FIXED VERSUS DISCONNECTABLE TURRET SYSTEM

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ABSTRACT

With the anticipated development of a large number of fields offshore in the South China Sea in the areas known as typhoon alley, there is a need for the owners and operators of the field to evaluate a fixed versus disconnectable turret moored system for FSO's and FPSO's in terms of CAPEX, OPEX and system availability during service life which impacts “Lost Production and Risk” . These two turret mooring systems are each unique and result in differences in general arrangements, operational characteristics and life of field costs. The selection of which turret mooring system for a FSO or FPSO is complex as it depends on a variety of factors including environmental conditions, field layout, production rates, storage capacity, offloading frequency and typhoon shutdown.

This paper presents information and results that allow a structural evaluation of fixed versus disconnectable turret moored FSO's and FPSO's from a technical, commercial and operational viewpoint. The objective of the paper is to provide a guide to the decision making process of the appropriate selection of the FSO or FPSO based on comparative turret mooring and fluid-transfer issues, CAPEX, OPEX, Lost Production and Risk due to typhoons.

This paper compares fixed and disconnectable turret mooring systems by:

• Defining typical design parameters for the two systems;
• Evaluating the turret mooring and fluid-transfer systems;
• Contrasting the engineering, procurement, construction and field installation costs (CAPEX);
• Assessing operational consideration such as system availability, Lost Production, product offloading and OPEX for life of field; and
• Evaluating Risk due to typhoons.

The example used to illustrate the selection process between the two systems is a generic field in the South China Sea in the area known as typhoon alley. The example presents results from the global analysis to allow comparison of the mooring and riser performance and availability of the production and offloading systems. Cost estimates of the two systems are presented showing the breakdown among various components and comparisons between the two based on CAPEX, OPEX, system availability, Lost Production and Risk.

This paper provides a mechanism to help owners and operators to evaluate FSO and FPSO options with both types of turret mooring systems

INTRODUCTION

The first turret mooring in the offshore industry was used on the "Discover" class drillships developed in the late 1960's by the Offshore Company. This background of experience combined with Single Point Mooring technology has led to the use of turret moored vessels for offshore production and storage application.

Fixed mooring systems for floating, storage and offloading (FSO) and floating, production, storage
and offloading (FPSO) vessels have been in use since the mid 1970’s. These systems are normally designed for a 100-year storm conditions and have been employed worldwide. Although complex, they are relatively straightforward to design. However, fixed mooring systems in harsh environments (particularly those produced by seasonal cyclonic weather systems) are not always the most cost effective.

There are about six (6) FSO’s and nine (9) FPSO’s presently in the South China Sea Area with nine (9) units fixed and six (6) units disconnectable.

Image 3 South China Sea Area

This paper evaluates the fixed versus disconnectable FSO and FPSO mooring systems for an average South China Sea with parameters as shown in Table 1 “100-YEAR SURVIVAL TYPHOON CONDITIONS”. The field is a medium range field to be developed in an area having seasonal cyclonic weather systems. This Case assumes the following design criteria:

- The water depth is 150 m,
- The FSO or FPSO has 1.25 million barrels of cargo storage (approximately 170,000 dwt tanker),
- The offloading tankers are up to 150,000 dwt,
- The field life is 20 years,
- The oil production rate for the FPSO is 100,000 bopd and the offloading rate is 50,000 barrels/hour for a parcel size up to one million barrels

There are many prospects similar to this criteria that are presently under consideration for the South China Sea Area today.

This paper will attempt to guide you through the process that is involved in selecting which mooring system is suitable for your application. This is done by the two cases that will be discussed in this paper and then comparing them using a set number of design parameters and deciding the...
most viable solution based on the analytical results.

