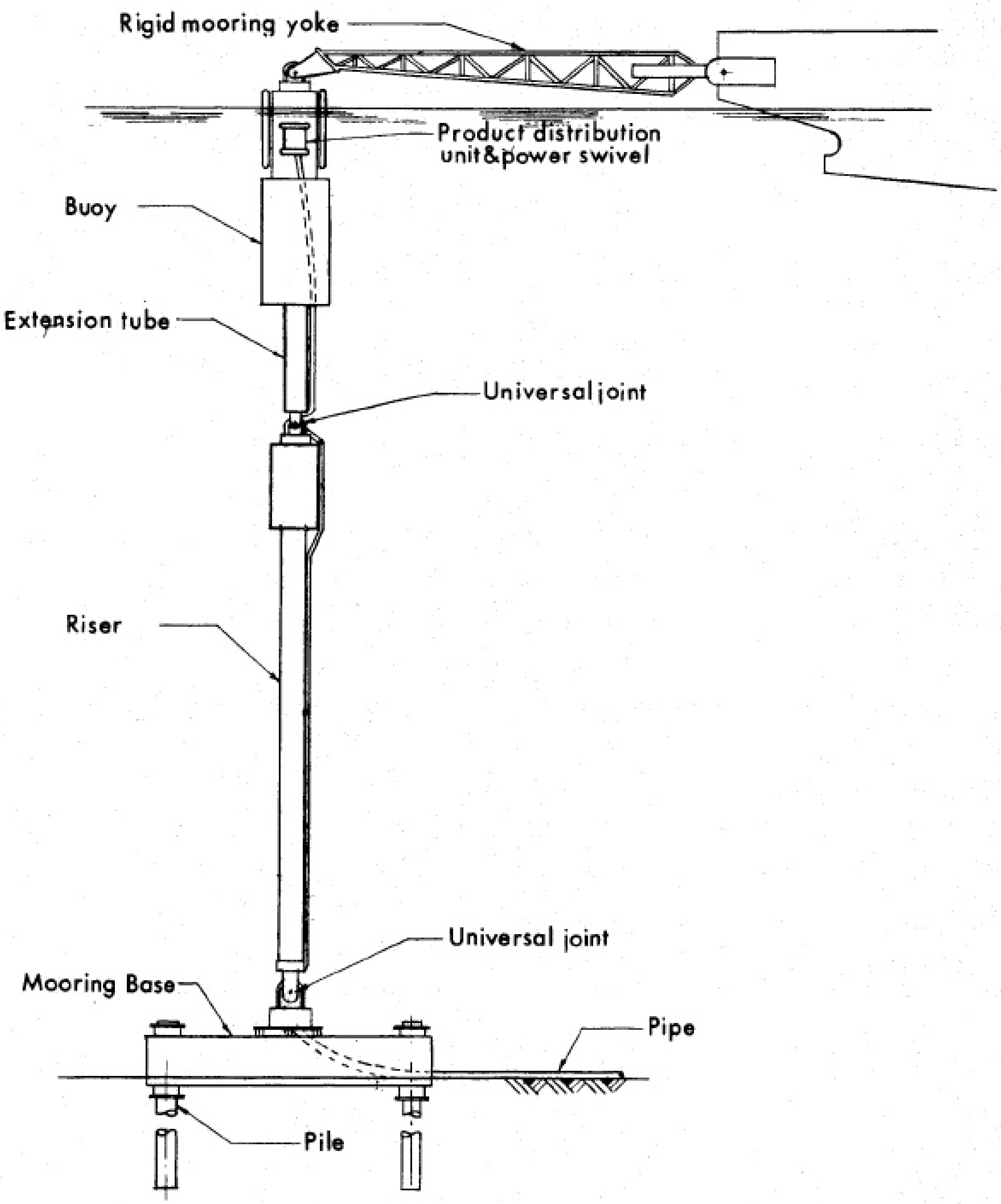


FIG. 6 SALM-YOKE DEEP WATER

