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Installation, Testing, and Commissioning of a Disconnectable Turret Mooring for FSOU Vessel in a Typhoon-Prone Area

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ABSTRACT

A disconnectable turret mooring system and FSOU vessel have been installed for the LUFENG 13-1 Oil Field Development operated by JHN Oil Operating Co. in 142 meter water depth in the South China Sea. This facility is very unique by virtue of the tolerances maintained throughout the installation process, including high holding power anchor placement to final vertical and horizontal location of the combination steel and syntactic foam Spider Buoy. Adjustment of the anchor legs (combination chain-wire-excursion limiter-wire-chain) to compensate for variances in the individual anchor drag distances is discussed with recommendations given for consideration in preparing geotechnical survey specifications for areas where the soils characteristics are lesser known. Adaptation of equipment to the methods needed to perform the weather sensitive installation are discussed.

INTRODUCTION/OPERATIONAL SCENARIO

JHN Oil Operating Company specified a tanker based, floating storage and offloading unit (FSOU) for installation in the Lufeng 13-1 Oil Field in the South China Sea, located approximately 100 miles ESE of Hong Kong, and lying in 142 m(meters) of water. A 124,000 DWT tanker was selected and purchased by JHN for conversion into the self propelled FSOU, NANHAI SHENGKAI. MODEC, Inc. was awarded the conversion contract with SOFEC, Inc. awarded the design of the disconnectable turret mooring system. Refurbishment of the tanker began in August of 1992. In December 1992 conversion of the tanker began with installation of the "on-vessel" mooring equipment accomplished during April-July 1993. Installation of the "off-vessel" mooring components, Spider Buoy and Riser was done on location concurrently with the shipyard installation of the "on-vessel" turret mooring system.

References, tables and figures at end of paper.

The specification for the disconnectable system required the FSOU to be capable of remaining moored unless threatened by an imminent typhoon. Evaluation of normal winter monsoon storm conditions required a mooring system to be designed to remain connected up to an 8 m significant sea state.

With the FSOU disconnected, the "off-vessel" mooring components were required to survive a 14.4 m significant sea state.

In event of a typhoon exceeding the connected design basis, the disconnection sea state of 7.4 m significant was chosen.

Typhoon activity at the FSOU site is primarily in the August through October time frame. However, typhoon activity in winter, during the typical monsoon storm season, has occurred six times in the past fifty years. Therefore, to minimize loss of production following a possible winter disconnect, the re-connection sea state of 3.5 m significant was selected.

Operational states of the FSOU can be differentiated into four distinct modes:

1. The primary operational state, which also incorporates the offloading event, is to be moored, riser connected and receiving produced oil. In the prime typhoon weather window the FSOU propulsion system can be operational in 12 hours.

2. During disconnection preparation, production is stopped. The FSOU is prepared to sail. The riser is flushed, disconnected, and stowed. The operational status of the mooring disconnection system is verified.

3. Disconnected and sailing is the survival operational state. The FSOU is actively avoiding the path of the typhoon by seeking deep water out of the track of the typhoon.

4. During recovery/re-connection, the FSOU returns to the mooring site and the re-connection mooring system is prepared for Spider Buoy recovery. The floating retrieval rope of the submerged Spider Buoy is recovered to the forecastle of the FSOU resulting in temporary mooring.

The turret re-connection equipment is rigged, and the Spider Buoy is recovered to the turret of the FSOU. Upon completion of the mechanical mooring re-connection, the riser is recovered and re-connected. Transfer of produced crude oil to the FSOU storage tanks is resumed and the "on-vessel" mooring components are prepared for the next disconnection.

DESCRIPTION OF "OFF-VESSEL" MOORING SYSTEM

The "off-vessel" part of the mooring system as illustrated in Figure 1 consists of a Spider Buoy and eight composite anchor legs secured to the sea floor by high holding capacity drag anchors. Each anchor leg is composed of wire rope and anchor chain as indicated.

The largest single component of the "off-vessel" part of the mooring system is the Spider Buoy. This combination steel frame and syntactic foam structure is the major interface between the on-vessel part of the turret mooring system and the catenary anchor legs. The upper center part is fitted with a mechanical hub for attachment to the large hydraulically powered collet connector in the turret. Around the lower outside of this 10.3 m diameter and 8.0 m tall buoy are the eight chain support assemblies that provide the mechanical means of attaching each of the eight catenary anchor legs to the trunnion mounted and freely pivoting chain support assemblies. A riser guide and support tube is incorporated in the Spider Buoy to interface the 152 mm diameter insulated flexible riser. Additionally, the Spider Buoy supports the retrieval chain assembly and shock absorber assembly which are connected to the retrieval line to be deployed during disconnection to facilitate Spider Buoy recovery/re-connection operations.

DESCRIPTION OF "ON-VESSEL" MOORING SYSTEM

The most significant component of the "on-vessel" portion of the disconnectable turret mooring system mounted permanently to the FSOU during its conversion in Singapore is the turret shaft. This component is the main structural member of the SPM (Single Point Mooring) providing the means to efficiently transfer mooring loads from the ship's structure to the mooring system via the dual bearing assemblies. Refer to Figure 2. The turret is supported near the main deck by the upper bearing assembly, utilizing a three row roller bearing to provide radial, thrust, and moment load transfer. The turret is radially restrained near the keel of the FSOU by the lower bearing assemblies, utilizing self aligning, segmented permanently lubricated bushings. The upper and lower bearing assemblies provide the capability for the FSOU to weathervane through a full 360 degree continuous rotation and align with the prevailing wind, wave and current conditions.

Transfer of mooring loads to the vessel and the capability to re-connect/disconnect is made possible by key mechanical components mounted on the turret. The top of the Spider Buoy is gripped and preloaded against the turret shaft by the hydraulically powered connector assembly and connector tensioner assembly, respectively. Water seals close the boundary at the turret to Spider Buoy interface and allow water trapped in the base of the turret to be pumped overboard after a re-connection has been completed. This feature provides a dry interior of the turret to facilitate inspection, access and maintenance. The pipe deck structure, located atop the turret and supported by the vessel structure, supports the Artemis mast, a material handling monorail trolley/hoist, and means for personnel access. The swivel support structure, mounted atop the turret shaft, supports the swivel stack assembly composed of an air swivel, electrical swivel and product swivel.

Ancillary subsystems are supplied on the turret shaft primarily to support the Spider Buoy and riser disconnection and re-connection activities. The major categories of ancillary subsystems are: electrical power, electrical instrumentation, electrical lighting, dewatering system, ventilation system, and hydraulic power and control system. Major elements of the hydraulic power system are the 450 metric ton capacity chain jack, 150 metric ton capacity winch, riser handling winch and the turret drive system used during re-connection to align the turret to the Spider Buoy while the FSOU heading is determined by surface conditions. Other subsystems on the turret are provided to support maintenance of all equipment. These subsystems are: air (pneumatic) power and control system, connector handling system and lubrication system.

SUMMARY OF SYSTEM PERFORMANCE CHARACTERISTICS

The design of a disconnectable mooring system is far more complicated than a conventional mooring system. In addition to survivability with a vessel attached, the system must also survive typhoon waves and current without the vessel attached. There is a delicate balance that must be achieved between both conditions. Additionally, consideration must be given to the forces associated with disconnect and re-connect of the vessel.

When disconnected the Spider Buoy descends to a level 30.5 m below the surface. In this disconnected condition the mooring is designed to survive a 14.4 m significant sea and a 2.4 m/s current. Horizontal and vertical force deflection characteristics and additional discussion of system design can be found in Reference 1.

