FIXED VERSUS DISCONNECTABLE TURRET SYSTEM FOR F(P)SO'S FOR GULF OF MEXICO

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ABSTRACT

With the anticipated development of a large number of deepwater fields offshore in the Gulf of Mexico. 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 tropical storms and hurricane 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 tropical storms and hurricanes.

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 hurricanes.*

The example used to illustrate the selection process between the two systems is a generic field in the offshore oil and gas fields in the Gulf of Mexico. 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. The disconnectable mooring systems provide an alternate solution for the production and storage of these fields.

Image 1 Fixed turret for Amoco Orient Petroleum Co., People's Republic of China, Liuhua 11-1 Field, Nan Hai Sheng Li FPSO

The first disconnectable turret was developed in the mid 1980's for the "JABIRU" field in the Timor Sea between Australia and Indonesia, an area frequented by severe cyclones during parts of the year. The decision to utilize a disconnectable turret for the "JABIRU" field was driven by economics after it was determined that a permanent fixed system which was technically feasible and relatively straightforward to design was far more expensive than the lighter, more complex disconnectable design for this project.

This paper evaluates the fixed versus disconnectable FSO and FPSO mooring systems for an average Gulf of Mexico with parameters as shown in Table 1 "100-YEAR SURVIVAL HURRICANE CONDITIONS". The field is a medium range field to be developed in an area having seasonal cyclonic

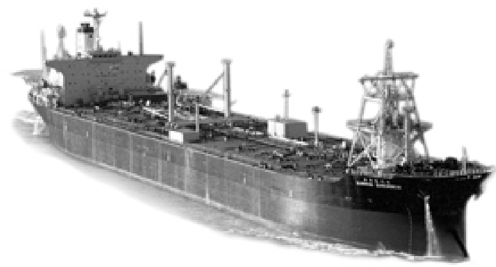

Image 2 Disconnectable turret for JHN, People's Republic of China - Lufeng 13-1 Field, for Nan Hai Sheng Kai FSO

weather systems. This Case assumes the following design criteria:

- The water depth is 500 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 Gulf of Mexico 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.

TABLE 1. 100-YEAR SURVIVAL HURRICANE CONDITIONS

STORMS / DIRECTIONALITY		100-YEAR HURRICANE Collinear	Option 1	Option 2
CURRENT	Velocity @ Surface (m/s)	2.33	2.33	2.33
	Direction (deg)	180	210	225
WIND	Velocity (m/s, 1 minute)	52.1	52.1	52.1
	Direction (deg)	180	180	180
WAVE	Significant Height (m)	12.1	12.1	12.1
	Peak Period (s)	13.8	13.8	13.8
	Peak Parameter	3.3	3.3	3.3
	Direction (deg)	180	180	180

DESIGN CRITERIA FACTORS

Environment:

Tropical storms and hurricanes for this case is shown in the evaluation of history of the tropical storms and hurricanes in the Section 6 “TROPICAL STORMS AND HURRICANES GULF OF MEXICO 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 one and half (1.5) 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 hurricane 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: 500 meters
- Soils Conditions: Assume suitable for high-holding power drag-embedment anchors or suction 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.

DESIGN BASIS

The Design Basis for this paper uses the following criteria, which represent a normal range for a typical marginal field in the Gulf of Mexico hurricane area.

Water Depth:	500 meters
Service Life:	20 years
Vessel:	170,000 dwt
Storage:	1,250,000 barrels
Maximum Offloading Parcel:	1,000,000 barrels
Oil Production:	100,000 bopd
Gas Production:	130 MMsfd
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 Gulf of Mexico 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.
- Tropical Storms and Hurricanes Evacuation Costs: All associated costs with crew evacuation during tropical storms and hurricanes.

The Lost Production and Risk are costs resulting from shutdown due to tropical storms and hurricanes, which has an average of about one and half (1.5) times a year for a vessel in the Gulf of Mexico Area. The tropical storms and hurricane shutdown is discussed in the next section "TROPICAL STORMS AND HURRICANES GULF OF MEXICO 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.

TROPICAL STORMS AND HURRICANES GULF OF MEXICO AREA

The National Hurricane Center (NHC) maintains a continuous watch on tropical cyclones over the Atlantic, Caribbean, Gulf of Mexico, and the Eastern Pacific from 15 May through November 30. The Center prepares and distributes marine and military advisories for other users.