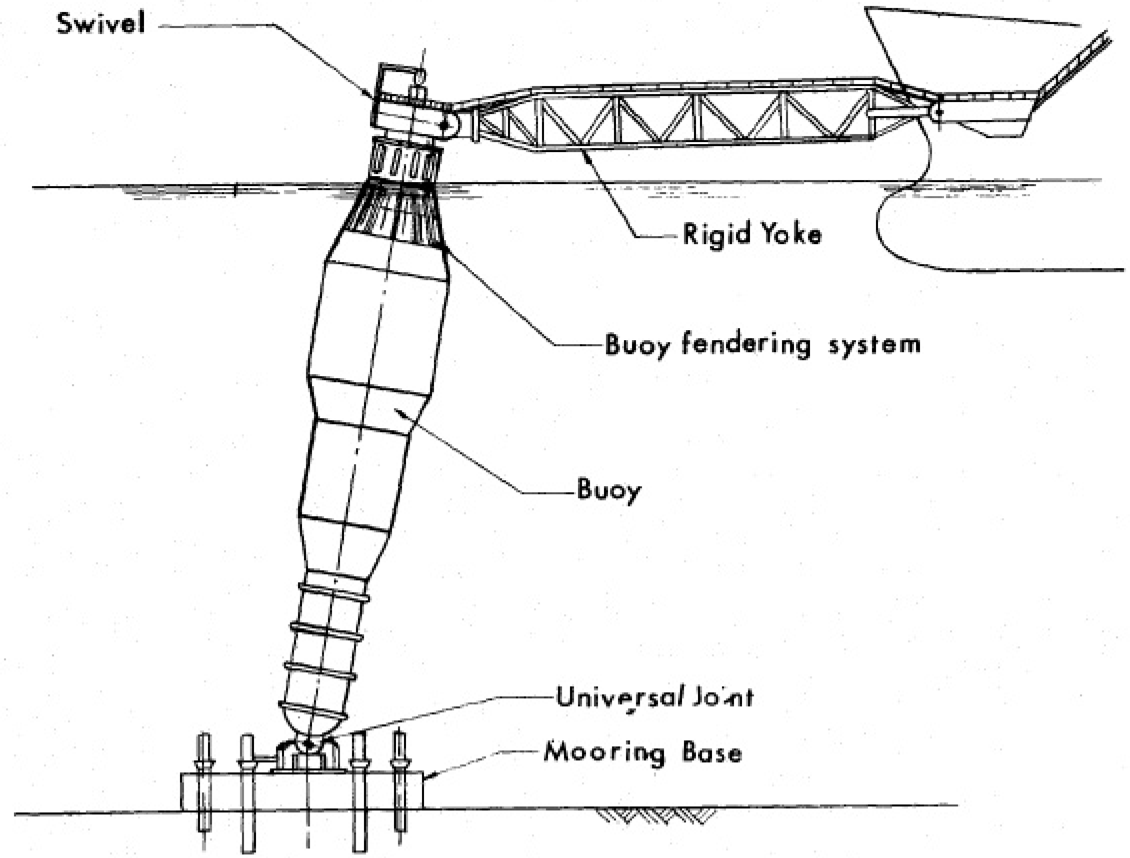


FIG.7 ALT.-YOKE

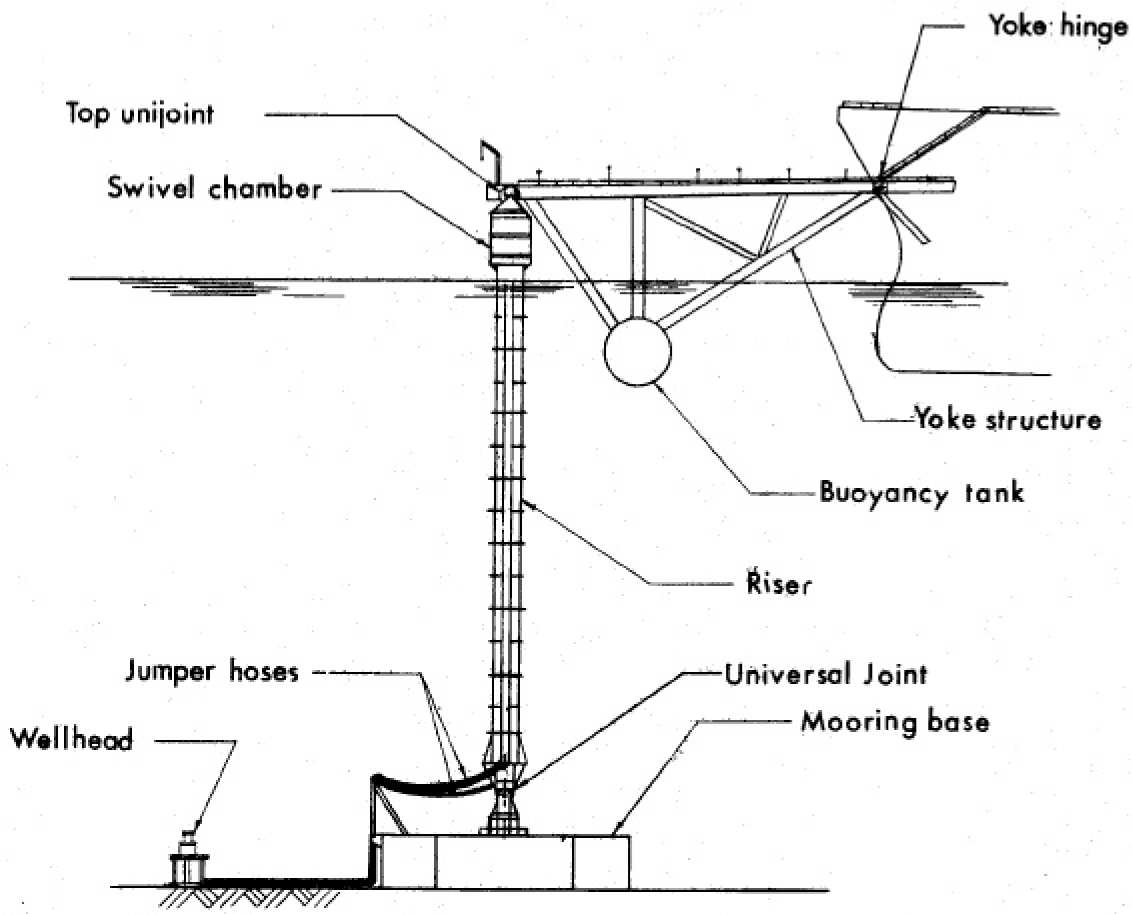
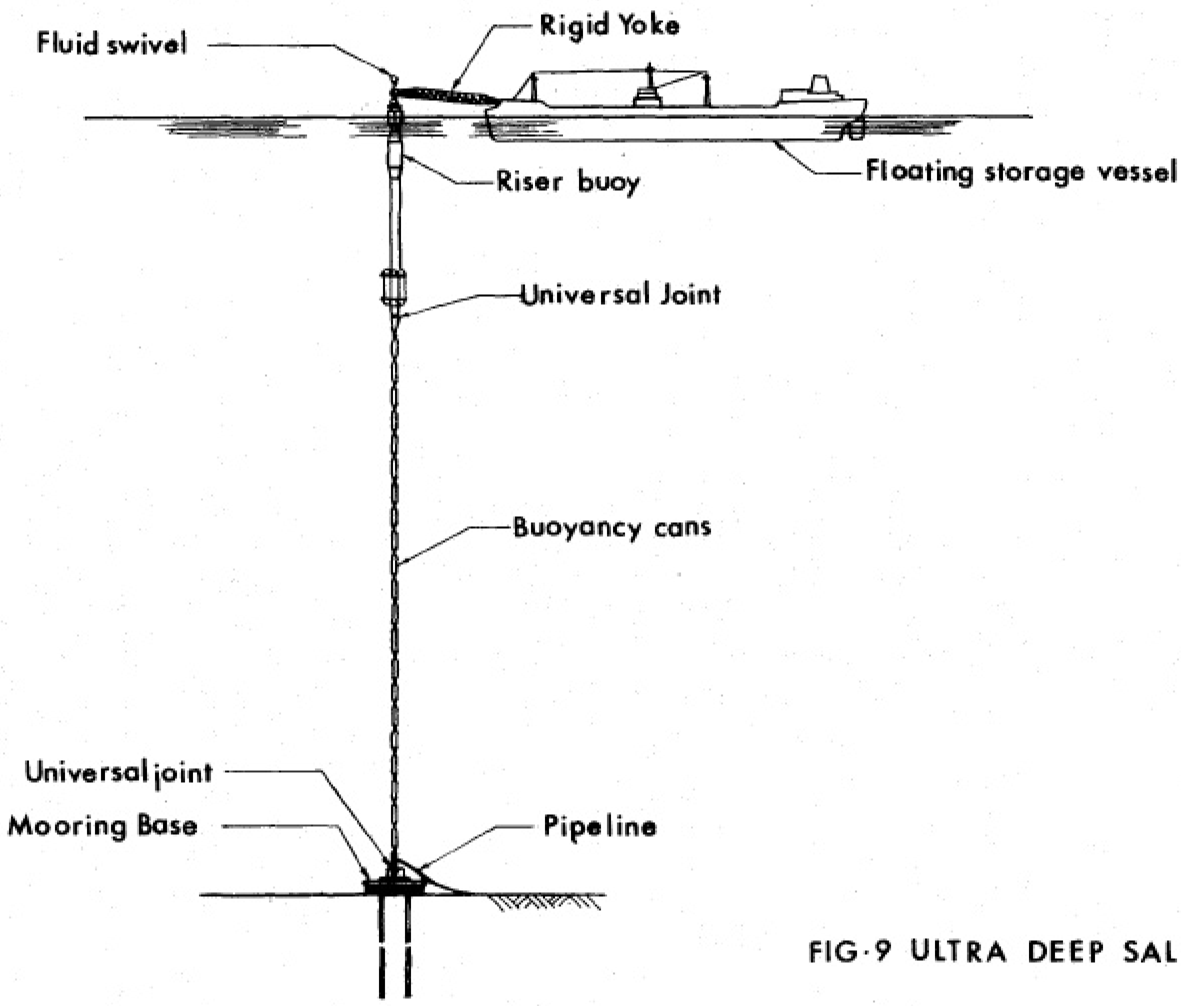

Yoke hinge
Top unijoint
Swivel chamber
Yoke structure
Buoyancy tank
Riser
Jumper hoses
Universal Joint
Mooring base
Wellhead

FIG. 8 - SALS



FIG·9 ULTRA DEEP SALM YOKE

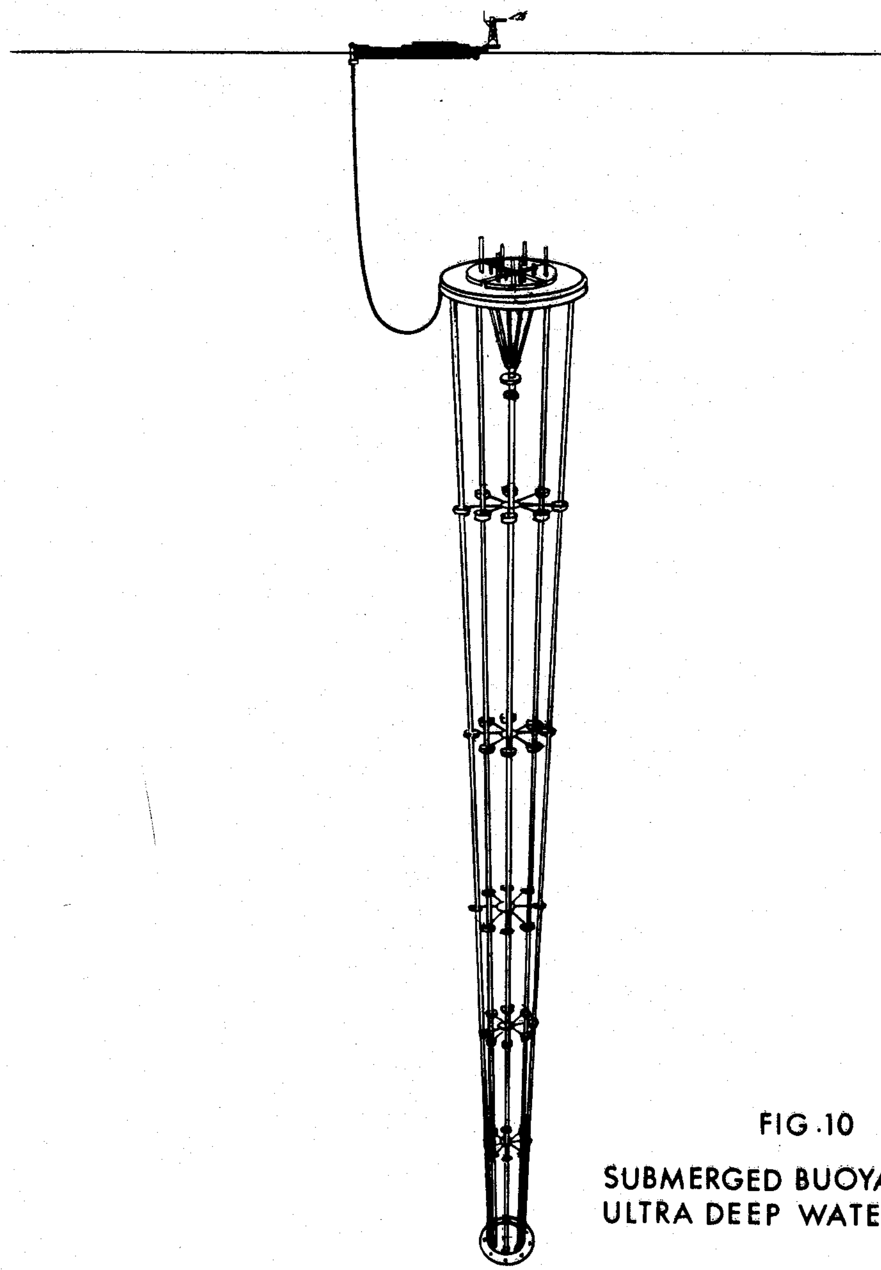