**DESIGN CRITERIA FACTORS**

**Environment:**

Typhoon for this case is shown in the evaluation of history of the typhoons in the Section 6 “TYPHOONS SOUTH CHINA SEA AREA”. This section shows that the typical cyclonic season mainly occurs in the last half of the year. The FSO's and FPSO's average shutdown time is three (3) times a year where shutdown of storage and production occurs and the crew must leave the area. The survival environment assumed design conditions for the 100-year typhoon are the following:

- **Collinear:** Wind and current collinear with waves.
- **Crossed Option 1:** Current acting 30 degrees to wind and waves.
- **Crossed Option 2:** Current acting 45 degrees to wind and waves.

**Field Characteristics:**

- **Water Depth:** 150 meters
- **Soils Conditions:** Assume suitable for high-holding power drag-embedment anchors
- **Production Criteria:**
  - **Production:** 100,000 bopd
- **Field Life:**
  - Twenty (20) year field life

**Flexibility-Operability-Risk:**

These factors must be analyzed in accordance with the field parameters of the field being evaluated.

### 100-YEAR SURVIVAL TYPHOON CONDITIONS

<table>
<thead>
<tr>
<th>STORMS / DIRECTIONALITY</th>
<th>100-YEAR TYphoon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collinear</td>
</tr>
<tr>
<td><strong>CURRENT</strong></td>
<td></td>
</tr>
<tr>
<td>Velocity @ Surface (m/s)</td>
<td>2.33</td>
</tr>
<tr>
<td>Direction (deg)</td>
<td>180</td>
</tr>
<tr>
<td><strong>WIND</strong></td>
<td></td>
</tr>
<tr>
<td>Velocity (m/s, 1 minute)</td>
<td>52.1</td>
</tr>
<tr>
<td>Direction (deg)</td>
<td>180</td>
</tr>
<tr>
<td><strong>WAVE</strong></td>
<td></td>
</tr>
<tr>
<td>Significant Height (m)</td>
<td>12.1</td>
</tr>
<tr>
<td>Peak Period (s)</td>
<td>13.8</td>
</tr>
<tr>
<td>Peak Parameter</td>
<td>3.3</td>
</tr>
<tr>
<td>Direction (deg)</td>
<td>180</td>
</tr>
</tbody>
</table>

**TABLE 1 – 100 Year Survival Typhoon Conditions**

**DESIGN BASIS**

The Design Basis for this paper uses the following criteria, which represent a normal range for a typical marginal field in the South China typhoon area.

- **Service Life:** 20 years
- **Vessel:** 170,000 dwt
- **Storage:** 1,250,000 barrels
- **Maximum Offloading Parcel:** 1,000,000 barrels
- **Oil Production:** 100,000 barrels oil/day
- **Gas Production:** 130 MMscfd

- **Water Depth:** 150 meters
Pressure at Vessel: 285 psig
Offloading Rate: 50,000 barrels/hr

Risers:
12" Production: 3 Lines
Umbilicals: 3 Lines

CASE STUDY

This section of the paper utilizes two case studies to illustrate the differences between utilizing a fixed turret moored FSO or FPSO versus a disconnectable turret moored FSO or FPSO both in terms of design and performance, and also in terms of CAPEX, OPEX, Lost Production and Risk. The two case studies are based on hypothetical marginal fields in the South China Sea Area. Environmental data typical for the region has been used to evaluate the system performance described in the case studies.

CAPEX, OPEX, Lost Production and Risk estimates are made consistently for both systems based on common subsystems and relative operational expenses. As a final comparison a Present Value (PV) estimate is made for both systems, allowing for a direct comparison of total cost of each system at the first oil milestone. The following sections provide a description of the global system analysis and financial analysis performed and then a detailed description and evaluation of the two case studies.

