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OPTIMIZATION OF A DISCONNECTABLE TURRET MOORING SYSTEM

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One of the major innovations in conjunction with Floating Production and Storage Systems is the development of mooring systems that can be quickly and easily disconnected with the approach of major storm conditions. However, the design process for disconnectable systems is much more complex than for non-disconnectable systems.

1. INTRODUCTION

Permanent mooring systems for offshore storage/process vessels have been in use for many years in a variety of environments. These systems are normally used for large fields and are designed to survive 100-year storm conditions. Although complex, they are relatively straightforward to design. However, permanent mooring systems for smaller fields, in equally harsh environments (particularly those produced by seasonal cyclonic weather systems) are not cost effective. Disconnectable mooring systems provide an elegant solution and allow production of these fields.

A typical disconnectable mooring system is shown in Figure 1. They are designed for a much lower environmental return period and the vessel does not remain moored in extreme seas. As a storm approaches the vessel releases the mooring and sails to safe waters. They re-connect themselves when the storm passes. Even though the motions and forces of the system are much less than those associated with a permanent mooring system, the design of a disconnectable mooring system is far more sensitive and complex because of the additional criteria that must be met. The first requirement, of course, is the strength and excursion characteristics to satisfy the environmental loadings on the tanker

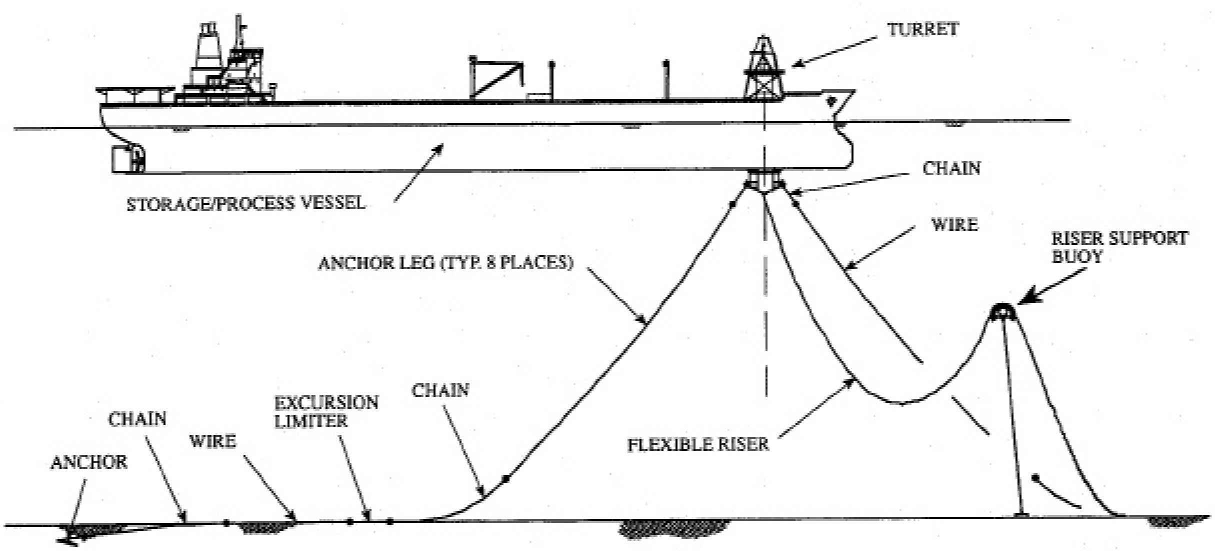

Figure 1. Typical mid-depth disconnectable turret mooring system.

when it is moored. The second requirement is that the mooring itself, in the disconnected condition, must be able to survive the 100-year storm. Additionally, the system must be designed to facilitate the lifting and re-connection of the mooring to the vessel. Superimposed upon this are the considerations for anchoring the system to the sea floor and the need to simplify installation and obtain the correctly preloaded system.

Many design iterations are normally required in order to achieve an optimized system. A change in one variable can affect many other aspects of the system. Model testing of the final configuration of the disconnectable mooring system, especially the re-connection must be treated as a necessity.

2. VARIABLES FOR CONSIDERATION

2.1. Water Depth

Water depth is the major factor in determining the make up of the mooring legs (chain, wire or a combination of chain and wire). This in turn determines the amount of buoyancy required to hold up the detached mooring system and whether or not the buoyancy will be concentrated in a single module or if additional buoyancy will be necessary as distributed units attached to the mooring legs. Due to the impact on installation costs, use of distributed buoyancy is to be avoided if possible.

2.2. Connected Environment (Vessel Moored)

For a given size vessel and load condition, the performance and sizing of the mooring system is controlled by the forces acting on the vessel due to the maximum connected environment. The combination of wind, waves and current, both in-line and crossed, determine maximum system motions and forces. System forces determine the size and strength of the mooring legs and turret structure. Maximum system motions determine, in part, the configuration of the flow lines (riser system). Interference between the mooring legs and the riser system must be addressed.

