‘Oil and Gas FPSO's Marine Project Execution - Where Are The Weak Links?’

IMEC
Independent Marine & Engineering Consultants

AOEC
Asia Offshore Energy Conference

Asia Offshore Energy Conference
Bali October 2013
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The paper reviews the history and state of the art of FPSO field development. It deals with the marine aspects of FSPO projects outlining critical issues and weak links. Key lessons learned are examined. The importance of effective project integration and operations integrity is discussed. Recommendations are given for future applications.

AUTHOR PROFILE

Mr Bush has over 30 years international experience as a Consultant Naval Architect and Executive Director in the Marine and Oil & Gas industries. Richard has been involved in many international projects as Consultant Naval Architect and gained international experience in Europe, the Far East, the Middle East and the Americas. He has 10 years main board experience with a major global consulting company as Regional MD for the Far East and latterly for Europe. Richard decided to stand down from senior executive roles in January 2009 and commenced training that led to his admission as an IOD Chartered Director in February 2010. Since then he has returned to consulting on numerous floating production projects. In December 2010 he became non-executive Chairman of the IMEC Group of Companies.

Historical Development of the FPSO Concept

The first FPSO to be developed was the Shell *Castellon*, built in Spain and installed in the Mediterranean in 1977. FPSO's provided an economic solution for the development of oil fields that lacked pipeline access. Early examples were conversions from trading tankers. To begin with many contractors preferred steam ships as their power plants could be more easily dual fueled. Today new build and intercept hulls are commonplace and most modern conversions are motor ships with extra power provided by dual fuel gas turbines.

Early challenges included the development of reliable;

- Turret systems
- Fluid and Electrical Swivels
- Hull and Machinery Life extension
- Arrangements for in water survey
- Tandem stern off loading arrangements
- Long Term (LTM) mooring connectors

As FPSO's were successful in benign areas, they were then deployed in harsher locations. The new challenges included;

- Configuration of internal turret systems
- Designing dynamic mooring and riser systems
- Extending hull strength and fatigue life.
- Green water protection & process deck elevation
- Provision of adequate bow slamming capacity
- Provision of heading control
- Extending Shuttle Tanker operational limits
- Developing offloading hose recovery systems
- Extending the limits of crew transfers and logistics
- Dealing with sloshing (cargo tanks and process vessels)
- Extending motions limits for power gen & other utilities

Key Design Drivers

Key FPSO design drivers for marine aspects include;

Key Design Drivers (cont.)

- Water depth and metocean climate.
- Production profile (required storage capacities).
- Topsides Payload requirement (weight and VCG)
- Sub-sea interface (no, type of risers, umbilical's etc.)
- Power requirements & Design life.

Standard Solutions

One of the key challenges of the Oil and Gas industry is to develop standard solutions that reduce the cost of preferential engineering. However, whilst this has been possible for some components it's harder for whole FPSO's.

There are many reasons for this. Firstly functional requirements vary a great deal from field to field. Compare for example an FPSO for a medium water depth oil field in a benign environment with 2 production risers, with a deep water harsh environment facility, 24 risers, gas compression, water injection and gas export.

Secondly the starting points vary. Some facilities will be new builds and others conversions. For conversions an operator will be offered the choice of hulls none of which is ideal. For a new build, configuration may be a function of a generic design, but differences in shelf practice, may be important (e.g. Norway require bow accommodation whilst UK accepts either bow or stern layouts).

The United States shelf administration has only recently been prepared to approve FPSO's for the Gulf of Mexico and rules and regulations vary from shelf state to state. Even in basic design, solutions vary around the world with different outcomes for harsh medium and benign environment conditions.

Standard Solutions (cont.)

Schedule pressure can also lead to greater diversity. The delivery date for first oil is fundamental, so operators rarely have the luxury of defining all relevant project specifications at the outset. A workable system delivered on time, yields greater net present value than a refined system delivered late.

So alternative solutions proliferate all with different strengths, and vulnerabilities, operated by a range of different companies with different skills and cultures. In reality there is no such thing as a standard FPSO's, although differentiating between the associated risks can be a complex task.

Usually it is only feasible to standardize parts of the package, but Sevan Marine's cylindrical FPSO's show how this can be extended. They now offer hull types 300 to 1000, (all with different sizes and storage capacities). The designs all have different topsides outfit, water depth and design bases, but standard approaches to structures, main utilities etc. can lead to better project definition by the end of FEED.

The Sevan concept hulls are not suitable for all applications, but tighter standardization would be desirable if applied to mono-hulls (as for example was possible for Kizomba A and B).

Representative Examples

However, some idea of the variability of FPSO's can be appreciated by listing typical examples, (see Table 1). The table contains just a handful of representative projects from around the word, some of which have been worked on by the author. In reality there are many more variations in FPSO type and specification than can be listed here.

Challenges and Weak Links

Whatever the concept is selected there will always be challenges some of which will be on the marine systems. The following sections of the paper examine some of the weak links that typically fall within the remit of Naval Architects and Marine Engineers. They haven't been listed in any particular order of importance and the list is not comprehensive. They are merely a snap shot some of issues that have recently been addressed by the author.

Schedule - Long Leads – Model tests and other issues

A typical FPSO project execution schedule is shown in Figure 1. Chain cables, fairleads, winches and turret details are commonly long lead items and hull foundations often have to be installed at a relatively early stage in the program. This means that maximum characteristic mooring line tensions have to be established as soon as possible. If model tests are required, test tank slots have to be booked well in advance.

Schedule - Long Leads – Model tests (cont.)

This rarely occurs with the result that orders for mooring chains, fairleads, winches and foundations are often placed well before the model tests. So if there is a substantial change to mooring design basis as a result of the model tests, the impacts can be significant.

Moorings are not the only long lead items. Orders for power generation, pumps, compressors, swivels etc. also have to be placed at an early stage. Topsides module strength, green water protection etc. all depend on the early completion of naval architecture, which in turn requires good weight definition.