GLOBAL ANALYSIS

Each FSO and FPSO turret mooring systems was analyzed and designed with sufficient detail to provide a +/- 15% accurate cost estimate. Care was taken to ensure consistent analysis, design methodology and design margins between the fixed and disconnectable turret moored FSO or FPSO for each case study. The global analysis and design was performed with state-of-the-art industry analysis tools and design methodology. This allowed a consistent development of the mooring system design for both systems including the definition of all anchor leg components, anchors, fairleads and required vessel-based installation equipment. In addition system loads (turret loads) and responses were computed for both systems, thus allowing an evaluation of the vessel motions and associated production system relative downtime analysis. The offloading system design and performance as a function of the mooring system and environment was also obtained from a detailed numerical analysis of the offloading operation with export tankers of opportunity and tug assistance.

FINANCIAL ANALYSIS BASIS AND METHODOLOGY

The financial analysis performed in this paper provides a means of comparing the two FSO or FPSO turret mooring systems and is considered to be accurate within +/- 15%.

The design basis for the two cases, the various sub-systems and components are identified to determine the appropriate CAPEX of the common sub-systems between the two turret mooring systems, including engineering, management, fabrication/assembly costs. For the purpose of this paper the CAPEX costs were accumulated for the following sub-systems based on present costs with typical profit and overhead rates.

- Mooring: This includes all systems of the mooring to vessel load-transfer system including anchor leg components, fairleads and chain stoppers, the turret structure, mooring installation equipment, etc.
- Fluid-Transfer: This includes all equipment required for fluid-transfer from the risers to the topsides production stream. This includes manifolding, pig launching and receiving, swivel stack, riser specific installation equipment and etc.
- Hull Systems: This includes the turret moonpool, bilge keels and etc.
- Topside Systems: This includes equipment specific to topside system cost due to turret mooring system selection, e.g. metering, chemical injection skids, electrical and hydraulic systems that may be located in the turret system, modifications to topsides to accommodate the selection of either system and etc.
- Offloading System: This includes the specific offloading system components required for the mooring system. This also includes offloading system related equipment onboard the vessel.
- Installation: This includes all installation costs to install and hook-up the FSO or FPSO to the turret mooring and offloading system.
- Service and Administration: This includes all engineering, management, procurement and mark-up costs associated with each of the turret moored systems specific items described above.
The operational costs (OPEX) of the two systems are also estimated within +/- 15% accuracy again focusing only on the costs that are specifically related to the turret mooring system selection. We have also assumed an inflation rate of 2% per year. The OPEX estimates are based on:

- **Demurrage**: Tanker demurrage time and charges.
- **Maintenance and Inspection**: This includes all maintenance and inspection requirements for the turret mooring and offloading systems specific components.
- **Offloading Tugs and Pilots**: This includes the costs for offloading assistance from support vessels and pilots required for navigating around the FSO or FPSO.
- **Difference in Crew Costs**: Disconnectable crew must contain a complete maritime crew required for sailing vessel.
- **Typhoon Evacuation Costs**: All associated costs with crew evacuation during typhoon.

The Lost Production and Risk are costs resulting from shutdown due to typhoon, which has an average of about three (3) times a year for a vessel in the South China Sea Area. The typhoon shutdown is discussed in the next section “TYPHOONS SOUTH CHINA SEA AREA.”

The Present Value (PV) of the two systems serves as a method of comparing the total cost of the mooring systems on the same time reference, accounting for inflation and the present value of future expenses. The PV for both case studies are based on a 10.5% discount rate computed from the first oil milestone.

**TYPHOONS SOUTH CHINA SEA AREA**

The Naval Pacific Meteorology and Oceanography Center / Joint Typhoon Warning Center (JTWC) have been recording all typhoons since 1959 for the Southwest Pacific Ocean and Southern Indian Ocean.

Table 2 “Typhoons South China Sea Area, 1959 to 2001 - 42 Years” gives the year, month, name and maximum sustained surface wind speed in knots.

A typhoon is a storm that attains at least 64 knots sustained surface winds during its lifetime. One of the most awesome natural forces on earth is the super typhoon. The first known reference to the term was by Kinney (1955) when he used it to describe large typhoons in general. The first official use of the term by JTWC was in their 1963 Annual Typhoon Report. Nevertheless, it has attained common usage both as a technical classification and by the news media as a description term for the stronger typhoons. It is quite probable that the 130 knots sustained surface winds during its lifetime delineation was chosen because it is the value, to the nearest 5 knots, that is twice the 64 knots intensity adopted for classification as a typhoon.