A tropical storm is a storm that attains at least 39 mph and a hurricane is a storm that attains at least 74 mph sustained surface winds during its lifetime. One of the most awesome natural forces on earth is the category 5 hurricane with sustained surface winds over 155 mph during its lifetime. The legacies of Gulf of Mexico tropical cyclones span many cultures and thousands of years. Early evidence of these storms predates extant weather records. Geologists believe that layers of sediment at the bottom of a lake in Alabama were brought there from the nearby Gulf of Mexico by storm surges associated with intense hurricanes that occurred as much as 3,000 years ago. Similarly, sediment cores from the Florida west coast indicate exceptional freshwater floods during strong hurricanes more than a thousand years ago. Perhaps the first human record of Atlantic tropical cyclones appears in Mayan hieroglyphics. By customarily building their major settlements away from the hurricane prone coastline, the Mayans practiced a method of disaster mitigation that, if rigorously applied today, would reduce the potential for devastation along coastal areas..

The months with all 151 years of tropical storms and hurricanes are shown on Figure 1.

The average number of tropical storms and hurricanes per year in the Gulf of Mexico Area is 3.2 tropical storms and hurricanes with 1.2 of that total being hurricanes.

The first alert is started on the FSO or FPSO when a tropical storm or hurricane is within four hundred (400) nautical miles. The FSO or FPSO is evacuated when the tropical storm or hurricane is within three hundred fifty (350) nautical miles. This happens approximately 50% of the time a tropical storm or hurricane enters the Gulf of Mexico Area, which results in an average of 1.5 shutdowns a year on the FSO or FPSO.

Figure 2, shown at the end of this paper, shows the average frequency of the tropical storms and hurricanes a month over the last half of the year.

CASE 1: FIXED INTERNAL TURRET SYSTEM

To moor a large tanker in five hundred (500) meters water depth in hurricane 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.

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 hurricane requires three directional cases to be investigated as specified in Design Criteria Factors, Environment, Table 1: 100-Year Survival Hurricane Conditions.

On the approach of a tropical storm or hurricane, production is shutdown and the FSO's or FPSO's crew is evacuated by helicopter and returns to the FSO or FPSO when the tropical storm or hurricane 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-tropical storm and hurricane environment and be a symmetrical eight (8)-leg system. In the event that a tropical storm or hurricane 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 tropical storm or hurricane 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 Gulf of Mexico 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 1% 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 Case1 "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

Tropical Storm and Hurricane 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 tropical storm or hurricane has left the area. These are considered in tropical storm and hurricane evacuation costs. The crew must upon return inspect the vessel for tropical storm or hurricane damage and then start-up production in a short time span after given clearance from the tropical storm or hurricane 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 in Table 2.

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 from Figure 10 showing 20 years of annual oil production for the disconnectable turret system is greater than that of the fixed turret system primarily due to turret maintenance costs.

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 $25 to $30 per barrel range for the life of the field.

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 3.75% less.

RISK:

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

CONCLUSION:

This paper provides an overview of the comparison

TABLE 2. LOST PRODUCTION due to Maintenance, Tropical Storms and Hurricanes per Year

	Case 1 – Fixed Turret System	Case 2 – Disconnectable Turret System
Process Facilities Maintenance	4.0 Days	4.0 Days
Well Major Workover	0.5 Days	0.5 Days
Downtime Due to Shortage Limitations	4.0 Days	4.0 Days
Downtime Due to Tropical Storms and Hurricanes (1.5 Times)	6.0 Days	4.0 Days
Annual Average Lost Production	14.5 Days	12.5 Days

TABLE 3. RISK FACTORS

Description	Case 1 – Fixed Internal Turret System	Case 2 – Disconnectable Internal Turret System
FSO or FPSO	Hull, topside equipment and mooring system must be designed for 100-year survival hurricane conditions and stay on location for 20 years with all maintenance done offshore.	Since the vessel leaves the site as the tropical storm or hurricane approaches, the hull, topside equipment and mooring system will be designed for much lower load conditions than the 100 year hurricane conditions. Also the vessel has the additional option of leaving for drydock maintenance such as every five years or in an unexpected maintenance requirement.
Crew	Crew must be evacuated by helicopters as the tropical storm or hurricane approaches.	Crew will sail on vessel as the tropical storm or hurricane approaches.

