Doug Davidson, Mooring Systems Ltd, UK, explains how Tri-Catenary mooring systems are proving to be a flexible and effective station-keeping and production system.

FPSO MOORING IN MARGINAL FIELDS

Tri-Catenary mooring systems (TCMS) were first designed for extended well testing (EWT) in the North Sea in the mid-1990s. They provided a better and more cost-effective alternative to dynamic positioning tankers. After various EWT projects, the TCMS systems was successfully used to moor storage tankers and floating production, storage and offtake (FPSO) vessels. It provided an alternative to submerged turret production buoys, tower yoke mooring systems and conventional multi-line turrets for vessels up to 250,000 dwt, most notably for marginal fields where the field economics dictate a simpler, easy to deploy mooring system for fields with a limited production life.

The TCMS is based on three mooring legs radiating at more or less equal angles from a connecting node below the sea surface, with a single length of chafe chain rising from the node to a chain stopper positioned on the bow of the moored vessel. A key feature of many TCMS systems deployed to date is the existence of only one chain mooring line in any one direction, with the adjacent one being 120° away. The seabed end of each leg is typically held in place by a high holding power, drag anchor, firmly embedded by cross tensioning as an integral part of the standard deployment procedure. The mooring system allows the vessel to weathervane around the node in response to wave and wind movements.

Figure 1. *TCMS production tower on the Ikdam project offshore Tunisia, showing three risers and two umbilicals.*

Secure Mooring System

Particularly when used with an FPSO, all mooring system design codes require there to be a means of safe positioning in the event of a single line failure. The TCMS offers a choice of options to ensure that there are no single point failure modes; this can either be with the use of additional mooring legs and a redundant chafe chain; or, as has been approved by a number of classification societies, a package of individual measures which together have been accepted as providing an adequate level of protection. One of these measures is an enhanced strength factor of safety for non-redundant systems, which is recognised in the latest version of the DNV Position Mooring Code OS-E-301. This measure takes advantage of the efficiency of this type of mooring system, where the peak mooring forces can be reduced by 'tuning' the mooring system's response to match the vessel's response in severe weather. The TCMS can be tuned by the careful design of such factors as the length of the chafe chain and the mass of the node. Thus, use of larger components to increase the strength, and reduce the risk of equipment failure, is not financially burdensome.

By using three lines compared with other mooring systems including CALM buoys and turrets that have typically six, eight, or more legs, the TCMS is quicker to deploy and less 'stiff' than other tanker moorings. This ensures that the tanker's natural fore and aft motions, with the right engineering, can be dampened by the mooring catenaries and the pendulum effect of the chafe chain.

Flexible Production System

With the use of guide collars attached to the chafe chain, the moored tanker can act as an FPSO with multiple high pressure risers. The risers are unaffected by the degree of vessel offset experienced, as the riser catenary shape is affected by the movement only of the mooring node, which is considerably less than the vessel movement. The distance from the node to the tanker bow is a fixed length (typically 40-50m for a 90,000 dwt Aframax tanker). Horizontally, the node will move perhaps only 10m, and vertically perhaps 25m in extreme conditions. These sorts of motions are easily taken up with a lazy wave or steep wave design of riser shape. For some applications, it has been feasible to rely on the inherent stretch in bonded hoses to accept the node offsets – the right choice of bonded hose can have elastic stretch to as much as 40% of its original length – without structural damage or loss of integrity.

A single axial swivel on each riser is sometimes used depending on the amount of weathervaning anticipated; single axial swivels being much cheaper than multi-path toroidal swivels and with a much shorter delivery time.

So far, 11 TCMS systems have been deployed in applications ranging from extended well testing, oil recovery, and floating storage and FPSO production. One of the three FPSOs moored to a TCMS to date is the Lewek Arunothai FPSO Arthit Field in the Gulf of Thailand.

Approximately 143 miles (230km) offshore Songkhla in Malaysia, the Arthit gas and condensate field spans 1 million acres (4185km^2) across Blocks B14A, B15A and B16A. Moored at a water depth measuring 262 ft (80m), the Lewek Arunothai FPSO field is operated by Thai oil and gas company PTT Exploration & Production (PTTEP).

The Arthit FPSO TCMS also features four 8 in. Manuli bonded risers and one 8 in. DeepFlex bonded riser, plus a multi core hydraulic umbilical. The TCMS and riser system has successfully handled production levels of 370 million ft^3/d of natural gas and 19,800 bpd of condensate.

As experience of the TCMS mooring system has increased, so the principle of providing a cost-effective mooring system for marginal fields has been developed for both deepwater and ultra-shallow water applications.

Getting Into Deep Water

The growing number of deepwater marginal fields in the Gulf of Mexico, offshore West Africa and Brazil, present both practical and economic challenges for independent operators. By their very nature, deepwater fields in water depths greater than 1000m can be expensive to develop and so marginal fields lacking existing pipeline infrastructure are often neglected. Conventional deepwater mooring systems are complex and expensive to deploy at water depths greater than 1000m. In addition, they often require substantial modifications to the FPSO, such as the addition of a mooring turret. In a marginal field, a turret capable of handling a small number of risers is inappropriate, whereas a deepwater TCMS, designed for four or five risers, is more practical. And with a lifetime of around seven years, compared with 25-30 years for more substantial deepwater fields, the TCMS mooring system provides a less complex mooring at half the cost of a traditional deepwater mooring system.

The differences between the shallow and deepwater TCMS are longer mooring lines based on synthetic fibre rope rather than chain, together with the addition of discrete buoyancy units that give the mooring system a wider profile and prevent clashing between the mooring lines and risers. The risers too are lengthened and hang off loads from the TCMS production tower maintained by changing the riser profile and enhancing the buoyancy. Subsea, the production risers can be supported by buoyancy tanks and connect to the FPSO via flexible jumpers, reducing tension on the production risers.

The major difference between the shallow water and deepwater TCMS is the ability to disconnect the bow-mounted riser production tower in the event of adverse weather conditions. The production system tower is designed to be fully disconnectable within eight hours and abandoned to 70m water depth while the FPSO sails to a safe port. When the FPSO returns, and is on station, the tower is retrieved and reconnected to the bow of the vessel.

Ultra-Shallow Water Production

For ultra-shallow water project at 55m, the TCMS traditional three leg mooring system can be used. Each leg is typically made up of 500m of Grade 3 chain connected to the mooring system node. This type of mooring project will be close to the shore and so the wave movements will be a good deal less than those found further offshore. In such shallow water, vessel rotation is restricted to ±90° movement either side of the mean heading. The TCMS production tower is also shorter and less complex and supports a maximum of four risers/umbilical orientated in a lazy wave profile from either pipeline or subsea trees.

Figure 2. *TCMS production tower on the Ikdam project offshore Tunisia.*

Figure 3. *TCMS production tower showing chafe chain, guide collars, risers and umbilical.*

THE FLEXIBILITY OF THE TRI-CATENARY MOORING SYSTEM OFFERS INDEPENDENT OPERATORS A RELIABLE MOORING AND PRODUCTION SOLUTION FOR OFFSHORE MARGINAL FIELDS. THE OPPORTUNITY TO DEPLOY THE TCMS MOORING SYSTEM QUICKLY AND COST-EFFECTIVELY COMPARED WITH TRADITIONAL MOORING SYSTEMS PRESENTS A COMPELLING CASE FOR OPERATORS WISHING TO MAXIMISE FIELD PRODUCTION AND PROFITABILITY.

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