2.3. Disconnected Environment (No Vessel Moored)

When disconnected, the mooring system descends to a depth of between 25 and 50 meters. The exact depth is a trade off determined by the amount of weight (mooring legs, risers and buoyancy module construction) that the unit must support, the restoring force characteristics (both horizontal and vertical) of the detached system; and the severity of the survival storm. Figure 2 contains a typical vertical force deflection curve.

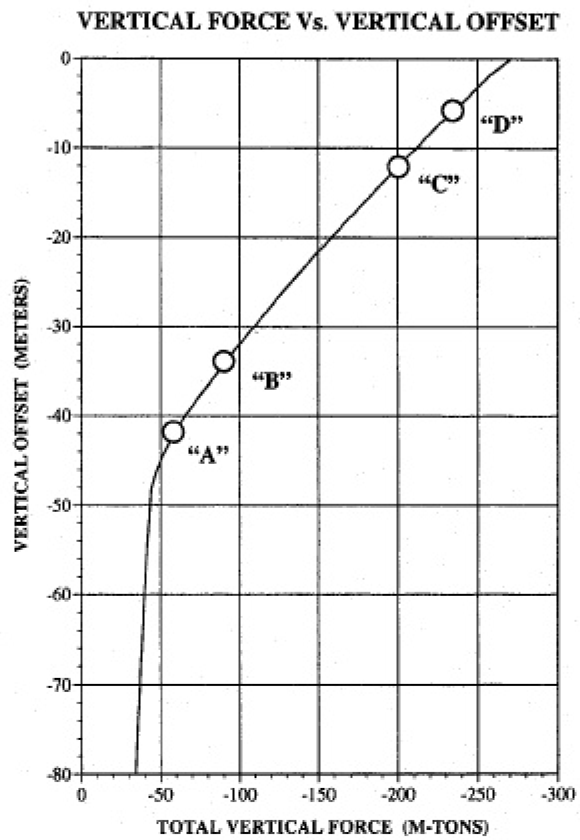

Figure 2. Vertical force deflection characteristics.

Mooring leg forces are generally of low order, however motions of the system do play a strong roll in the design of the riser system. Damaged cases (anchor leg damage or buoyancy loss) must also be analyzed in order to determine maximum excursions and, more importantly, the maximum head for which the buoyancy unit must be designed.

2.4. Soil Conditions

The condition of the sea floor determines the type of anchoring required (piles or drag anchors) and the accuracy to which the anchor point can actually be set to avoid the need for further adjustments during anchor leg installation. For accuracy of placement, piles are preferred. However, cost and available installation equipment may dictate use of drag anchors in many cases.

2.5. Anchor Leg Configuration

Optimization of the anchor legs is the most significant factor in achieving an optimized disconnectable turret mooring. This element must have adequate strength and safety factors to satisfy code requirements in addition to having minimum weight while simultaneously having a spring constant that will be compatible with the system motions while not adversely affecting the loads.

The anchor leg configuration will also have a significant effect on the installation costs and the necessity of set point accuracy for the anchors or piles.

2.6. Lifting Force For Re-connection

Minimization of the lifting force is imperative in order to have an optimized system. All marine operations and equipment necessary on the storage/process vessel are heavily influenced by this variable. The vertical force versus displacement characteristics of the anchor leg system as well as the shape and location of the buoyancy of the anchor leg support system will have a major effect upon the lifting requirements for re-connection of the mooring system to the storage/process vessel. Reference to Figure 3 allows one to relate to the lift force requirements depicted in Figure 2.

2.7. Riser Connections

Flow lines to satisfy production needs will have a limited influence upon the configuration of the connection system. However, it is necessary to place the connection point for the risers at a location that is easily accessible to operational maintenance