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 Gulf of Mexico 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.

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About the author …

Figure 1
Gulf of Mexico Hurricane Seasons 1851 to 2002 by Month

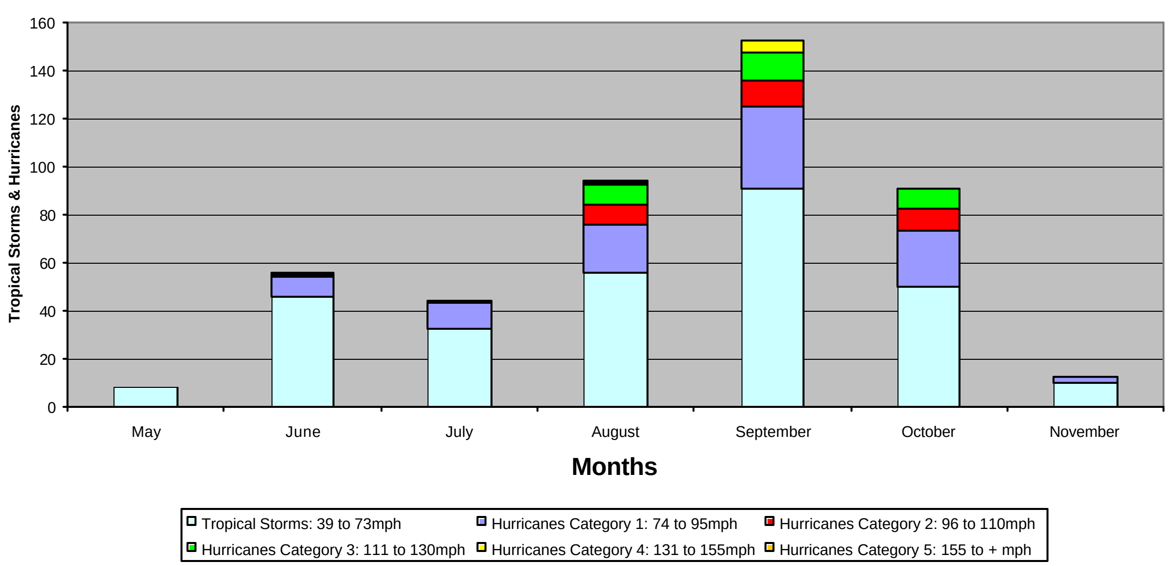

Figure 2
Tropical Storms and Hurricanes Annual Change of Evacuations

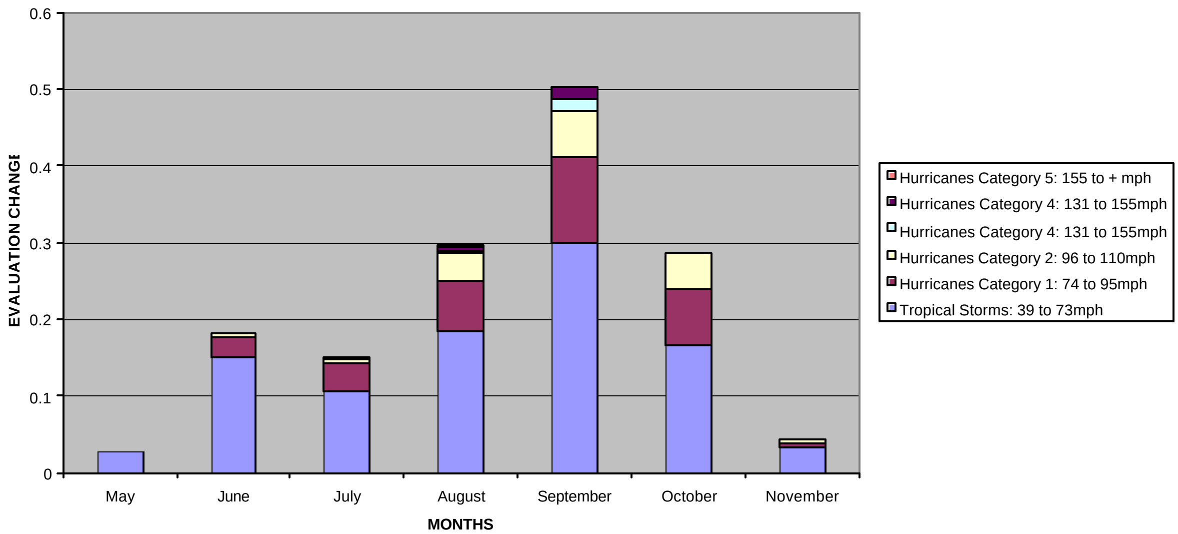