However, these issues are frequently carried into detailed engineering where they can cause significant schedule impact. Occasionally projects are sanctioned with significant remaining conceptual design issues to be resolved and if direct schedule impact is to be avoided, there is typically no more than a few weeks to resolve any front end naval architectural issue.

This is why standardisation is potentially attractive and helps to explain how it was possible to complete the Kizomba B program five months quicker than Kizomba A.

Weight Control

The most basic naval architectural requirement of FPSO's is the ability to carry the payload of topsides equipment, cargo and consumables and hull must have sufficient buoyancy, hydrostatic stability and longitudinal strength to do this. All Naval Architects are taught that excess weight is excess cost and failure control weight and vcg can also affect the schedule.

FPSO's have historically been much less sensitive to extra weight than semi-submersibles. This is still true for large simple fields with big volume hulls and small topsides. However, many smaller FPSO's are now being deployed on marginal fields and topsides requirements are increasingly complex. Consequently topsides weight is very much back on the agenda. Unfortunately weight control is often quite poorly implemented, so it's worthwhile to consider some of the possible reasons for this.

Firstly despite the availability of new materials our industry does not always seem to produce lighter topsides packages. This may be because of the desire for less congested layouts and additional safety requirements due blast etc. Conservative approaches to corrosion margins and excess capacity might also have some influence. However, perhaps we are no longer as focused on driving out excess weight.

Weight control (cont.)

Whilst the measures required to set up good weight control are simple, they have to bridge many interfaces. To be effective procedures require firm lines of authority and clarity of intent. They also need focus on weight control as well as monitoring.

Generalists might think, "why not just design for sufficient weight contingency from the beginning", but this is mistaken. Not only does this drive in un-necessary cost, but it also carries un-necessary risk into detailed engineering. If FEED is completed without a good weight and VCG estimate, the basic naval arch design will have to be repeated until such estimates are available. The naval architectural team is then employed chasing the latest weight "estimate" from topsides and repeating the exercise until weight stabilizes.

The early crystallisation of weight properties is just as important as absolute value. Late changes have large impacts even when weight & VCG are reduced. Projects that run topsides/sub-sea FEED's in parallel with hull definition, run the risk that at the end of FEED a revised topsides weight will invalidate the naval architecture. In extreme cases, poor topsides weight definition can significantly impact schedule.

Hydrocarbon Gas Blanketing

The introduction of new technologies can impact both cost and schedule so the trend for cargo tank blanketing with hydrocarbon gas as opposed to inert gas is worthy of review.

Cargo tank explosions and fires were commonplace in the oil tanker industry since its pre-war inception well into the 1960's and early 1970's. In February 1932 The Sun Oil Tanker 'Bidwell' experienced multiple explosions whilst loading cargo on the Delaware River. The incident killed 18 crew, including the master. By 1933 all Sun Oil vessels were fitted with an early nitrogen inert gas blanketing system. Unfortunately this initiative wasn't taken up by the rest of the industry.

BP started experimenting with inerting in the early 1960's initially to secure reduced cargo system corrosion rates. However, once more the tanker industry as a whole failed to implement IG systems and between 1961 and 1969 over two hundred mariners were killed in cargo tank fires and explosions In December 1969 three nearly new VLCC's with no IG systems experienced serious cargo tank explosions. Ignition was attributed to static electricity generated by tank washing jets.

From 1970 Shell and many other companies required IG systems on all new tankers and US coast guard introduced regulations in 1974, but these were not retrospective and not all vessels traded in the US. So casualties continued at quite high rates into the early 1980's. In the early 1980's Lloyds introduced an insurance surcharge on all non in-erted tankers.

Hydrocarbon Gas Blanketing (cont.)

This combined with IMO regulations in 1982 applied retrospectively in 1984 ensured that the vast majority of tankers had IG systems by the end of the 1980's. Since then the casualty rate has reduced by a factor of at least 5 and nearly all the remaining casualties are attributable to failures of IG systems or procedures. Inert Gas Nitrogen blanketing systems have therefore been standard practice on FPSO's since the outset. IG is typically supplied from a conventional IG scrubber system either on a diesel engine or boiler exhaust or from a stand-alone nitrogen generator.

However, on some FPSO's there have been operational difficulties with IG 'cold' venting. Standard practice is to manifold the IG vents and/or vent the common IG header and take a vent line up the flare stack to atmosphere. Ignition arrestors can be fitted at or near deck level where they can be more easily maintained.

However, tanker IG vents are typically oversized for FPSO loading operations so mixing may be poor. On still days hydrocarbon rich IG and/or crude 'ends' can drop out on to the process plant causing gas alarms and trips. These events do not have much escalation potential, but they do cause product interruption and add to VOC's lost to atmosphere.

In response to these concerns the industry has moved towards combined Hydrocarbon Gas (HC) and IG (Nitrogen Gas) blanketing systems. In these arrangements HC gas (usually large parts methane) is supplied from the process system to the IG header so a cargo tank can be started on Nitrogen and then purged with Methane.

In this way the cargo tank(s) can achieve low enough oxygen content to allowing the vent gas to be taken into process system for VOC recovery and as HC gas has much lower CO2 and O2 content, corrosion rates are reduced.

However, once an FPSO is offloaded, cargo tanks on a HC gas blanketed vessel will be full of methane. Admittedly nitrogen blanketed tanks would also contain hydrocarbon gas, but the nitrogen will displace some of it. Furthermore additional connections are made between the cargo tanks and the process system and these introduces new hazards that require careful examination, by independent HAZID, HAZOP, FMECA etc.

Historically the key advantages of IG gas blanketing are;

- Reduced risk of initial ignition
- Reduced risk of escalation
- Reduced risk of corrosion

Hydrocarbon Gas Blanketing (cont.)

As the industry moves to hybrid HC/IG systems we must be certain that we haven't re-introduced a significant risk of escalation or avoidable failure modes by connecting the cargo tanks to the process system.

Cargo Tank Isolation

As an industry we are rightly concerned about tank isolations and confined space entries that are required for FPSO inspections and maintenance. The hazard potential is considerable and there is HSE and asset risk whenever we enter a cargo tank. However, difficulties arise from the application of standard tanker practice to FPSO's.

Tank inspection and maintenance on trading tankers can more easily take place inshore and the economic penalty of preparing a batch or even the whole tankage for inspection is tolerable. For an FPSO we ideally want to enter one tank at a time perhaps whilst some of the other tanks contain hydrocarbons and production is ongoing.

Whether we can do so safely and efficiently generally boils whether we can;

- Easily purge, gas free and ventilate individual tanks.
- Effectively isolate the subject tanks from others.
- Reduce the risk of injury to personnel when inside tanks.
- Safely recover any casualties from inside tanks.
- Prevent fire & explosion incidents & their escalation.

Conventional tanker IG venting systems may not allow us to purge and gas free individual tanks without risking over pressure events or incurring process trips due to gas alarms. However, designing an effective blanketing and venting system is straight forward provided it is addressed early enough.

In a conventional trading tanker, the cargo system is driven from the pump room. The pump room has historically been a concern, because leaks can cause a dangerous buildup of hydrocarbons. However, at a more fundamental level a conventional tanker cargo system does not support the test isolation of individual tanks (i.e. double block/bleed) or positive isolations (i.e. spool piece removal or insertion of blanks).

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Cargo tank valves are typically located in the target tanks or in adjacent tanks that could be full of oil. There are therefore many possibilities for hydrocarbons to enter a nominally isolated tank via valves whose isolations cannot be guaranteed. Passing cargo tank valves are common and cargo pipework typically passes through several tanks. The safest way to enter such tanks is therefore by preparing them in batches but this has big commercial implications for an FPSO.

Cargo Tank Isolation (cont.)

The recent trend has been to specify deep well pumps in each tank with separate cargo headers. This allows each tank to be positively isolated, although provision must be made for the failure of the dedicated deep well unit by providing a portable spare. Unfortunately these systems are expensive (prohibitively so as a retrofit) so many FPSO's are managing the continued risks of conventional systems.

Sufficiency of Met Data – Current Extremes – Directional Divergence

Site specific met ocean data is clearly important for the design of an FPSO, but the data requirements vary with each application. Operators therefore have to select an appropriate data set for each case. Options include;

- Base Case Omni-directional Extremes
- Directional Extremes
- Directional Divergence Distributions
- Spells Data

Spread moored mono-hulled FPSO's are sensitive to environmental loadings on the beam that can affect mooring capacity and offloading regularity. Even weather-vaning units can be affected by beam weather conditions especially in harsh environment areas where directional divergence in the wave climate and local shelf currents can both have significant effects on operations and the need for heading control.

Location specific current data is the least well defined of all the environmental design extremes. Frequently this doesn't matter very much, but there are cases where it can be very important. Current data is of often of poor quality in the Far East Region and a common problem for Far East FPSO's is with beam currents. Several projects have experienced serious operational difficulties with mooring capacity and offloading operations resulting in additional costs and deferred production. In some cases there have been system failures, material insurance claims and litigation.

Whilst long-term current measurements are required to establish design extremes, even limited location specific data can be of very great assistance. Short-term measurements can at least give some indication of the characteristic current values (especially the directional components). It is therefore in the operator's interest to install current meters on fixed platforms and ensure current data is automatically gathered during exploration drilling.

Integrated Mooring and Riser Design

During the mid to late 1980's it became apparent that the design of moorings and dynamic risers for FPSO's was being performed by two different groups, to different codes and standards. Traditionally moorings are designed by naval architects. Riser systems are designed by sub-sea engineers. This was causing inconsistency in safety levels and substantial cost impact.

This was particularly relevant for FPSO's operating in harsh environments, so a comprehensive JIP was organized in Europe to address the issue. Over 3 years new analytical methods were developed and the advantages of integrated design were demonstrated. This work was completed by the early part of the last decade, so 10 years later it's disappointing to report that many harsh environment FPSO projects are still not adopting an integrated approach to moorings and riser design.

The reason for this is usually contractual. It is convenient to bundle dynamic risers with the sub-sea facilities rather than with the hull. More often than not the sub-sea contract (including riser design) runs behind the hull and moorings so it's difficult to integrate these designs. As a result many projects don't do integrated mooring and riser designs. However, they should at least agree a characteristic mooring offset and freeze it at the end of FEED. Most projects believe this what they have done, the reality is sometimes otherwise.

Surprisingly many projects still commit to functional specifications that essentially state; 'mooring design shall accommodate risers' and 'risers design shall accommodate moorings'. If one or other of the designs is significantly constrained (e.g. by shallow water) the technical solution and the associated costs can be a major source of dispute.

If the project does not go for an integrated design, the 'least worst' alternative is to select a design offset as some percentage of water depth. Optimization can still occur but both designs can progress with a firm basis for any variation orders.

Serious Station Keeping Incidents

The FPSO mooring design community has some other perhaps more pressing challenges. During the winter of 2012 – 2013 at least four serious station keeping incidents were experienced by floating production facilities on the UK Continental shelf. All four were high potential safety and environmental incidents and although there were no major HSE impacts all resulted in significant lost production and major capital repair costs. Two of the incidents resulted in extensive damage to the sub-sea production facilities and two of the largest insurance claims made in recent years.

Serious Station Keeping Incidents (cont.)

The immediate lessons learned from these incidents were;

- Station Keeping Failures are a significant potential hazard for harsh environment floating production operations the risk of which has previously been underestimated.
- The UK sector 'state of the art' of station keeping design and operation cannot be relied upon to prevent serious station keeping incidents.
- Harsh environment heading controlled FPSO's have an inherent vulnerability to station keeping failure that requires the high standards of operations integrity to avoid future incidents.

Given the significance of these incidents, it is unfortunate that only one set of lessons learned (i.e. for Gryphon Alpha) is generally available. The author of this paper has been consulted on 2 out of the three remaining incidents, but cannot provide further details here owing to confidentiality issues. There is however, sufficient information in the public domain to reach some initial conclusions.

HSE Offshore Information Sheet and its Consequences

In response to the incidents the UK HSE have recently published "Offshore Installation Moorings" OIS 4/2013. This has useful guidance on station keeping and will have a large impact on future UK sector mooring design.

The main impact will be to mandate UK operators to comply with ISO 19901-7 Annex B.2 "where reasonably practicable". Annex B.2 is the section that applies to Norwegian Sector FPSOs and it implies about 32 % increase in the minimum line strength requirement(s) plus increased system redundancy & corrosion margins for chain cables.

The OIS makes it much more likely that the moorings of heading controlled FPSO's will be designed for the black out condition and this will significantly increase the cost of the moorings. More generally the OIS will result in;

- Engineering to evaluate the effects on existing FPSO's
- Little or no retrospective impact. Modifications will not usually be reasonably practicable.
- The number of mooring lines on FPSO's will increase.
- The redundancy requirements will reduce the risk of shut down due to mooring failure.

HSE Offshore Information Sheet and its Consequences

In general the new guidance can be considered to be a step forward, but it is legitimate to ask whether we have drawn all key lessons from the incident. In the authors view the most serious aspect of the Gryphon Alpha incident was the serious operating integrity problems that were identified.

Reading the detailed report on the incident is a shocking experience for a system designer, because of the widespread human errors and deficiencies that were identified. Comfortable assumptions regarding double jeopardy and rates of human error that are present in all our marine risk assessments were simply demolished by this incident.

The probability of total station keeping failure was 100 times greater than had previously been assumed in most FPSO safety cases. If similar failure rates are applied to stability management, structural integrity, etc. the implications are very disturbing. So whilst the HSE have made some observations about operational matters, operating limits, mooring inspection and so on, in the authors opinion these issues are ultimately more important than line tension factors of safety.

Mooring System Fairlead Lock Off

One of the consequences of the serious mooring incidents that occurred on the UKCS is that we have had an opportunity to see how azimuthing fairleads might perform in service at tensions close to their maximum design loads.

It is well known that if a fairlead adopts a significant angle to that of the mooring line that passes through it, the moments that are generated can cause premature failure.

Failures may be in fatigue due to cyclic bending loads in the chain cable, may affect the retention details of the fairlead gypsy wheel pin, or cause a global failure of the support details on either side of the main body of the fairlead.

FPSO mooring fairleads are not currently designed to withstand the moments associated with large mooring line off lead angles, because it has been assumed that the fairlead would rotate under the influence of any large off lead angle. The break out angle of the fairlead support bearings is therefore a critical design parameter (see figure 2).

It has been known for some time that fairlead bearings may seize due to corrosion or wear, so operational tests to ensure that the fairlead body can still rotate, are important for long term integrity. However, it can be challenging to check that the azimuthing bearings are still running freely and difficult to improve matters it if they are not.

Recent experience from major storm incidents has identified another problem that may affect some fairlead designs.

Mooring System Fairlead Lock Off (cont.).

As mooring line tensions increase towards break, large forces are transmitted to the fairlead. In some designs the structural supports for the two horizontal mounting bearings (upper and lower) lack sufficient stiffness. The resulting deformation (ovalising) can be sufficient to cause the fairlead bearing assembly to 'lock off' causing large moments to be transmitted to the fairlead assembly.

The effect of this is to materially reduce the mooring system capacity following an initial mooring line failure and increase the probability of a multiple line or total system failure. Mooring system designers should therefore ensure that fairlead bearing supports have sufficient structural stiffness to prevent 'lock off' and that the fairlead assembly, side supports, locking pin etc. have a sufficient moment capacity to deal with accidental cases.

If this can be achieved we will be left with the operational challenges associated with the seizure of fairlead bearings, but at least one failure mode will be eliminated.

Marine Risk and Commercial Hazard Management

The station keeping incidents described in the previous section all had significant hazard potential but did not escalate any further. This implies that whilst measures seeking to prevent the initial incidents failed, those designed to control and mitigate HSE were effective. The commercial losses were however considerable.

It is good practice to focus on Health Safety and Environment before commercial issues and in most projects commercial pressures are strongly driven via capex and opex controls. However, commercial as (opposed to HSE) hazard management may not be adequately addressed by these processes.

It often stated that good HSE hazard management will deliver good commercial hazard management and this is generally true, especially where it relates to incident avoidance and prevention measures. However, it will not necessarily be the case for control and mitigation measures.

For example if there is a stern offloading incident in which the shuttle tanker collides with the stern of the FPSO, the typical focus for control and mitigation will be on preventing escalation due to fire and flood and limiting the size of any oil spill using isolation, bunding, MARPOL compliance etc. Consideration may also extend to EER and pollution response.

Significant commercial impacts (e.g. loss of hose reel, flooding of engine room, etc.) may however still occur even if the HSE issues have been mitigated.

Marine Risk and Commercial Hazard Management (cont.)

These exposures rarely receive anything like the same level of formal attention. Some operators consider them in their Reliability and Availability (RAM) analyses, however the majority tend to focus on the topsides issues and ignore the effects of marine (and possibly non marine) accidental events.

The RAM analysis can be extended to cover accidental events by performing commercial risk assessment. Commercial risk screening of this type should be performed during concept select and FEED. As the main drivers are likely to be for layout it's important that commercial impact assessment is done as early as possible in the program. It also needs to be considered in the pre-operational phase.

In both cases a more direct focus on commercial risk management will help investors and underwriters alike, but it does require an extension to current practice that must be squeezed into projects that are often overloaded with other execution challenges.

Fatigue factors of safety – Critical Hull Structures

The industry has already dealt with the challenges of in water survey of sea chests, hulls, turrets etc. Coatings and corrosion protection is similarly not that challenging technically although attention to detail is particularly important. The question of hull fatigue assessment is typically more complex.

The commonly accepted approach to fatigue factors of safety is that they should be increased for critical structures and structures that are not accessible for inspection and repair. The typical range is between 2 and 10 depending upon the design code and the application (see Table 2). The problem is that not all classification codes consider the full cost of repair. This may be because many of rules originate from conventional tanker service rather than an offshore environment.

As critical structures within FPSO cargo tanks are both 'inspectable' and 'repairable', according to class rules they would be assigned a lower factor of safety than critical inaccessible structures in way of the turret. However, even though cargo tanks are accessible, the impact on cost, safety and production of a program of extensive FPSO cargo tank repairs is so large that operators should consider specifying the highest fatigue factors of safety.

This is an example of a commercial impact issue that could be identified in concept screening (see previous section). In this case a corrective action can be taken to mandate increased fatigue factors of safety in Cargo Tanks. Of course any such proposal must pass a simple test of reasonable practicability.

Fatigue factors of safety – Critical Hull Structures (cont.)

However, the general point is that commercial assessments of this type are generally only weakly driven in most projects and by the time the asset goes into operation opportunities for major risk reduction may be limited.

Mooring Integrity inspection and replacement

The general subject of mooring integrity and mooring system inspection could take up many more pages and it is not the intention of this paper to enter into the subject in any detail. However it is equally impossible to complete a paper of this type without commenting on this issue.

Significant efforts have been made in this area by JIP studies over the last 10 years. However, despite this;

- Many FPSO's have no mooring line tension monitoring.
- Many line tension monitoring systems are un-reliable.
- Line failures are not always identified at the time.
- In water survey of moorings still has major limitations.
- The cost of removal/replacement is usually significant
- Many operators do not carry critical spares.
- Many operators do not have replacement procedures
- Many operators do not inspect moorings in air
- Many operators do not rotate for inspection onshore.

Owing to practical considerations mooring system integrity remains a weak link in the design and operation of FPSO's.

Temporary Phase Operations

One of the key areas of marine risk exposure in any offshore Oil & Gas project is in the temporary phases (i.e. the operations typically covered by construction all risks CAR policies). The key phases are typically as follows;

- Module Load Out Transportation & Installation.
- Transportation & Pre-installation of Moorings.
- Transportation & Installation of Risers.
- Transportation & Installation of Pipelines.
- Transportation & Installation of sub-sea facilities.
- FPSO transit yard to yard
- FPSO transit to field
- Location & Hook Up of FPSO.

The risk of marine transportation and installation is well known within the industry and we have a fairly well developed approach using marine assurance and marine warranty processes. The largest exposures are generally with in-experienced contractors or where schedule constraints prevent effective planning and verification. Often problems arise with the smaller modules because they get the least attention.

Temporary Phase Operations (cont.)

Operations that require particular attention include;

- Transverse skidded load outs
- Harbour Transits in Crane Hook(s)
- Site integration lifts
- Ocean Tows and transits

Sub-Sea Installation Operations

Sub-sea installation operations are another area of significant risk exposure. This is because they generally feature an extended schedule of weather limited operations. Contractors therefore have to judge limiting operating conditions on an on going basis, estimating the time required to abandon operations and secure the worksite. There may also be other batch processes e.g. welding, preparation etc., so there is plenty of opportunity for human error.

As the operations are typically continuous they, the traditional approach using MWS certificates of approval to control each stage of an operation may not be effective. The loss potential extends into other areas e.g. welding, field joints, coatings, corrosion protection etc. In the Far East the generally benign environment may tempt in-experienced contractors to take on challenging activities for which they are neither properly equipped nor sufficiently experienced.

A sub-sea installation contractor's background is usually helpful when applied to loss prevention and independent reviews (especially for deep water installations). There are however relatively few individuals of the required experience working in this area and the scope of work can be a competitive issue. Sub-sea installation operations therefore represent an on going project execution risk for FPSO's.

Temporary Phase Issues to Highlight

In addition to the focus that is normally applied to temporary phase operations, two subject areas have been highlighted because of their major loss potential. These are;

- Ship Yard Fires and
- Inshore Moorings.

Shipyard Fire and Explosion

The fire and explosion hazard in marine construction and conversion yards is simply an extension of the same hazard in conventional ship building. A simple Google search shows that these events are relatively common.

Shipyard Fire and Explosion (cont.)

Vladivostok September 2013
Reuters Sept 17 2013- A fire burned for five hours on an atomic-powered submarine undergoing repairs near Russia's eastern port of Vladivostok on Monday. The fire started in a ballast area of the submarine during welding works after an acetylene torch was used to cut through a grate, setting a rubber seal, cables and paint on fire, RIA cited an unnamed official at the shipyard as saying.

Singapore March 26th 2013
The SCDF conducted a fire-fighting operation at Tanoto Shipyard. The fire started from a tug boat and later spread to three others that were adjacent to it, said the Ministry of Manpower (MOM) on Wednesday.

The historical record shows a large number of other incidents. These events all have the potential for fatalities, pollution and constructive total loss, so there are a key concern for FPSO's. In the authors experience shipyards vary considerably in their attention to fire watch, fire protection & firefighting arrangements. It is therefore good practice to regularly confirm the suitability & effectiveness of the fire prevention/fire fighting arrangements.

Inshore and Quayside Moorings

The provision of inshore and quayside moorings is a similar area of concern. Just one recent example is instructive.

Apr 3 2013 Mobile Alabama
The Carnival Triumph broke loose of its moorings at a Mobile, Ala. shipyard Wednesday afternoon. The Mobile Press-Register said strong winds may have pulled the 900-foot-long ship from its dock at BAE Ship Systems where it was undergoing repairs. At about 1 p.m. Wednesday, winds were reported gusting up to 41 miles per hour, according to the National Weather Service.

FPSO's are potentially exposed to this hazard owing to typically large wind areas, the high value of the construction and the temporary nature of the quayside or inshore phase. Key success factors for the design of inshore moorings include;

- Large Capacity bits and anchorages shore side
- Large Capacity connection points on the hull
- Effective quayside fendering and/or
- The ability to hold the vessel off the Quay
- Prevention of chafe points and low line bend radii
- Space to deploy longer breast and spring lines
- Winch capacity to adjust line tensions
- Sufficient mooring lines to provide redundancy
- Effective marine watch keeping

Inshore and Quayside Moorings (cont.)

Once these practical issues are solved the mooring should ideally have sufficient capacity for the 10 yr. return seasonal design storm. Large scale construction yards offer the opportunity to address these issues on a pre-planned basis and investment can be provided in the longer term in suitable facilities. However, documenting the capacity of shore side bitts, strong points etc. is challenging and almost impossible in many cases. The problem is even more severe when short term quayside or inshore moorings are considered.

In reality there are very few very short term inshore/quayside locations that can provide all of the above requirements. This is especially so for the UK East Coast. Completed hulls delivered from the Far East for deployment in the North Sea are therefore exposed. Projects rarely plan for the necessity of quayside operations on arrival and once a hull is put alongside carry forward work, mobilization logistics, waiting on weather etc. can extend the period spent alongside.

As few projects realize the cost and pre-planning required to meet safe mooring requirements even for short exposures, the resulting arrangements are frequently compromised even when MWS approval is secured.

Design Integration and Operating Integrity

In proceeding sections several specific Marine & Naval Architectural issues have been addressed. In fact there are many more issues that could have been brought forward and each of the topics that have been listed could have been developed in greater detail. There are however two underlying themes that run through all of the matters discussed in this paper and these are the related issues of;

- Design integration and
- Operations integrity.

The failure to achieve adequate design integration during concept, FEED and EPCI phases leads to sub-optimal designs being deployed to the field. Poor standards of operating integrity lead to human errors in maintenance, operations and real time hazard management. Both issues are critical for HSE and commercial value improvement.

Design Integration

Design integration is compromised principally by the way in which our industry executes projects, the nature of the interfaces, internal controls etc. and the time that is available to complete design and verification activities. Given the net present value associated with timely project execution, it is inevitable that projects will be under pressure to deliver on cost and schedule and some compromises are therefore unavoidable.

Design Integration

Some projects perform better than others, but in most cases it is the relatively short period provided for project definition in FEED that is at the heart of the problem. The practice of running topsides and Naval Architectural FEED in parallel will always result in challenges that can in some cases seriously derail the schedule. This is especially so where there are novel technologies or concepts to be integrated in the design.

Schedule pressure tends to squeeze out the ideal processes (e.g. effective commercial hazard management, change control, verification and design integration). Modern projects all contain multiple interfaces, between company, geography, technical discipline and function. IT techniques and fast broad band have made this possible but the project integration challenge has therefore increased.

Lessons learned processes are frequently compromised, and operator technical specialists few in number so many projects rely upon skilled individuals, contractors and consulting companies.

The flexible employment practices used in our industry have a number of benefits, especially in the allocation of short term resources. However, as the most effective learning mechanism is in the experience of individuals, the application to projects is sometime a random function of mobile labour force. Individuals have little incentive to commit lessons learned to other media and consulting companies efforts to build up intellectual capital are squeezed by competition.

There some industry wide mechanisms for lessons learned transfer, websites, databases, codes and standards and even conference papers, however the hard reality is that exactly the same issues arise project after project, so it is relevant to ask just how effective these processes are.

Marine Operations Integrity

Most of the major accidents that have occurred in our industry (and will occur in any industry) are attributable to poor standards of operating integrity. Piper Alpha was initially caused by an operating integrity failure and whilst there were major issues with the inherent safety of the platform, there were operating integrity issues throughout the response to the emergency.

The same picture emerges for the 'Gryphon Alpha' station keeping incident. Whilst the design had an inherent vulnerability, deficiencies in operations integrity made significant contributions to both cause and escalation.

Marine Operations Integrity (cont.)

The problem reaches across all disciplines including marine operations, maintenance, process safety, transportation, logistics etc., and whilst the details vary, the fundamental vulnerability to variations in human behavior is a constant.

The marine industry has been dealing with this 'elephant in the control room' for many years and whilst there have been improvements, attempts to shift the elephant have never been (and perhaps never will be) totally successful. There are particular challenges for marine operations within the Oil & Gas industry which make that task more challenging;

- Process Operations and Marine Operations have different risk drivers. Process operations can be shut down, FPSO Marine operations are by definition continuous.
- Marine Operations are difficult to automate/make inherently safe and must therefore rely on competency assurance and procedural control, which are both subject to human factors.
- It is extremely difficult to write performance standards, verification standards and operating limits for human factors.

These challenges will be clear to anyone that has been tasked with writing performance standards for the marine aspects of an FPSO. In areas as diverse as stability, heading control, ballast control, shuttle tanker offloading, ship collision and many others, the principal safety critical elements are the procedures and the competency of the individuals engaged in operations. These are not parameters that are easily captured in a performance standard.

During 2010, the author was tasked by the UK HSE to assist with task of extending an existing integrity framework for fixed structures to cover FPSO's and MODU's. It quickly became apparent that the Structural Integrity Management (SIM) concept that lies at the heart of the UK Design and Construction Regulations (DCR) is insufficient to cover all critical aspects of a floating facility. The concept of "Primary Integrity Management (PIM)" (of which SIM is just one part) had to be introduced to cover other critical systems, e.g. stability, ballast, bilge, marine operations (etc.). In this document the critical issue of marine operating integrity was highlighted but not resolved.

Marine Operations Integrity (cont.)

One way forward may to consider an operating integrity dash board using a standardized process to objectively measure the condition of an operation. The process side of the industry has recently begun to look at this subject once more. There are also examples in the UK public health industries, that are increasingly exposed to similar issues. Certainly choosing a common and established frame work would be the right step forward. This is however just one of the tools that will be required to tackle this problem.

Conclusions

The paper has highlighted a number of challenges and gaps in the marine and naval architectural aspects of FPSO projects. Many other similar issues could have been included, but have been omitted due to confidentiality issues and time constraints.

Whilst there remain a large number of weak links in the marine aspects of FPSO projects, the outlook remains generally positive. Demand for FPSO's remains high and the future must belong to those contractors that can better integrate and therefore better execute projects.

The balancing the time required to achieve reasonable project definition with the project execution risk will always be difficult to judge. Truncating FEED to run topsides and naval architecture in parallel may not always lead to sufficiently well defined tenders from contractors.

However, the key challenge for marine loss prevention is in the area of operating integrity. Before we can move forward we will need some consensus on the criticality of this issue and the gap between where we are now and where we need to be in 10 years time. It is hoped that in some small way this paper might help to stimulate the required debate.

Table 1: FPSO's – Diversity of Design Solutions - Representative Examples				
Vessel	**Field**	**Location**	**Specifications**	**General Description**
Buffalo Venture Modec	Buffalo – Field	NW Australia (Timor Sea) Benign Environment	255 m water depth, 1 riser, 6 leg mooring 40,000 bpd oil, 8 mmscfd gas	Small FPSO, sloping sea bed – connected to well head platform – field life 5 years. Hull conversion, stern accommodation, forward flare. Small process foot print.
Anoa Natuna Modec	Anoa – Field (Premier)	Natuna Sea (Indonesia) Benign Environment	32,000 bpd oil, 5.4 mmscfd gas 550,000 barrels storage	Purpose built small barge, external turret, limited process foot print, forward flare, aft accommodation, stern taut hawser off-loading to mid-ship manifold.
Fulminese Modec	Bijupera – Salema (Enterprise)	Brazil Campos Basin Medium Environment	740 m water depth, 15 Risers 3 umbilicals 81,000 bpd Oil, 75 mscf/day Gas 1.3 million barrels storage, 110,000 bpd WI	Conventional FPSO, external turret, conversion hull, limited topsides, stern offloading, forward flare, aft accommodation. Medium process foot print. Power requirements gas export, WI & offloading.
North Sea Producer Mearsk	Mac Culloch Field (Conoco)	UK North Sea Harsh Environment	92 m Water depth, 76,000 bpd oil 560,000 barrels storage, WI 70,000 bbls/day 9 point mooring (3 x 3)	Harsh environment FPSO, internal forward turret. Converted product tanker with hull upgrade for fatigue, stern offloading hose reel, for 150,000 dwt bow loading tanker. Large topsides footprint.
Petrojarl I Teekay Corporation	Glitne Previously; Troll, Oseberg, Blheim Kyle, Angus, Lyell, Fulmar, Balder	Norway Harsh Environment	110 m water depth, 45,000 bpd oil, 200,000 bbls storage, Gas Lift 20mmscfd 8 point mooring, Central tentech 685 turret Main propulsion + 2 fore + 2 aft thrusters	Early harsh environment FPSO, by Golar Nor built 1986 for term marginal fields, Glitne 2-3 yrs extended 12 yrs. Fwd accom, central turret, ground flare aft. Heading control by propulsion/thrusters. Riser disconnection system. Large topsides foot print.
Skarv FPSO	Skarv Field (BP)	Norway Ultra Harsh Environment	370m water depth, 85,000 bbls/day oil 19 mscm/day gas, storage 875,000 bbls 15 mooring lines, 21 riser slots 3 Aft & 2 fwd azimuthing thrusters	Ultra harsh environment FPSO, with fwd accommodation, central turret and power gen package between turret and accommodation. Stern flare, oil off loaded by shuttle, gas by pipeline. Heading controlled but moorings designed for black out.
Haewene Brim Bluewater/Shell	Pierce Field (Shell)	UK North Sea Harsh Environment	70,000 bpd oil, 110 mmscf/day gas, storage 600,000 bbls storage. 90,000 bbl/day WI added in 2004. DP class 2 heading control. 83m water depth. 10 riser slots.	Converted MST with first APL STL removable mooring buoy. Delivered 1996. Fwd accommodation and engine room with diesel electric drive. Aft flare. Dual fuel diesel engines converted to burn produced gas at 350 bar.
Scheihallion FPSO BP	Sheihallion Field (BP)	UK Atlantic Margin Ultra Harsh Environment	154,000 bpd oil, 950,000 bbls storage 14 moorings lines, 24 riser slots. 400 m water depth	New built ultra harsh accommodation FPSO barge with forward SPM, turret and flare. Aft accommodation and 2 x aft thrusters. Escape tunnel running down port side. Installed 1998. New FPSO planned under quad 204 re-development.
Petrojarl Foinaven Teekay Corporation	Foinaven Field (BP)	UK Atlantic Margin Ultra Harsh Environment	95,000 bpd oil, 300,000 bbls storage 165,000 bpd water injection 10 moorings, 15 riser slots	Converted Russian submarine service vessel delivered to field 1996. Internal turret, heading control, fwd accommodation, turret immediately after accommodation.
Kizomba FPSO	Kizomba A (Exxon Mobil)	Angola West Africa Benign environment	1,200m w depth 2.2 mbbls storage, 150,000 bpd oil. 13 line taut catenary mooring.	New build spread moored barge with extensive topsides foot print and steel catenary risers. The worlds largest FPSO when installed in 2005. Operates in close proximity to TLP.
BW Athena FPSO BWO	Athena Field (Ithaca)	UK North Sea Harsh Environment	28,000 bpd oil, 25,000 bpd water injection 50,000 bbls storage.	One of two smallest FPSO's in world. STL turret, moored with forward accommodation, aft flare (relocated inboard) and shuttle tanker stern of loading. Limited deck space for process systems.
Voyageur Spirit	Shelley Field (Premier Oil)	UK North Sea Harsh Environment	120m water depth , 30,000 bpd oil 270,000 bbls storage.	Novel Cylindrical FPSO, established on Shelley in August 2009 with 3 x 4 fibre rope mooring. Offloading by shuttle tanker from twin hose reel system.

Table 2 – Fatigue Factors of Safety – From Ref [1] Fatigue Methodology of Offshore Ships - Recommended Practice DNV-RP-C206, October 2006		
Structural Members	**Critical Structural Details**	**Example Fatigue Load**
Longitudinal Hull Structural Members	Doubler plates Bracket toes and heels Rat holes and erection butts Deck openings. Longitudinal girders. Structural terminations	Hull girder bending/shear loads. Wave pressure loads. Pressure loads from internal fluid. Topside loads, stresses due to loading/offloading
Transverse Hull Structural Members	Shear lugs and cut-outs . Hopper corners. Transverse frames and gussets. Transverse bulkheads.	Wave pressure loads, Pressure internal fluid , Topside loads, Differential pressure loads.
FPSO Specific Details	Topsides module supports, Flare Tower Foundations, Riser Porches, Caissons, Mooring Foundations, Crane Pedestals, Deck Penetrations, Helideck/deck, Hull/Turret interfaces.	Hull Girder bending, Variation side shell pressure loads. Deck deformation loads, riser loads, mooring loads, topside inertia loads, crane loads, wind loads, temperature loads.
Fatigue design factor (DFF)	**Category Description**	
2	Internal structure, accessible and not welded directly to the submerged part.	
2	External structure, accessible for regular inspection and repair in dry and clean conditions.	
3	Internal structure, accessible and welded directly to the submerged part.	
3	External structure not accessible for inspection and repair in dry and clean conditions.	
10	Non-accessible areas, areas not planned to be accessible for inspection and repair during operation.	

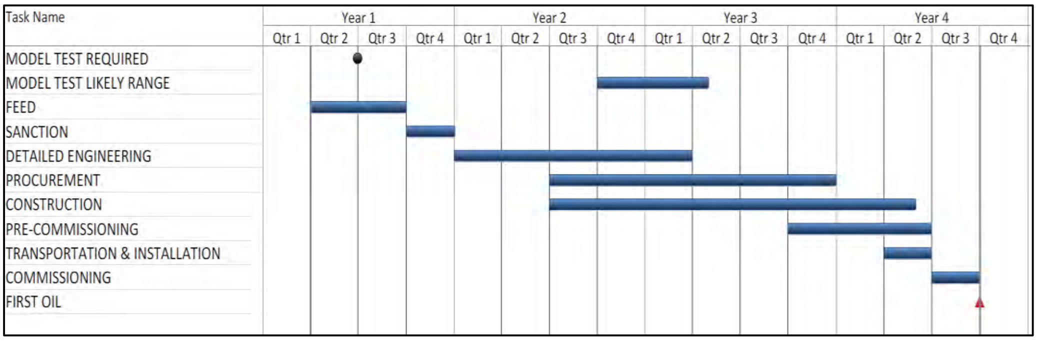

Figure 1. Fast Track FPSO Project Execution Schedule

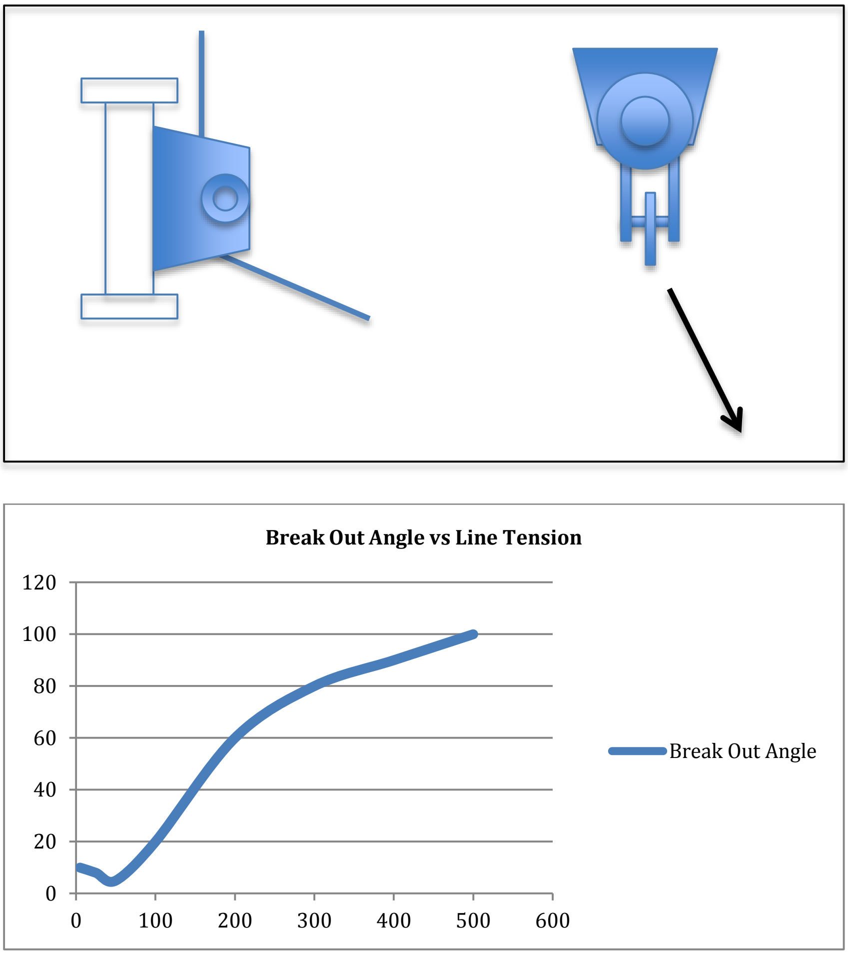

Figure 2. FPSO Fairlead Break Out Angle - Illustrative