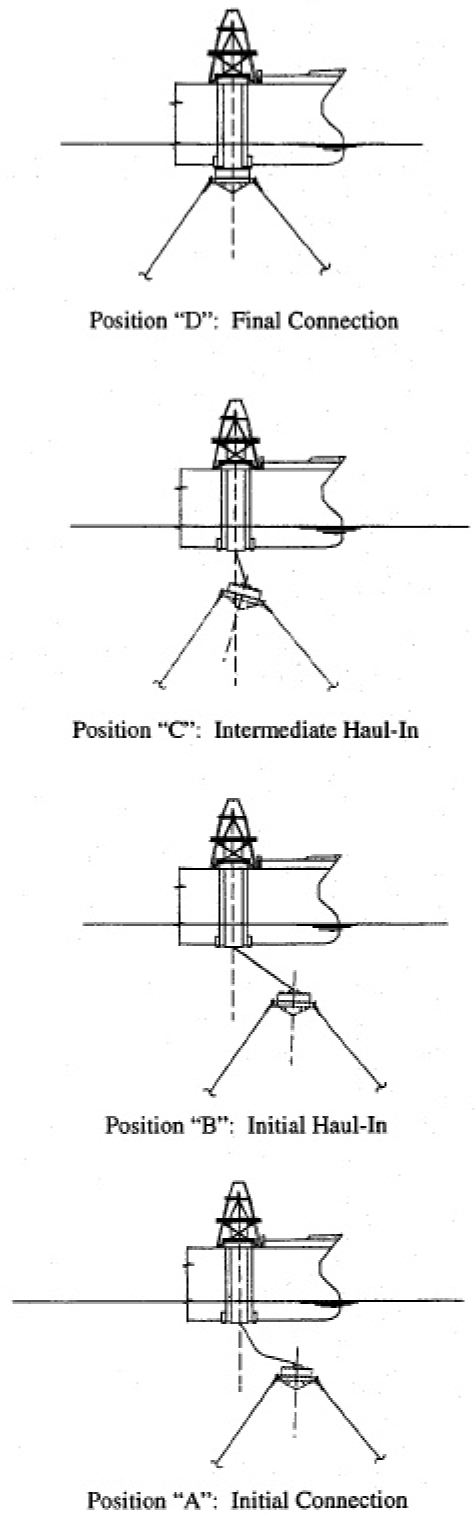

Figure 3. Re-connection of the mooring system.

personnel. Handling aids must be provided in order to facilitate connection operations. Operators should endeavor to minimize the size and number of flow lines since accommodating large lines into the disconnectable system will have a major cost impact.

2.8. Storage/Process Vessel Interface

The turret should be located on the storage/process vessel at a location where the existing structure is intersecting the turret center line. This allows the best control of vessel stresses and greatest fatigue life of the existing vessel structure. Additionally, the loads and motions for the mooring system and recovery system can be quite dramatically influenced by the location of the turret on the vessel.

If the turret is located too far forward, large hydrodynamic forces can be experienced. If it is too far aft, the angular position of the vessel will be greater and low-frequency surge and yaw motions and their associated forces can increase.

2.9. Fatigue Of Anchor Legs

Fatigue characteristics of a permanently moored system usually are dominated by significantly lower sea states than those for which the system is ultimately designed. In a disconnectable mooring, fatigue life must be determined not only for the turret structure but also the mooring legs, especially the connectors. The reason is that sea states to produce maximum anchor leg loads are only slightly greater than the conditions that occur on a much more frequent basis.

2.10. Arrangement Of Handling Gear

To minimize costs, especially on conversion installations, it is desirable to leave the mooring winches and their associated chain lockers undisturbed. Relocation is expensive and this equipment must remain completely operational during periods of disconnection. Compromises must be investigated early to make the proper choices involving structural arrangement, cargo tanks, mechanical equipment relocation and optimization for sea-keeping or hydrodynamic reasons.

In the case of new built vessels the freedom to optimize arrangements on the storage/process vessel is much greater and may perhaps result in savings in the final mooring system design.

2.11. Inspection And Maintenance

Because of the added complexity of the mechanical components of a disconnectable turret mooring system, inspection and maintenance requirements will of necessity be greater than for a "typical" permanent system. Of course, a trade-off to the added effort is the ability to perform major inspection and maintenance during times of disconnection when the vessel and the key components for connecting to the mooring system can be brought alongside a quay where added facilities may be readily available for assistance.

3. MANUFACTURING CONSIDERATIONS

Because of the size and weights of the major components that must be manufactured into the tanker structure, careful attention must be paid to the machinability, handling and heat treatment of each component. Elimination of machining of bearing foundations on the tanker or storage vessel structure is a major opportunity for cost savings because of the portable equipment required and the reduction of dry dock schedule needs.

To facilitate the mounting of the system on the storage or process vessel, all needs for cradling, transporting and lifting must be manufactured into the hardware. It is desirable that these aids be arranged to avoid fatigue prone "hot spots" and also be a permanent part of the mechanical assembly where possible. Major savings will eventually result when these guidelines are met.

4. FAILURE MODES EFFECTS ANALYSIS AND DESIGN RELIABILITY

Operators are continually requiring more utilization of their equipment and manpower during the life of a floating production and/or storage system. In order to accomplish re-connection and disconnection satisfactorily and maintain a high degree of safety, more complex mechanical equipment is necessary. Because of this, and the potential for extensive damage and loss of life as a result of untimely failure on this type of equipment, it is necessary that the highest degree of reliability be designed and included in the budget for these installations.

Performing a failure modes and effects analysis of the system and its operation is recommended in order to fully evaluate all conceivable situations that may potentially occur during the life of a mooring system. When performed properly at the appropriate early time in the project, the cost and schedule impact of this effort will be minimized and the results be more useful to achieve operating success.

5. SUMMARY

Disconnectable mooring systems have already been shown to offer a good mooring solution when properly optimized and will gain wider acceptance as their application for use and the technology for manufacture and installation is improved. Use of stronger synthetic materials for anchor legs has a good potential for eventual use for these systems. Improvements in capabilities and reduction in cost of synthetic buoyancy materials is leading to reliable alternatives to conventional steel buoyancy tanks. Production in remote, harsh environmental conditions and/or deep water locations may soon be achieved by these systems.