Figure 3
CAPEX - CASE 1 GULF OF MEXICO
FIXED INTERNAL TURRET MOORING SYSTEM w/ TANDEM OFFLOADING

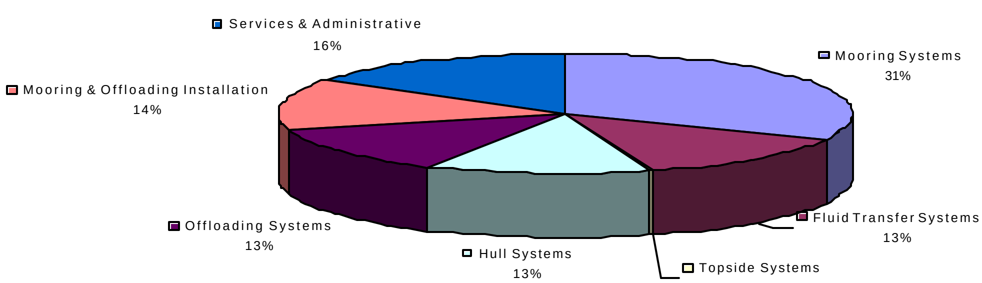

Figure 4
CAPEX - CASE 2 GULF OF MEXICO
DISCONNECTABLE INTERNAL TURRET MOORING SYSTEM
w/ TANDEM OFFLOADING

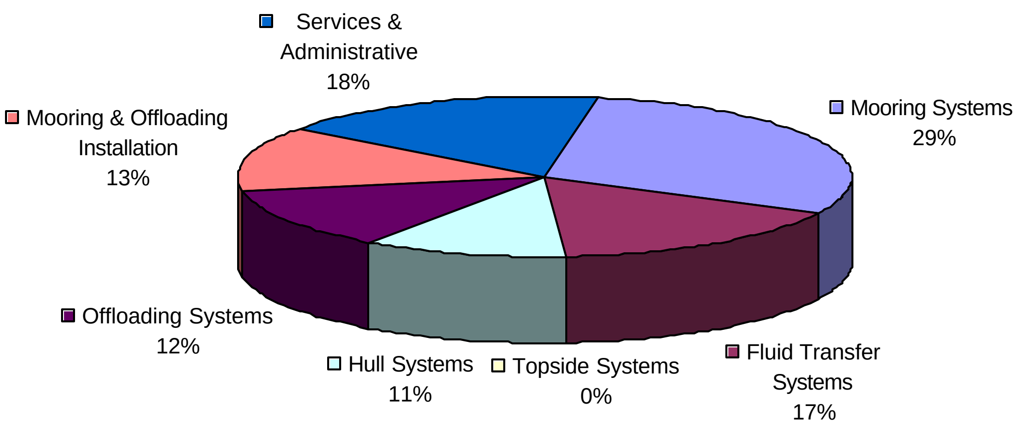

Figure 5
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CAPEX - CASE GULF OF MEXICO