Generally the mooring system for a disconnectable SPM system must satisfy two functional configurations with different and sometimes opposing operating constraints. With the FSOU connected, the system must provide proper restoring characteristics per the functional and regulatory requirements for the system. When the FSOU is disconnected, the system must balance the Spider Buoy both vertically and horizontally at a predetermined equilibrium position which is optimum for minimizing wave induced motions and forces, Spider Buoy design head, wire laydown at the dip zone, Spider Buoy recovery pull-in loads, and providing proper riser motion performance.

In addition to mooring design considerations, there are hydrodynamic loading constraints on the size and configuration of the Spider Buoy, both connected and disconnected, which limit the scope of anchor leg arrangement variations available for consideration.

SITE GEOTECHNICAL CHARACTERISTICS AND INSTALLATION IMPACT

The development site is located in the Pearl River Mouth Basin of the South China Sea. The seabed conditions at the site were determined based on geophysical and geotechnical investigations performed by Fugro McClelland during September 1990. These investigations included a survey of the proposed FSOU site and the proposed site of the production facility, a steel jacket platform located approximately 1800 m SSE of the proposed FSOU site.

The geophysical survey of the FSOU site included echo sounding, side-scan sonar and seismic reflection profiling. The geotechnical survey at the FSOU site included 3 CPT (Cone Penetrometer Tests) borings and 2 sampling borings. Two CPT plus two sampling borings were located on the preliminary anchor radius and one CPT boring near the proposed FSOU center.

The soils at the FSOU site are complex. In general the top soil is a loose / very loose to dense calcareous sand with significant amounts of silt and clay particles at varying depths. It is noteworthy that both the geotechnical and geophysical surveys classified the upper 7 to 10 m of soil as a sand with soft to firm silty clay below. For anchor design, phi angles were determined from the two sample borings based on laboratory tests.

Sandwaves were encountered over much of the survey area having a mean amplitude of 1 to 1.5 m. Due to the relatively short duration of the investigation, it was not concluded if the sandwaves are active. The geotechnical results indicate that the surface soils are predominantly loose fine to medium calcareous sands with numerous fine to coarse shells and shell fragments. Results of the geophysical survey suggest that these sands extend to depths of at least 6 m before encountering a soft clay stratum that was also identified in the soil borings.

Carbonate content tests were not conducted for the sample borings at the FSOU site. Carbonate content was inferred based on testing of samples from the platform site. These tests indicated carbonate content of 15 to 30% from 3 to 20 m depth. In the upper 3 m, carbonate content of 65% was measured. Based on these results, the predominately granular strata were classified as calcareous. A significant variation in CPT values was noted across the FSOU site indicating that although uniformly stratified, the soils are not homogenous.

The fluke angle for a drag anchor is typically preset in consideration of the soil type expected. A fluke angle which is suitable for sand may not penetrate into a clayey strata and vice versa. Therefore, it was decided to design the anchors to embed and remain in the sandy strata above the clay. In an effort to minimize drag length, a larger than required anchor size was chosen with steel ballast added to the flukes.

The geotechnical characteristics determine the anchor design and ultimately the anchor behavior. System performance is dependent on final anchor position. The anchor drag performance must be predictable within the window of available anchor leg length adjustment and in consideration of the positioning system accuracy.

Based on experience drawn during the anchor installation for this project, some recommended requirements for geotechnical and geophysical investigations for future similar projects are noted below:

• The number of soil borings must be adequate to clearly describe the realm of soil strata over the anchor radius. The actual number of borings may be influenced by the consistency and quality of the initial boring results and the knowledge of the soils in the region. Borings should be targeted at actual anchor locations. Drop core borings including CPT should be taken at all anchor locations which are not represented by a full boring.

• All boring locations should include both sample recovery borings as well as CPT borings. Over the assumed anchor penetration depth, the sampling frequency should not be less than every meter.

• Preliminary Index and classification tests should be conducted immediately upon sample recovery and included in the boring logs.

• If there is any indication of carbonate content over 10 to 15%, investigation of cementation is required. Potential light cementation, which may be broken during sampling and hence undetected, may skew the CPT results and should be carefully considered. Photomicrographs and X-Ray Diffraction analysis may be considered to determine the origins and likely behavior of the carbonate particles. Investigation of the crushing resistance of the carbonate material is recommended. Considerable judgement is required in determining appropriate in-situ phi angles for calcareous sands.

• The geophysical survey must be correlated to the geotechnical data. The survey area must cover the entire mooring area. Survey lines should intersect two or more borings to facilitate correlation.

• Full scale anchor performance testing may be warranted in some cases. Offshore scale model testing may be of value although caution is required in stratified soils. Laboratory scale model testing results for a specific site should be used with discretion.

INSTALLING AND PROOFLOADING THE ANCHOR LEGS

The installation spread provided by the Installation Contractor, Clough Stena (Asia) Joint Venture (CSJV) for the mooring installation phase included the following major equipment:

• Dynamically Positioned (DP) Dive Support Vessel (DSV), with complete Surface and Saturation Diving Facilities, and 84 metric ton revolving deck crane.

• 300 ft. Cargo Barge
• 6,000 BHP Anchor Handling Vessel (AHV)
• Crawler Crane
• ROV Spread with 100% Spare
• Acoustic Positioning Spread
• Deck mounted deployment/retrieval/tensioning system

For anchor leg deployment and proofloading operations, the cargo barge was moored alongside the DSV as shown in Figure 3. Arrangement of the major equipment items is also illustrated. The spread was capable of carrying the anchor leg components for all eight legs plus the Riser and related equipment.

The AHV was primarily used as a tow tug for the cargo barge when severe weather conditions required the barge to be released from the DSV.

All anchor leg handling operations were conducted from the deck of the cargo barge with the DSV providing stationkeeping and maneuvering capability. This arrangement, as designed by CSJV, worked very well although it was somewhat sensitive to weather. It is believed that the high degree of maneuverability and absence of barge related anchor handling more than compensated for weather related downtime.

The pre-installed and calibrated positioning system included an array of transponders which covered the entire mooring area. Communication with the transponders directly from the cargo barge was provided. At least one transponder was arranged outside the anchor setdown radius and inline with each anchor leg to provide for anchor drag monitoring.

The ROV system was located at the aft end of the cargo barge and away from the DSV. This location allowed maximum ROV excursion from the point of anchor leg deployment and monitoring of all items during lowering.

The deck mounted pulling system, designed and fabricated by CSJV, generally consisted of a fixed chain stopper/wire gripper assembly at the overboarding gypsy wheel and a mobile chain stopper/wire gripper assembly. By traversing along the deck of the barge, the mobile assembly could deploy, retrieve or apply proofload tension. The fixed assembly allowed restroking of the mobile assembly. An A-Frame above the gypsy wheel assisted anchor handling, wire rope spelter overboarding, and excursion limiter handling.

CSJV had loaded out all anchor leg components onto the barge or DSV deck prior to mobilization. The anchors had been assembled with a fluke angle of 30°. The excursion limiters had also been assembled.

Anchor leg deployment was completed during May / June 1993 including the following major activities:

- Anchor deployment and setdown
- 890 m Wire Rope deployment
- 50 m Excursion Limiter Assembly deployment
- 130 m Dip Zone Chain deployment
- Anchor proofloading
- 115 m Wire Rope deployment
- 4 m Chain deployment
- Pennant Buoy attachment and abandonment

The anchor legs were laid in opposing pairs and proofloaded prior to laying of the next pair. Although deviation was allowed due to prevailing weather, the deployment order was specified based on the directionality of the FSOU design environmental conditions. Anchors which were oriented into the least severe design environment were laid first so that experience gained could be applied to the more highly loaded anchors. Anchor legs #1 and #5 were deployed first.