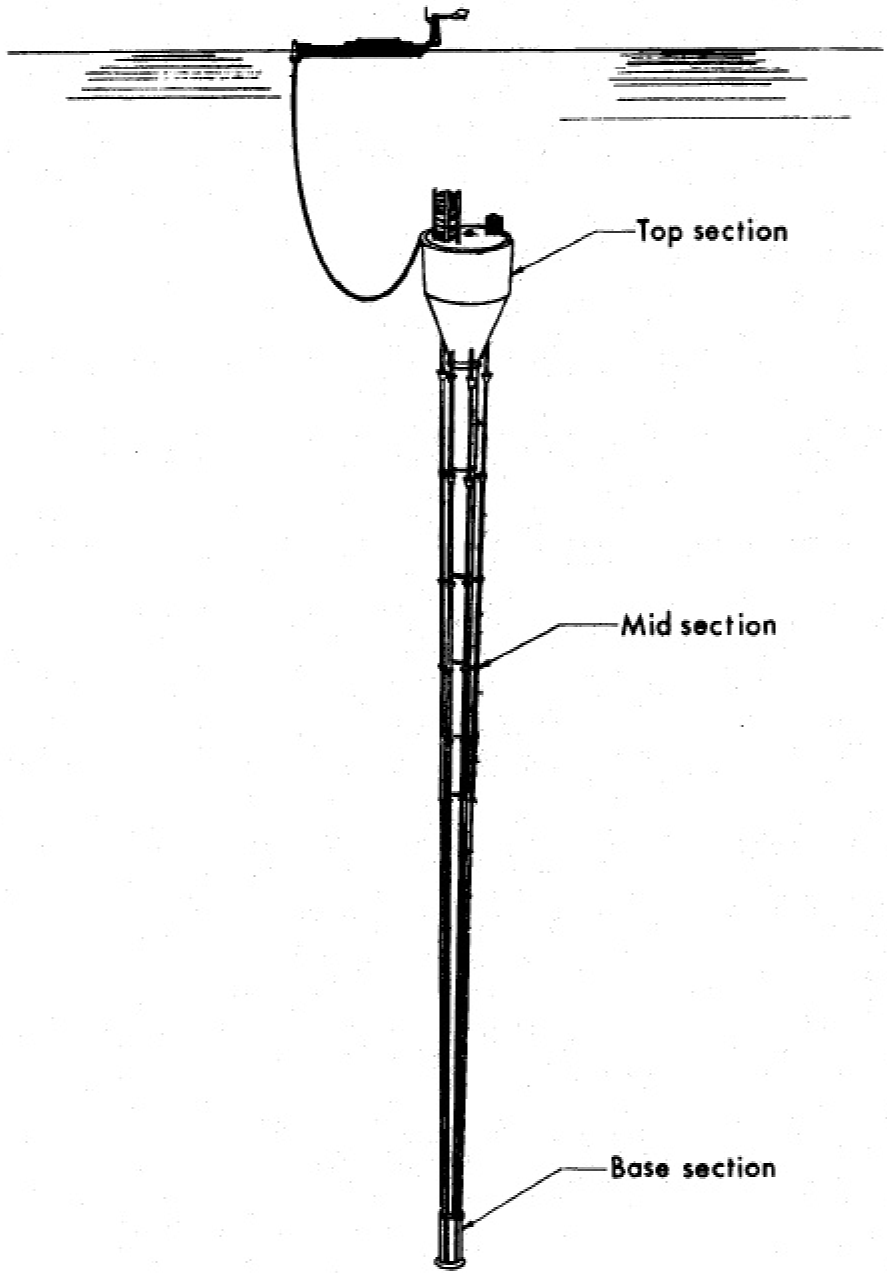


FIG.10

SUBMERGED BUOYANT TOWER FOR ULTRA DEEP WATER PRODUCTION



FIG·11 BUOYANT TOWER

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