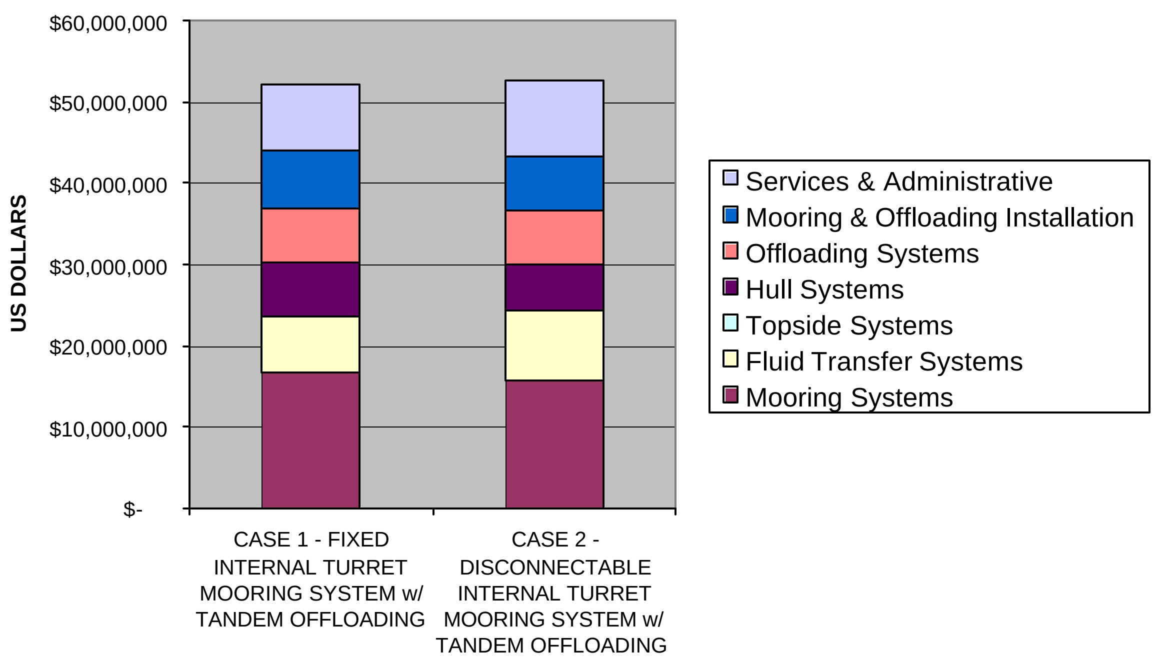


Figure 6

CASE 1 - FIXED TURRET SYSTEM

FPSO CREW COMPLEMENT (43)

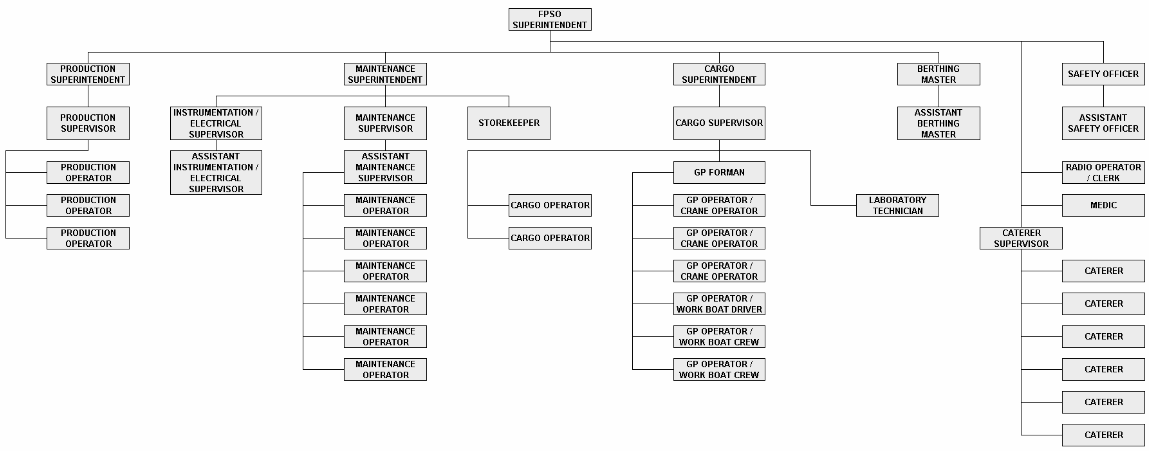


Figure 7

CASE 2 - DISCONNECTABLE TURRET SYSTEM

FPSO CREW COMPLEMENT (43)