The target setdown box for the anchors was ±2 m radially and ± 8.75 m perpendicular to the anchor leg radius. The anchor was rigged with a transponder which could be remotely released. In addition, the ROV was equipped with a transponder. Contrasting paint marks were applied to the anchors to aid the ROV in monitoring the setdown and in confirming correct orientation.

The available adjustment in the anchor leg length as noted in Figure 1 is 20 m. The 20 m of Ø127 mm chain was manufactured together with the 110 m of Ø102 mm chain as a single 130 m length. The setdown position was determined in consideration of the minimum predicted anchor drag length. Therefore, the available adjustment was +0/-20 m. The predicted anchor drag length envelope, i.e. maximum (18 m) minus minimum (10.8 m) prediction, was less than 8 m. The provided adjustment length was 150% in excess of the calculated requirement.

The anchor deployment operation began with lifting and layout of the 45 m chain section on the barge deck with one end at the gypsy wheel. The end of the first 890 m wire was reeved around a turning sheave on deck and connected to the end of the chain section. The mobile wire gripper was engaged onto the wire. A bridled tag line was connected to the back of the twin anchor shanks. The crawler crane lifted the anchor upside down and suspended it at the gypsy wheel. The anchor was connected to the chain end and lowered over the gypsy wheel so that its weight was supported by the mobile wire gripper. A transponder was attached to the anchor and the crane released.

The chain length was measured on deck under a slight tension prior to its overboarding. Similarly, all chain sections were measured and recorded. When the end of the 45 m chain was reached, the A-frame was used to support the chain/anchor weight using a modified spelter pin arrangement designed and supplied by CSJV. At every spelter overboarding, this arrangement was used to avoid bending the wire rope at the spelter termination. A transponder was attached at the chain / wire connection.

The anchor tag line was run from the bow of the barge and served to control the attitude and orientation of the anchor at setdown. The anchor was lowered until it was just above the seabed. The ROV monitored the anchor descent. The survey team directed the maneuvering of the DSV to guide the anchor to its target position. After setdown, the survey team confirmed the position and the ROV provided visual confirmation of the anchor attitude and orientation. The setdown target tolerances were easily achieved at each setdown.

With the survey team guiding the DSV, the wire was laid on line swiftly using the gripper system. The ROV monitored all lay operations. When the end of the wire was reached the fixed gripper was used to support the wire end.

The excursion limiter was then flaked out on deck by the crawler crane and connected to the end of the wire. The excursion limiter was clamped into the mobile chain stopper and the wire spelter overboarded as before. The A-frame was also required to assist in the excursion limiter overboarding.

The 130 m Dip Zone chain was flaked out on deck by the crawler crane and pulled in place for connection to the limiter end. This connection was made using a Ø127 mm Kenter shackle. To provide a reference point in the anchor leg nearer to SPM center, a transponder was attached at the Kenter shackle at overboarding. The Dip Zone chain was then deployed.

To avoid anchor uplift during proofloading, additional weight chain was suspended from the Dip Zone chain at the adjustment length section. At the end of the Dip Zone chain, CSJV installed lengths of temporary pulling chain for the proofloading operation. The first leg was buoyed off.

The opposing anchor leg was then laid in the same manner up to and including the deployment of temporary proofloading chain. The end of the second leg's proofload chain was attached to the stern of the barge via a connection arrangement designed by CSJV. This leg became the passive leg during proofloading.

The DSV/barge then recovered the end of the first leg temporary chain, the active leg, and began to apply load to the anchors. See Figure 4. A load cell was incorporated into the mobile stopper assembly which provided a signal to an onboard computer. The length of the active leg temporary chain on deck was measured at regular intervals. Knowing all lengths and weights plus the real time measured anchor drag and deck load, CSJV had developed software to calculate loads at the anchors.

During the first proofload operation, both anchors had dragged in excess of the maximum predicted drag length at only 70% of the minimum required proofload. The anchors would build up load and then drag suddenly several meters with a corresponding decrease in load. Due to the total drag experienced and the anchor behavior, the proofload operation was abandoned.

Both anchors were buoyed off and a ROV survey of each was conducted. Anchor #5 had penetrated much more than #1. Following the survey, anchor #1 was recovered with minimal pullout resistance. Anchor recovery required complete retrieval of the anchor leg.

To maximize anchor drag allowance the theoretical SPM center was shifted toward anchor #1 in consideration of the current position of anchor #5. Flowline length was considered in this decision. The laptop Macintosh-based onboard analytical capability greatly facilitated these decisions.

Inspection of a large sample of soil from the fluketips of anchor #1 indicated a significant quantity of shells and shell fragments. Judging by feel, the soil appeared to have some cohesive strength. From this inspection and because the soil at anchor #1 clearly was not performing as predicted for a predominantly sandy soil, it was decided to reset the fluke angle to 40° and to topple the anchor after setdown to ensure that the fluke tips would begin to penetrate immediately.

Anchor #1 was redeployed considering the revised theoretical SPM center and the proofload operation was restarted four days after abandonment of the first attempt, including weather downtime. The proofload was successfully completed in less than four hours with anchor #5 experiencing essentially zero additional drag and anchor #1 experiencing 12.8 m drag.

The transponder at the 45 m chain/890 m wire connection was used as a reference to monitor anchor drag. After completion of proofloading, the survey team reported the coordinates of this transponder and the transponder at the Kenter shackle connection. The ROV confirmed the Kenter position. Based on the known line lengths plus predicted wire stretch, these two positions on each anchor leg were correlated. Required anchor leg length adjustments were calculated based on these positions.

Anchor legs #1 and #5 were then adjusted as required, finally deployed, and laid back away from SPM center.

Based on the success of anchor #1, it was hoped the remaining six anchors would similarly perform well with a 40° fluke angle and toppling after setdown. Anchor legs #4 and #8 were next deployed with fluke angles reset to 40°. Upon proofloading, both anchors performed very well up to 80% proofload prior to experiencing "slips" of as much as 19 m.

This type of behavior was repeated in three of the final four anchors. The fourth, anchor #2, performed quite the opposite and in fact did not reach the minimum predicted drag length at a load 30% in excess of the minimum required proofload. However, onboard analysis showed that anchor #2 was within the tolerance allowed for system performance.

Anchor #2 was near to a CPT boring which had indicated a more dense sand strata. However, anchor #1 was even nearer to this boring and behaved completely opposite. In almost every case, correlation of the anchor performances with the nearest boring, whether sample or CPT boring, was not possible. Thus it was difficult to gain empirical knowledge to apply to the expected drag lengths although it was possible to learn how the anchors behaved in general. The DSV/barge pulling spread capabilities were sufficiently flexible that the pulling procedure could be tailored in response to the anchor behavior.

Proofloading from the surface using the DSV/barge spread provided the capability to apply differential load to the anchors during proofloading. To accomplish this differential, the DSV thrust alone or in combination with one or two tugs connected to the barge was used. The AHV served as one tug. The remaining tug, when required was borrowed from the nearby production platform. Differential loading was used to allow selected anchors to soak while applying more load to the opposing anchor.

Other advantages of the pulling spread were the load cell feedback and very fine control of the pulling load and speed. The sampling frequency of the load cell was variable and could be set to show or to filter out wave frequency load variations. The spread also had the apability to apply more than the minimum required roofload which proved valuable.

uture installation spreads should consider incorporating ie capability to retrieve and reset anchors without equiring recovery and redeployment of the anchor leg.

Onboard analytical capability is particularly useful in roviding necessary information for decision making and in rocessing survey data quickly. The ability to analyze the ntire system based on intermediate as-built data provides high degree of confidence in the installation and permits nodifications to the installation procedures and tolerances.

number of reasons have been proposed to explain the nexpectedly poor anchor performance. It was universally greed that the phi angles reported for the strata described s sandy were overly optimistic. Another possible reason s that the anchor may have reached the clayey layer and ien "skated" causing the sudden slippages. Another ieory is that the calcareous content in the upper strata aused the "slips". These carbonate particles may have rushed under the anchor loading causing the soil to lose trength rapidly. In any event, this experience illustrates ie importance of a comprehensive and thorough eotechnical survey of a mooring site, particularly in emote, lesser known areas.

RANSPORTATION AND CONNECTION OF SPIDER UOY

he Spider Buoy was fabricated and the syntactic foam istalled in Tsuneishi, Japan. It was then transported to long Kong via Heavy Lift Vessel and offloaded in Hong ong harbor. The Spider Buoy was safely secured to a iooring buoy in the harbor and monitored continuously.

owing padeyes, bridles and navigation aids were itegrated into the design of the Spider Buoy for the tow om Hong Kong harbor to the FSOU site. In addition, all istallation aids which were required for the offshore istallation were pre-installed. The approximate tow istance was 150 nautical miles.

he Spider Buoy was also outfitted with twenty-four each im weights which could be distributed around its perimeter adjust trim or added/removed to adjust final depth. iitially, twenty weights, each having a wet weight of pproximately 1 metric ton were installed.

fter towing to site, the Spider Buoy was pulled alongside ie DSV port side and moored between the DSV and tug. he Spider Buoy was located down-current from the DSV ith the tug assisting to maintain Spider Buoy/DSV separation as shown in Figure 5. The initial Spider Buoy freeboard was approximately 1.2 m.

At final deployment, the 115 m wires and 4 m chains had been abandoned using segmented pull-in lines as a part of the pennant lines. The Spider Buoy connection phase included retrieval of these pennant lines and subsequent pull-in of the anchor legs. The segmented pull-in lines allowed alternate stroking to accommodate the available lift height and capacity of the DSV crane and to minimize the intermediate Spider Buoy inclinations.

A surface diving spread was deployed to assist in the rigging and subsequent pull-in and connection of the anchor legs. The pre-rigged pull-in messenger lines were routed through the anchor leg chain support hawse pipes and secured to the Spider Buoy at hang-off hooks above the chain supports.

The initial sequence of anchor leg pull-in was dependent on the Spider Buoy tow bridle arrangement to avoid tug or DSV interference; not dependent on prevailing weather. The AHV retrieved the pennant line for anchor leg #4 up to the pull-in pennants onto its deck and approached the DSV port side sternfirst. The DSV crane then passed the pre-rigged messenger line to the AHV deck crew. The AHV crew connected the messenger line to the upper end of the segmented pull-in line and deployed this connection over the stern roller using a remote released hook. Using the crane line, attached by divers, the messenger/pennant line was pulled through the chain support assembly until the upper pennant was hung off resulting in Spider Buoy heel and a slight decrease in freeboard. Thus, the anchor leg #4 pull-in pennants were hung off on the Spider Buoy.

While the DSV crane pulled in the #4 pennant, the AHV maneuvered to and recovered the pennants for the opposing anchor leg #8. As before, the AHV approached sternfirst and received the messenger line for leg #8. The hook-up proceeded as before until leg #8 upper pennant wire was hung off. The Spider Buoy heel was decreased to near zero and the freeboard decreased.

Using the same procedures, legs #2 and #6 were pulled in and hung off on the upper pennants. With four legs hung off on pennants, the Spider Buoy Tow Tug was released but continued to stand by. The remaining four legs were pulled in and hung off using the same procedures. With all eight legs hung off on pennants, the Spider Buoy was storm safe and the Tow Tug was demobilized. At this time, the remaining Spider Buoy freeboard was less than 0.5 m.

The Spider Buoy was now ready for stroking down in stages to its final depth. Each stage is represented by pull-in and hang off of one segment of the three segment pennants. During the Stage 1 pull-in of the first pennant segments, the Spider Buoy became awash and then submerged.

At the end of Stage 2, each leg was hung off on a single 13 m pennant plus a final grommet at the chain end. The DSV/Spider Buoy mooring lines were disconnected. The top of the Spider Buoy had submerged to 16 m depth allowing more freedom of orientation and movement for the DSV above. Prior to start of Stage 3, the divers were placed into saturation and the diving bell was deployed.

The Stage 3 pull-ins were completed in less than eleven hours including approximately three hours dedicated to air diver decompression and bell deployment.

The final pull-in required a very short pull distance until the diver could install the chain stopper clamp which was pre-rigged for diver access. Due to DSV motion and potential friction between the chain and chain support, air bags were available for lift assistance in the event the lift was too great for the DSV crane. The air bags were not required. The final pull-ins required approximately twelve hours including one hour awaiting passage of a Soliton and one hour for bell retrieval and redeployment for diver change.

The Spider Buoy depth and trim were then checked. The trim was zero and the depth to the top of the Spider Buoy was 35.5 m compared to a final target depth of 30.5 m. Several factors contributed to the deeper Spider Buoy submergence. Firstly, a very large protective cover plate and riser pull-in bellmouth remained on the Spider Buoy which would be later removed. Secondly, the elastic stretch which had been locked into the 890 m ground wires during proofloading had been relieved during anchor leg adjustment and layback. Consequently, the anchor leg loads at pull-in were insufficient to re-establish this stretch. The magnitude of this stretch component was computed to be equivalent to a future decrease in Spider Buoy depth of 2.5 m. This decrease would be expected after a few loadings on each leg with the FSOU connected. Other contributing factors include variation in actual anchor leg component weights and buoyancies, variation in Spider net buoyancy, and local water depth variations at the anchor leg touchdown points.

Based on the expected Spider Buoy rise of 2.5 m explained above, trim weights were removed until the Spider Buoy top depth was 33 m. Trim ballast weights were removed in groups of four and the depth rechecked until a total of twelve weights had been removed. The final Spider Buoy depth was measured to be 33.1 m. The depth and attitude, at each check, were determined using the divers pneumo line to measure the depth at eight locations around the top of the Spider Buoy.

The horizontal coordinates of the Spider Buoy center were determined by suspending a transponder from the Spider. The as-installed position is less than 0.5 m from the target theoretical center.

It is noted that the Spider Buoy depth was rechecked during a survey a few months after commissioning of the system and the Spider Buoy had risen to its target depth of 30.5 m.

RISER INSTALLATION

The scope of the Riser installation phase included:

- Pull through and support of Riser at Spider Buoy
- Lay flexible Riser
- Deploy Mid Depth Buoy (MDB) with Clumpweight and Tether Line
- Connect Flowline to Flexible Riser
- Lay Flowline to Jacket and Tie-in
- Hydrotest Line and Pig

Also included were some repairs to the Jacket bellmouth and a video survey of the system. Saturation divers assisted as required in these activities.

In order to accommodate the DSV crane lift capacity, the Installation Contractor designed a 3-piece clumpweight on behalf of the Riser supplier. The clumpweight consisted of a ballast frame and two ballast weights.

Prior to lifting, the clumpweight ballast frame was fitted with two Compatt transponders to aid frame positioning and orientation. The ballast frame was deployed with the DSV crane Subsequently, the two ballast weights were individually lowered onto the ballast frame.

The operation of threading the Riser through the submerged Spider Buoy from a floating vessel required careful planning to avoid damaging the Riser. It was important to control the vessel position relative to the Spider and the deployed Riser length to maintain an acceptable catenary in the Riser. To minimize exposure, it was critical to hang off the Riser in the Spider as quickly as possible. The Spider was pre-rigged with a messenger line through the Riser guide tube and a temporary bellmouth at the lower guide tube end. A temporary installation stopper which could be slipped around the Riser and seated into the top of the guide tube by diver was supplied to facilitate temporary hang off of the Riser.

The Riser was equipped with a temporary pulling head able to pass through the Spider guide tube. Clamps were utilized to position the Bending Stiffener so that it would not contact the temporary bellmouth at initial pull through but would be near to its mating flange after Riser hang off.

On the DSV, the Mid-Depth Buoy (MDB) was arranged above the overboarding chute for the Riser/Flowline deployment. Initially, the Mid-Depth Buoy served as a chute for the Riser until MDB deployment.

With the DSV positioned a predetermined distance from the Spider Buoy, the crane wire was lowered and connected to the upper end of the Spider pull-through messenger line. The Riser was deployed until the lower end of the messenger line could be diver connected to the Riser pulling head. Payout of Riser and lift of Riser through the Spider was performed in increments with divers and ROV monitoring. See Figure 6.

When the Riser had been pulled through the Spider a short distance, the diver installed the temporary installation stopper and a hang off clamp onto the pulling head. The Riser was lowered and supported by the clamp/stopper arrangement and the crane line released. The temporary bellmouth was removed and the Bending Stiffener bolted into place.

The Riser was then attached to the MDB prior to deployment. To deploy the MDB, a floodable weight, designed by CSJV, was used to aid in MDB pull down and connection of the tether line to the clumpweight base.

Laying of the Riser continued up to the Riser/Flowline connection. The connection was then completed and nitrogen tested. A PLEM had not been required at this connection as the on bottom Flowline stability is adequate.

The Flowline was laid up to the platform bellmouth with adequate horizontal (U) curves to accommodate the platform pull-in length. The U-curve was lifted using a spreader beam during pull-in. After pigging of the platform J-tube and lifting of the U-curve, the platform pull-in was accomplished and the Flowline hung off at the J-tube top flange.

The Riser/Flowline system was hydrotested and finally ROV surveyed. For future systems having insulated Riser/Flowlines, it is recommended that careful planning be undertaken to consider the time required for the temperature inside and outside the Riser/Flowline to stabilize. Slow stabilization caused temperature induced pressure changes delaying successful completion of the hydrotest.

MOORING THE FSOU

The FSOU approached the vicinity of the moor and transitioned from sailing to adrift. While adrift, the FSOU captain assessed the direction of approach to the Spider Buoy; the deck crew keel hauled the turret recovery rope to the forecastle deck. The FSOU then slowly approached the Spider Buoy location. The ARTEMIS system provided real time location information for the FSOU in relation to the submerged Spider Buoy and assisted in the spotting of the 100 m of recovery rope on the ocean surface. The initial phase of re-connection therefore requires the grappling of the Spider Buoy floating recovery rope from the forecastle of the FSOU. The captain of the FSOU preferred the aid of a workboat and the passage of lines to facilitate recovery of the Spider Buoy recovery rope. Both methods were successfully used.

The recovery rope was grappled and retrieved by deck winch to a quick release hook on the port bow. The FSOU was allowed to moor by the bow. The deck crew installed the turret rope to the Spider Buoy rope connector. The quick release hook was energized and the FSOU was allowed to drift and moor by the turret. The recovery system is composed of soft line and stud link anchor chain. The soft line Spider Buoy retrieval winch then pulled the FSOU to the buoy. As loads increased in the recovery system the load was transferred to a chain jack. The winch was switched to light pull constant tension and the chain jack recovered the Spider Buoy to the turret base. Sensors and a video system indicated the condition and orientation of the Spider Buoy. The turret shaft was rotated relative to the buoy to align the riser hawse pipe. The chain jack pulled the Spider Buoy tightly against the turret base and the connector tensioner gripped the buoy, preloaded it against the turret base, and the connection was locked. The FSOU was moored.

The retrieval ropes and associated hardware were reconfigured for disconnection. This involved stowing the stud link anchor chain in the Spider Buoy centerwell and rope in a rope locker. The lower turret shaft was dewatered.

The end of the flexible riser was then retrieved to the winch deck of the turret from the Spider Buoy with a modified down hole tool and the riser retrieval winch. The product piping was made up to the riser. This completed the re-connection commissioning sequence.

Disconnection procedures were much simpler. The FSOU was prepared for sailing. The upper end of the riser was disconnected from the turret piping and stowed in the Spider Buoy. The turret was flooded and ball valves were set in position for use. Upon a signal from the bridge, which was monitoring the offset distance of the FSOU from the theoretical center of the mooring field, one hydraulic valve was activated and the Spider Buoy released. The FSOU was then free to sail from the site as the remaining retrieval line paid out of the turret. This completed the disconnection commissioning sequence.

ACCEPTANCE TESTING AND COMMISSIONING

To insure fully operational and proven components, equipment, and systems during the commissioning of the FSOU, a comprehensive program was established in addition to the standard SOFEC and ABS quality assurance and quality control program requirements. As new concepts for components were formalized, an in house systems analysis and performance risk assessment was conducted. Those concepts and items identified as possessing significant risk were either physically modeled or full scale tested to verify suitability. Each major equipment item in the connection/disconnection system was performance tested at the supplying vendor facility. Where feasible, complete subsystems were assembled for a performance test prior to overseas shipment to the conversion shipyard at Sembawang in Singapore.

A shipyard commissioning and testing checklist specification was prepared and used by MODEC, Inc. for each structural, mechanical, hydraulic, pneumatic, and electrical subsystem in the turret mooring system. Upon completion of installation of each subsystem, SOFEC, MODEC and ABS verified complete compliance with the commissioning specification.

Similarly, an offshore commissioning and testing checklist specification was created to verify the performance characteristics of the primary subsystems and operational procedures. In addition, any subsystems that could not be tested at the shipyard were included. Upon completion of the offshore commissioning checklist, the disconnectable turret mooring system was Classed **+A1** by ABS and accepted by JHN Oil Operating Company.

SUMMARY DURATIONS OF OFFSHORE INSTALLATION

The offshore mooring and riser installation began on 8 May and ended on 21 June 1993. Anchor leg deployment, including recovery and redeployment of leg #1, required 18.5 days. Anchor proofload operations required 4.5 days. Spider Buoy Hookup was completed in under 4 days including preparation time. The Riser/Flowline installation including pigging and hydrotesting required 6.25 days. Weather downtime was approximately 5.5 days. The remaining time was devoted to repairs to the production platform, travel to/from Hong Kong to receive the Flowline and minimal mechanical downtime.

With the arrival of the FSOU in the vicinity of the mooring site, final preparation and ROV inspection of the Spider Buoy was accomplished. Within the next six days, as suitable daylight sea conditions occurred, the commissioning of the disconnectable mooring system was completed.

During crew training on the system, procedures were refined, experience was acquired, equipment operation was verified, and all equipment had been removed from storage and prepositioned, a complete disconnection/re-connection cycle was completed in less than eight (8) hours total elapsed time. The following table depicts a comparison between initial and current elapsed times in hours for each phase of the cycle:

EVENT	INITIAL	CURRENT
Connection Preparation	6	4
Connection	6	2
Riser Recovery	5	1
Retrieval rope rigging	6	2
Disconnection Preparation	2	1
Riser Storage	4	1
Disconnection	0.3	0.3

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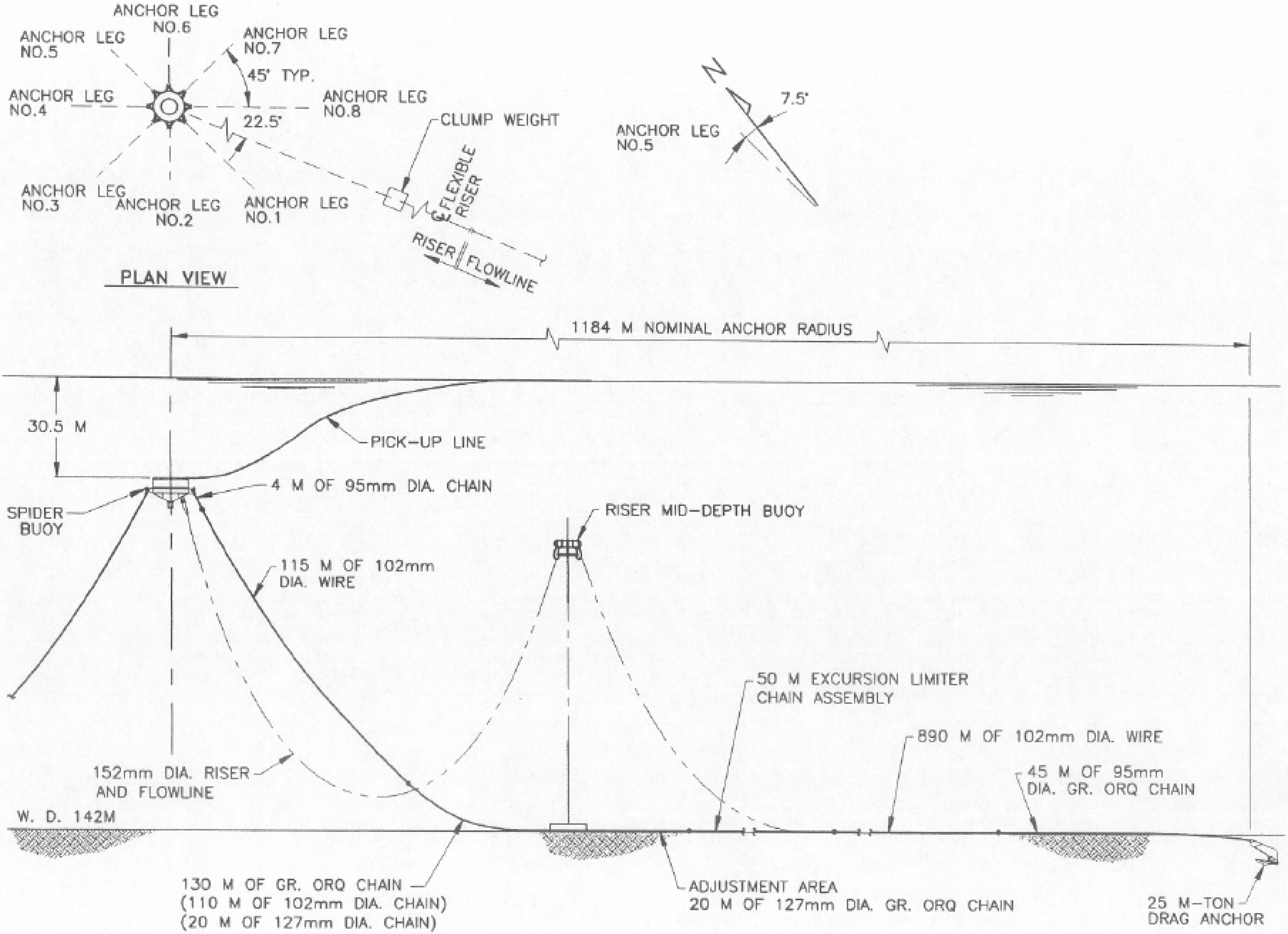

FIGURE 1 – ARRANGEMENT OF "OFF-VESSEL" MOORING SYSTEM

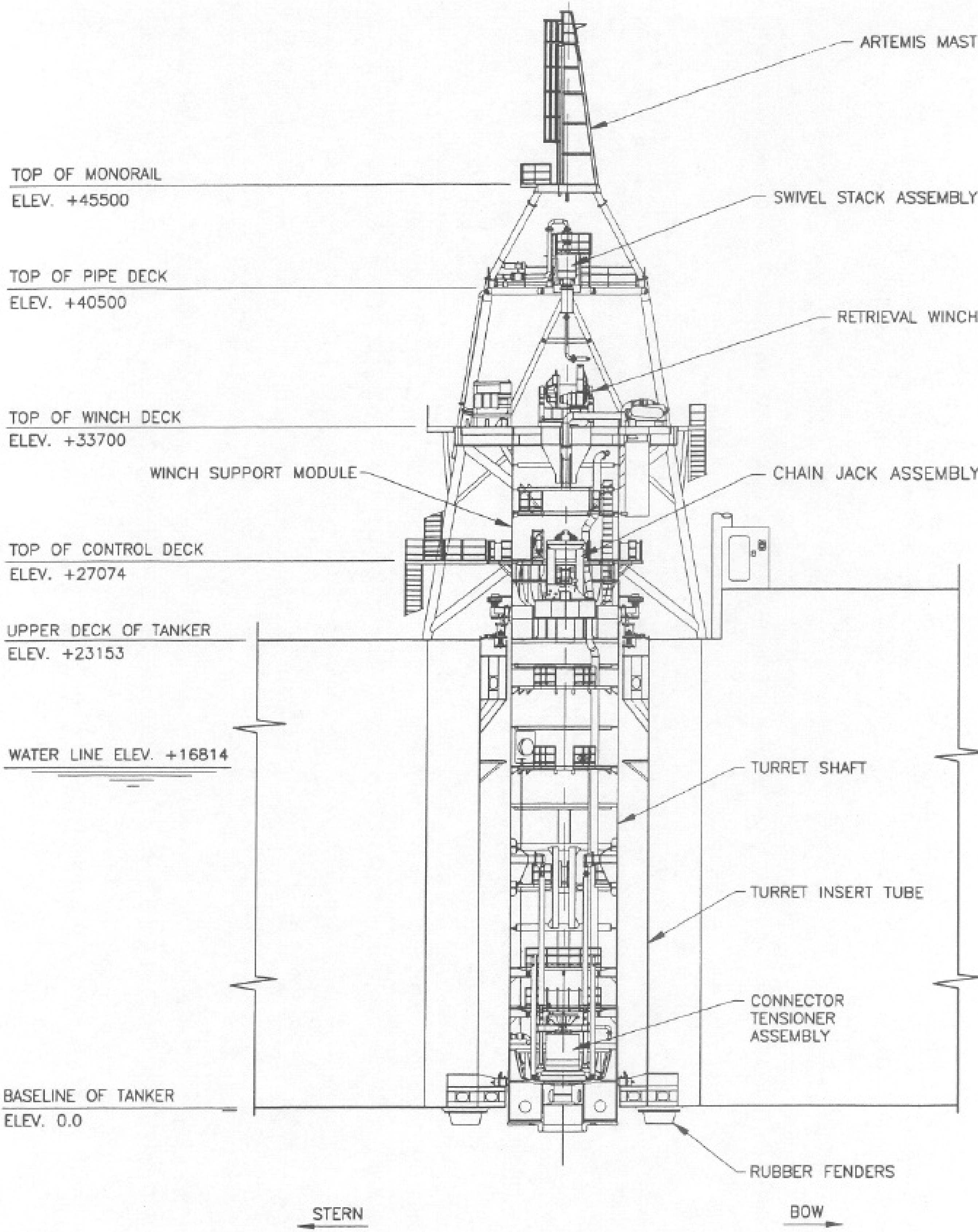

FIGURE 2 - ARRANGEMENT OF "ON-VESSEL" MOORING SYSTEM

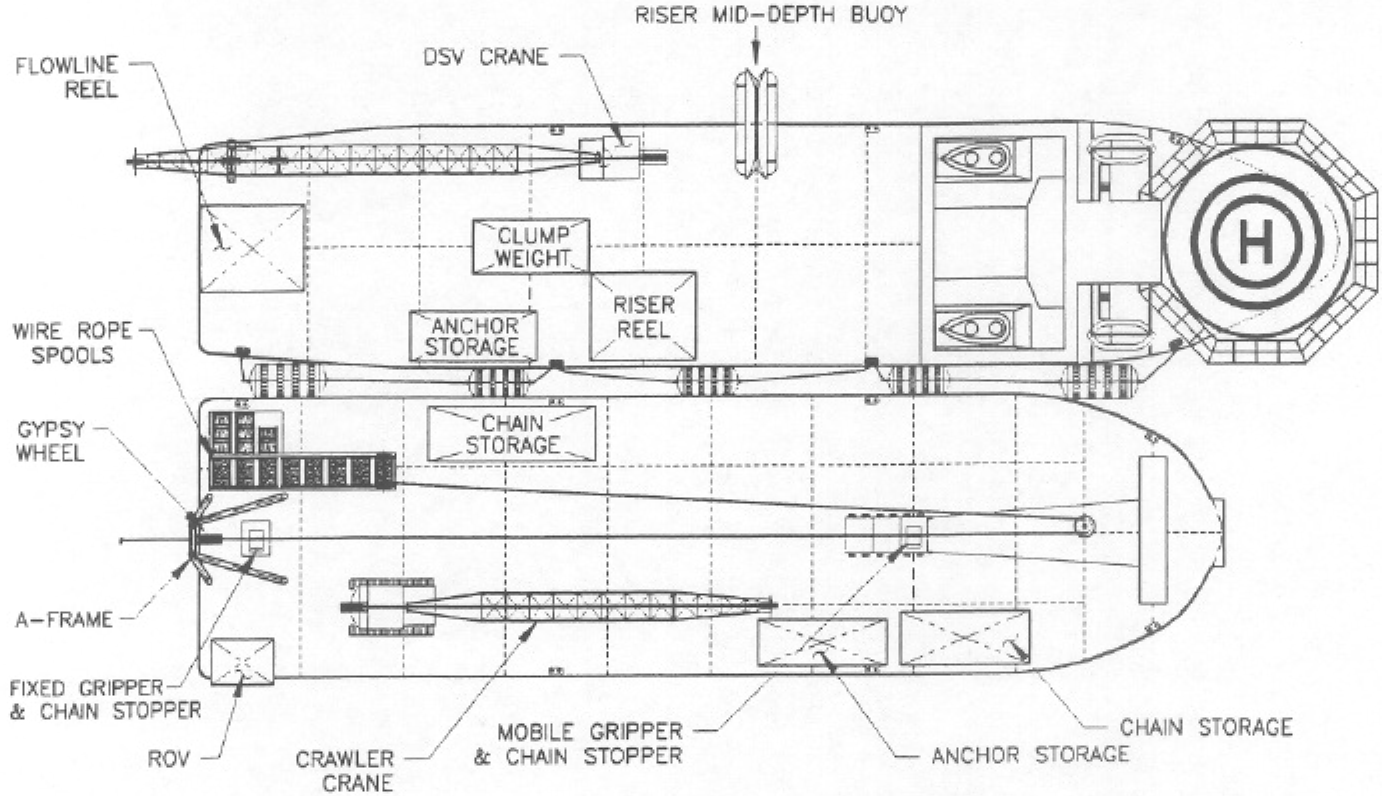

FIGURE 3 - DSV/CARGO BARGE ARRANGEMENT

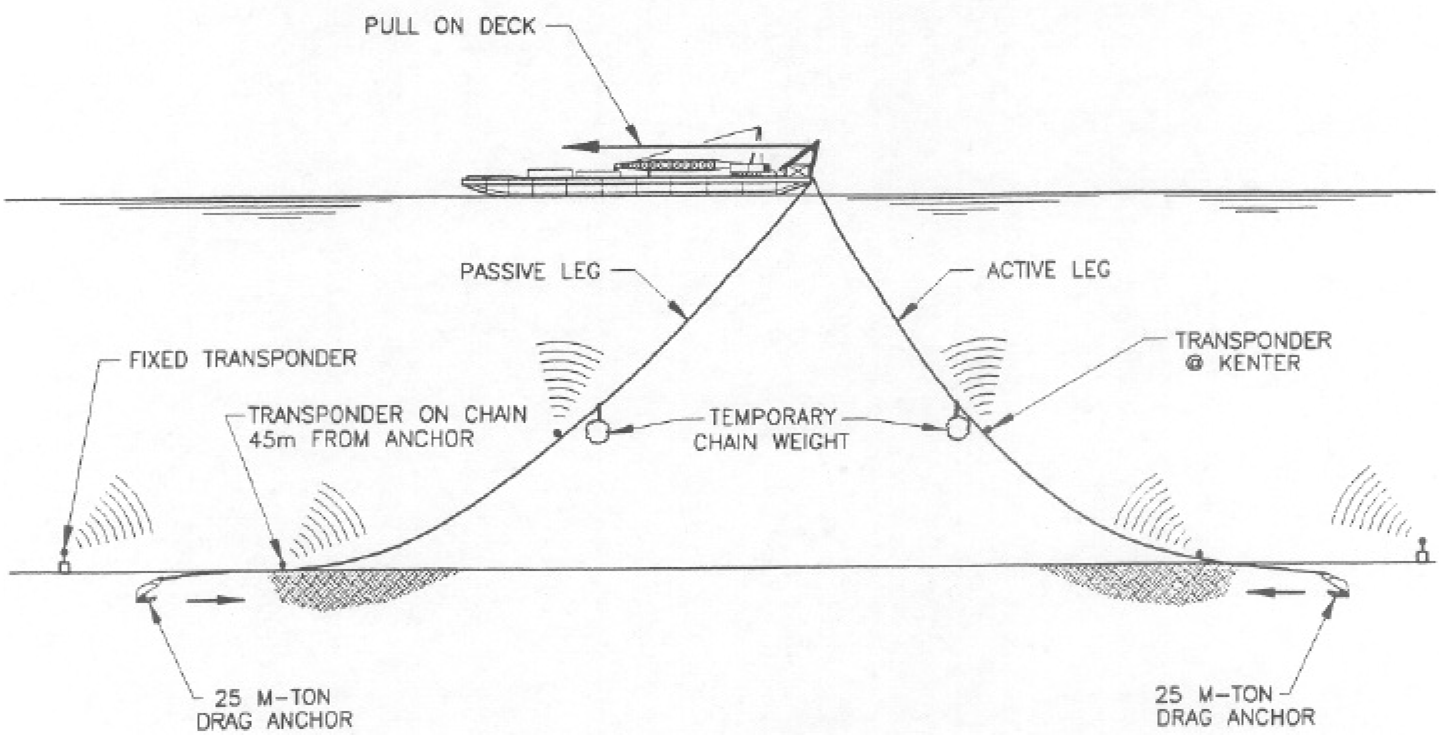

FIGURE 4 - GENERAL PROOFLOADING ARRANGEMENT

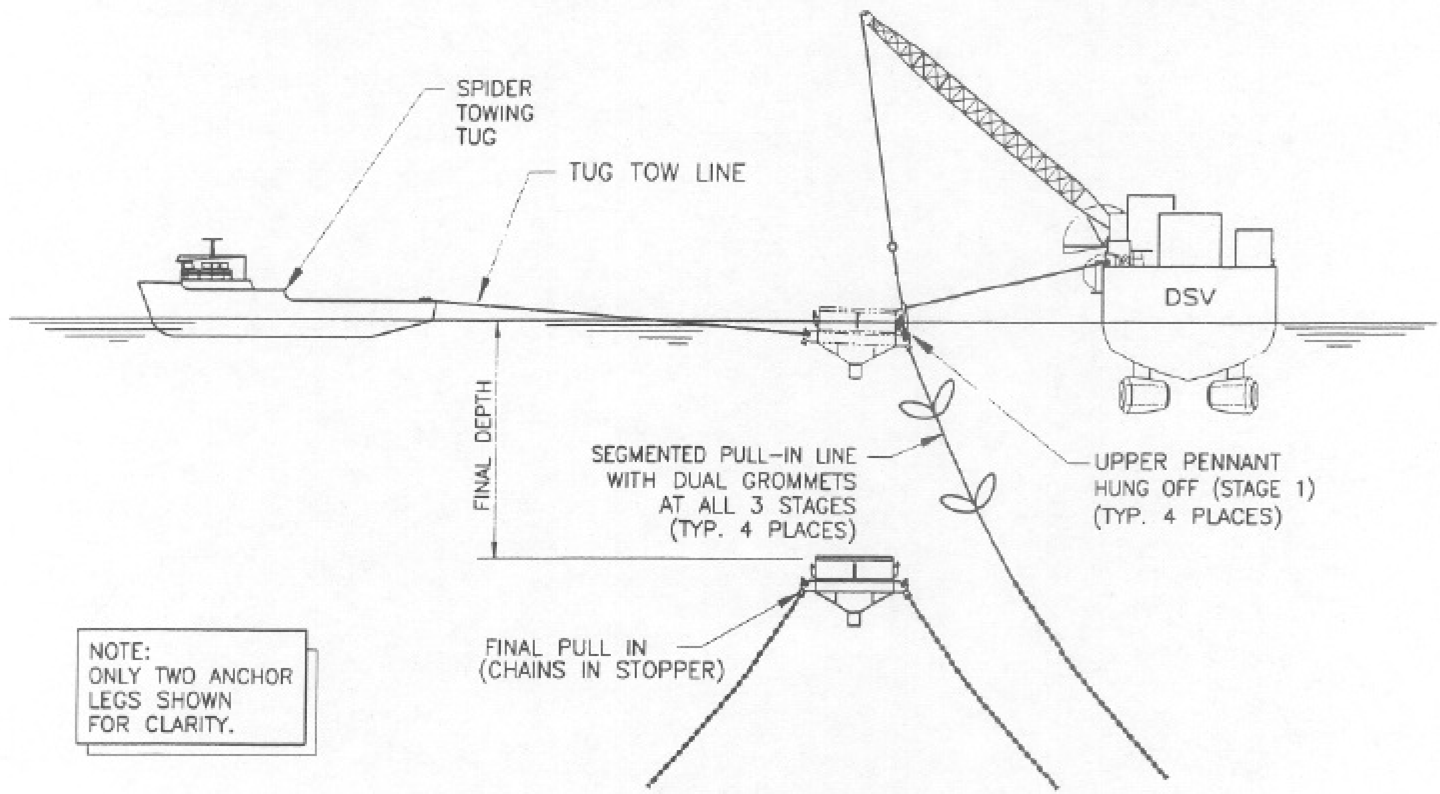

FIGURE 5 – BUOY/ANCHOR CHAIN HOOKUP

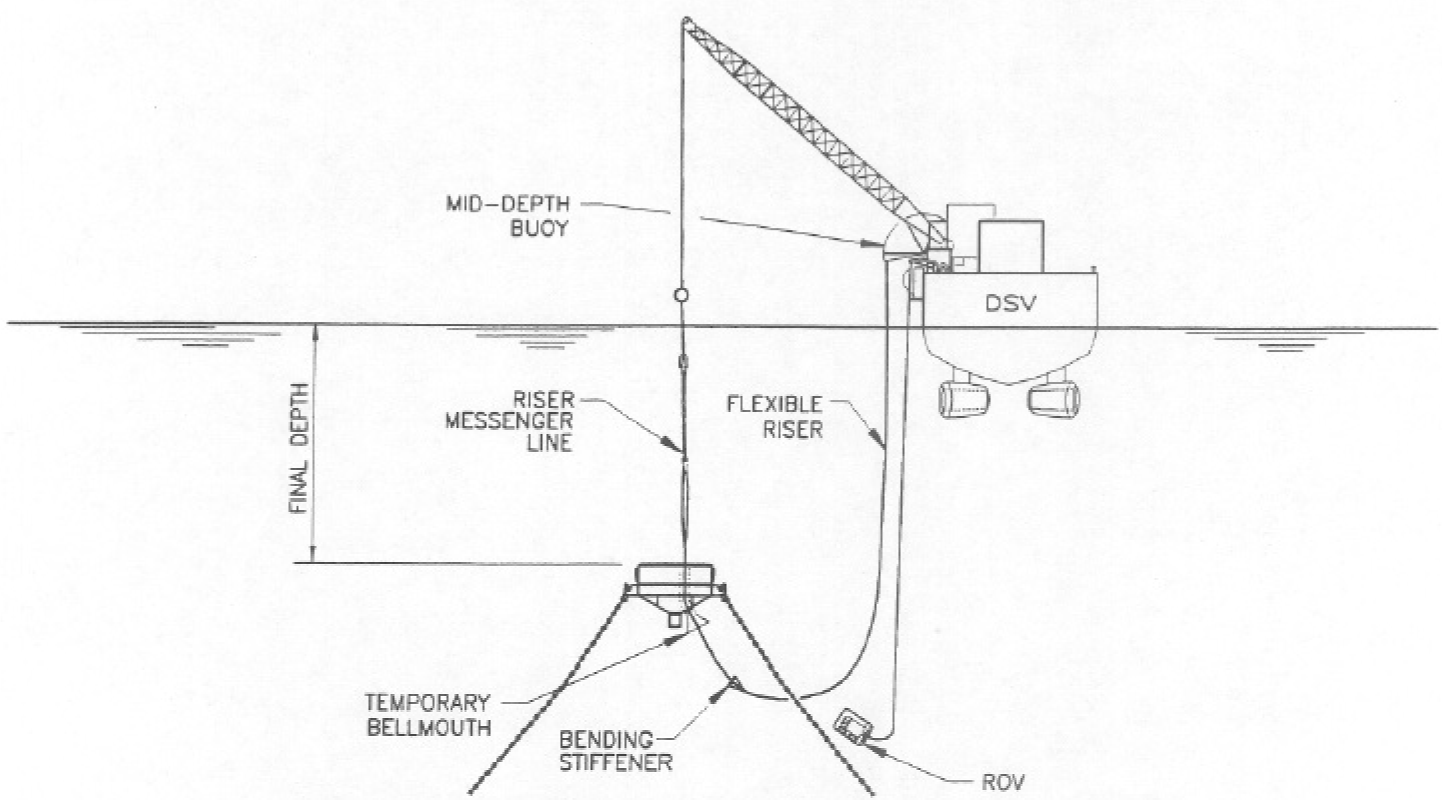

FIGURE 6 – DSV PULLING RISER THROUGH SPIDER BUOY