The months with all 42 years of typhoons and super typhoons are shown on Figure 1.

The average number of typhoons per year in the South China Sea Area is 6.4 typhoons with 1.2 of that total being super typhoons.

The first alert is started on the FSO or FPSO when a typhoon is within four hundred (400) nautical miles. The FSO or FPSO is evacuated when the typhoon is within three hundred fifty (350) nautical miles. This happens approximately 50% of the time a typhoon enters the South China Sea Area, which results in an average of 3.2 shutdowns a year on the FSO or FPSO.

Figure 2, shown at the end of this paper, shows the average frequency of a typhoon per month over the year with the last half of the year having over eighty-five (85%) percent of the typhoons occurring.

**CASE 1: FIXED INTERNAL TURRET SYSTEM**

To moor a large tanker in one hundred fifty (150) meters water depth in typhoon conditions requires a robust mooring system. The anchor lines include excursion limiters to stiffen the mooring.

The fixed internal turret system is arranged in three (3) groups 120 degrees apart with three (3) legs in each group. The anchor leg moorings consist of chain, wire and excursion limiter. The excursion limiters are made of additional heavy chain lengths attached to the ground chain and provide additional restoring force to reduce the vessel offsets.

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1 Table 2 is located at the back of this paper.

2 Figures 1 through 9 are located at the end of this paper.
The mooring leg design is conducted in accordance with the latest edition of API RP-2SK: Design and Analysis of Station Keeping Systems for Floating Structures with the minimum safety factors requirements of 1.67 for intact systems and 1.25 and 1.05 for damaged systems in equilibrium position and respectively. The safety factors account for the reduction in strength associated with the maximum expected corrosion and wear of chain over the design life of the project.

A steep-S riser configuration would be proposed for this type of project. No interference between anchor legs and the production risers would be permitted under any design stern conditions for intact or damaged mooring system.

The general design specification provided for a one hundred (100) year typhoon requires three directional cases to be investigated as specified in Design Criteria Factors, Environment, Table 1: 100-Year Survival Typhoon Conditions.

On the approach of a typhoon, production is shutdown and the FSO’s or FPSO’s crew is evacuated by helicopter and returns to the FSO or FPSO when the typhoon has passed and the area declared safe to return and start operating.

**CASE 2: DISCONNECTABLE INTERNAL TURRET SYSTEM**

The mooring system would be designed also to withstand the 100-year return period non-typhoon environment and be a symmetrical eight (8)-leg system. In the event that a typhoon is expected to approach the area, the production is shutdown, risers are flushed, disconnected and lowered into the spider buoy. The spider buoy is then released from the FSO or FPSO, submerges to a predetermined depth (generally 35 to 40 meters below the surface) where it stabilizes while supporting the risers and the mooring lines. After releasing the spider buoy, the FSO or FPSO will travel to safe waters. When the typhoon has passed, the FSO or FPSO returns to the site, recovers the floating retrieval line, reconnects with the spider buoy and production will quickly start again.

**CAPEX**

The financial analysis performed for this case study follows that of associated costs for South East Asia area. Figures 3, 4 and 5, present the CAPEX to First Oil for both the fixed and disconnectable internal turret mooring systems with tandem offloading. Figures 3 and 4 provide the relative contribution of the various groupings to the CAPEX for each Case and Figure 5 provides a direct CAPEX comparison in normalized US Dollars. The figures show that the fixed turret system has a lower CAPEX than the disconnectable turret system by approximately 4 to 5% for this Case study. The main difference is the additional cost for engineering and mechanical equipment. But the increase in engineering and mechanical equipment requirements will not have any impact on the schedule for the FSO or FPSO because the turret engineering and fabrication activities are parallel with the FSO or FPSO topside process equipment activities, and are normally not the project critical path items.

**OPEX**

**FPSO Crew:**

Figure 6 shows the Organizational Chart for a typical FPSO crew for Case 1 “Fixed Internal Turret System”.

Figure 7 shows the Organizational Chart for the same FPSO crew for Case 2 “Disconnectable Internal Turret System” but will require certain crew members to have their maritime license papers.

**Typhoon Evacuation Costs:**

In Case 1 “Fixed Internal Turret System” the crew must begin shutdown of production approximately four (4) to six (6) hours prior to evacuation. Most oil industry crew helicopters carry approximately eighteen (18) persons. The FPSO’s require approximately four (4) to five (5) trips and for FSO’s probably two (2) trips are required to complete evacuation of the crews and then return them after the typhoon has left the area. These are considered in typhoon evacuation costs. The crew must upon return inspect the vessel for typhoon damage and then start-up production in a short time span after given clearance from the typhoon damage inspection.

The crew for Case 2 “Disconnectable Internal Turret System” must also take about four (4) to six (6) six hours to properly shutdown production and disconnect the mooring system and began sailing from site. Upon return to the site, the vessel is reconnected and production is started within a few hours.
**Lost Production:**

The Lost Production per year is assumed as the following:

**LOST PRODUCTION due to Maintenance and Typhoons per Year**

<table>
<thead>
<tr>
<th></th>
<th>Case 1 – Fixed Turret System</th>
<th>Case 2 – Disconnectable Turret System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Facilities Maintenance</td>
<td>4 Days</td>
<td>4 Days</td>
</tr>
<tr>
<td>Well Major Workover</td>
<td>.5 Days</td>
<td>.5 Days</td>
</tr>
<tr>
<td>Downtime Due to Shortage Limitations</td>
<td>4 Days</td>
<td>4 Days</td>
</tr>
<tr>
<td>Downtime Due to Typhoons (3 Times)</td>
<td>10 Days</td>
<td>9 Days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Average Lost Production</td>
<td>18.5 Days</td>
<td>17.5 Days</td>
</tr>
</tbody>
</table>

**CASE OIL PRODUCTION - SOUTH CHINA SEA**

100,000 BOPD OVER 20 YEARS

[Bar chart showing estimated oil production per year from Year 1 to Year 20, with BOPD on the y-axis and years on the x-axis.]
Figure 8 presents a description of the OPEX per year for each of the FPSO turret mooring systems. The figure illustrates that the OPEX normalized over 20 years for the disconnectable turret system is greater than that of the fixed turret system primarily due to turret maintenance costs.

The Figure 9 illustrates that when the total cost of the two systems are compared the Case 1 “Fixed Internal Turret System” has the total lower cost for CAPEX and OPEX but Case 2 has less Lost Production which makes Case 2 total normalized cost about 3.7% less.

TOTAL COST COMPARISON:

Figure 9 represents a total cost comparison between the Cases. The total cost is presented as the PV at the first oil milestone based on a 10.5% discount rate, 2% inflation per year, and the price of oil in the $20 to $26 per barrel range for the life of the field.

RISK:

The risk comparison of the two cases is evaluated in the following Table 3.

<table>
<thead>
<tr>
<th>Description</th>
<th>Case 1 – Fixed Internal Turret System</th>
<th>Case 2 – Disconnectable Internal Turret System</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSO or FPSO</td>
<td>Hull, topside equipment and mooring system must be designed for 100-year survival typhoon conditions and stay on location for 15 years with all maintenance done offshore.</td>
<td>Since the vessel leaves the site as the typhoon approaches, the hull, topside equipment and mooring system will be designed for much lower load conditions than the 100 year typhoon conditions. Also the vessel has the additional option of leaving for drydock maintenance such as every five years or in an unexpected maintenance requirement.</td>
</tr>
<tr>
<td>Crew</td>
<td>Crew must be evacuated by helicopters as the typhoon approaches.</td>
<td>Crew will sail on vessel as the typhoon approaches.</td>
</tr>
</tbody>
</table>

CONCLUSION:

This paper provides an overview of the comparison of the two cases, describing the advantages and disadvantages of each Case.

The two Cases demonstrated that when making a cost, performance and risk comparison, the total cost of the FSO or FPSO mooring and offloading systems must account for CAPEX, OPEX, System Performance and risk over the life of the field.

The results of this case study indicate that for an average South China Sea Area field, cost and risk factors must both be considered in evaluation.

The results show that Case 1 “Fixed Internal Turret System” cost less for both CAPEX and OPEX, but that Case 2 “Disconnectable Internal Turret System” has the lowest Cost Production and Risk on design, crew safety and the additional flexibility of drydocking if required.

A point to remember is that as the water depth increases, the CAPEX of the Fixed Turret Mooring System will increase significantly faster than the Disconnectable System. Also, for each crew evacuation for the Case 1 “Fixed Internal Turret System”, one must consider how many helicopters are required and what other offshore production area location crews must also be evacuated before a final decision is made on which turret system to use.
REFERENCES


Figure 3
CAPEX - CASE 1 SOUTH CHINA SEA
FIXED INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

- Mooring Systems: 32%
- Fluid Transfer Systems: 13%
- Topside Systems: 13%
- Hull Systems: 13%
- Offloading Systems: 13%
- Installation: 13%
- Services & Administrative: 16%

Figure 4
CAPEX - CASE 2 SOUTH CHINA SEA
DISCONNECTABLE INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

- Mooring Systems: 28%
- Fluid Transfer Systems: 17%
- Topside Systems: 11%
- Hull Systems: 11%
- Offloading Systems: 13%
- Installation: 14%
- Services & Administrative: 17%
Figure 5
OSEA 2002
CAPEX - CASE SOUTH CHINA SEA

$10,000,000
$20,000,000
$30,000,000
$40,000,000
$50,000,000
$60,000,000

US DOLLARS

CASE 1 - FIXED INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING
CASE 2 - DISCONNECTABLE INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

Figure 6
CASE 1 - FIXED TURRET SYSTEM
FPSO CREW COMPLEMENT (43)
Figure 7
CASE 2 - DISCONNECTABLE TURRET SYSTEM
FPSO CREW COMPLEMENT (43)

Note: Cross indicates crew members which must have their maritime papers for serving FPSO.

Figure 8
OPEX
AVERAGE TWENTY YEAR OPERATION

- Maritime Crew Requirement
- Turret Maintenance
- Pilots, etc.
- Hawsers
- Typhoon Shutdown Helicopter
- Offloading Hose System
- Offloading Tugs, etc.
- Demurrage
CASE 1 - FIXED INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

CASE 2 - DISCONNECTABLE INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

OPPORTUNITY COST OF CAPITAL 10.5%

LOST OIL PRODUCTION
OPEX
CAPEX
<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Typhoon</th>
<th>Maximum Wind Speed (Knots)</th>
<th>Year</th>
<th>Month</th>
<th>Typhoon</th>
<th>Maximum Wind Speed (Knots)</th>
<th>Year</th>
<th>Month</th>
<th>Typhoon</th>
<th>Maximum Wind Speed (Knots)</th>
<th>Year</th>
<th>Month</th>
<th>Typhoon</th>
<th>Maximum Wind Speed (Knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>AUGUST</td>
<td>IRS</td>
<td>86</td>
<td>1964</td>
<td>MAY</td>
<td>VIOLA</td>
<td>70</td>
<td>1969</td>
<td>JULY</td>
<td>TESS</td>
<td>70</td>
<td>1974</td>
<td>JUNE</td>
<td>DINA</td>
<td>70</td>
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<td></td>
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</tbody>
</table>

Table 2 - Typhoons South China Sea Area

1959 TO 2001 - 42 YEARS