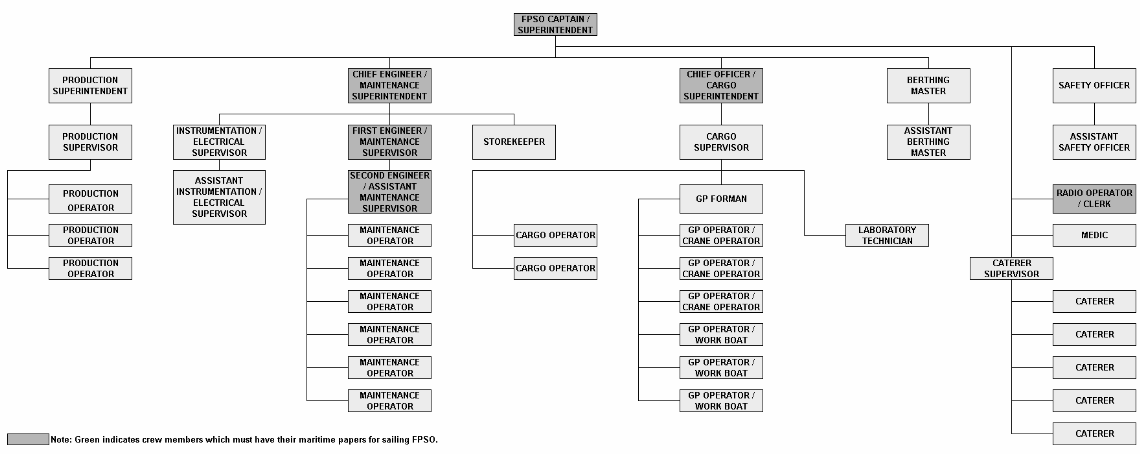


Figure 8
OPEX AVERAGE TWENTY YEAR OPERATION

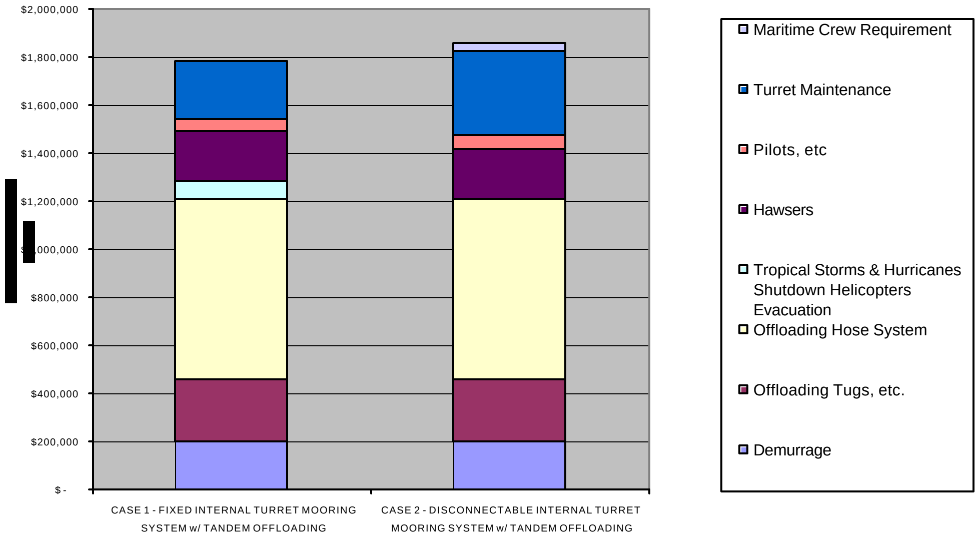


Figure 9 - Present Value at First Oil

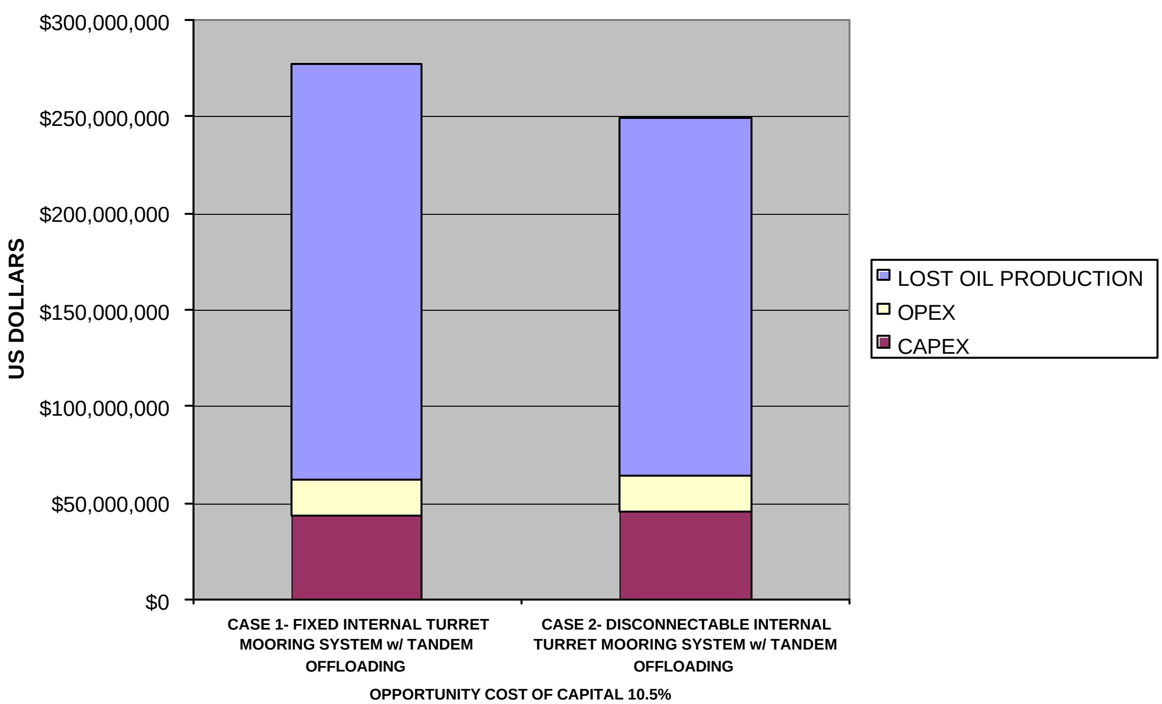
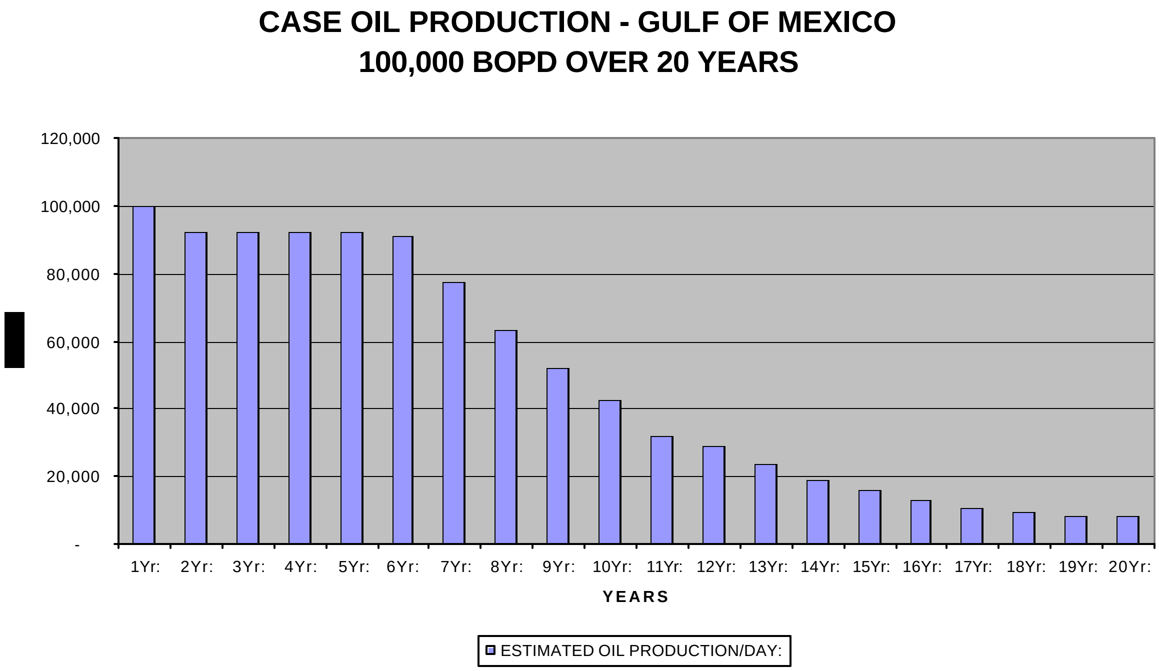


Figure 10


CASE OIL PRODUCTION - GULF OF MEXICO
100,000 BOPD OVER 20 YEARS
120,000
100,000
80,000
60,000
40,000
20,000
-
1Yr:
2Yr:
3Yr:
4Yr:
5Yr:
6Yr:
7Yr:
8Yr:
9Yr:
10Yr:
11Yr:
12Yr:
13Yr:
14Yr:
15Yr:
16Yr:
17Yr:
18Yr:
19Yr:
20Yr:
YEARS
ESTIMATED OIL PRODUCTION/DAY: