Recommended Practice for Planning, Designing, and Constructing Floating Production Systems

API RECOMMENDED PRACTICE 2FPS
FIRST EDITION, MARCH 2001

American
Petroleum
Institute

Helping You Get The Job Done Right.SM

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Upstream Segment

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FOREWORD

This "Recommended Practice for Planning, Designing, and Constructing Floating Production Systems" contains the API recommendations and guidelines for planning, designing, constructing (fabrication, transportation, installation, commissioning, and inspection), and operating of Floating Production Systems.

The recommended practice is based on sound engineering principles and many years of experience gained by the offshore floating system owners, operators, designers, fabricators, suppliers, and certifiers. In no case is any specific recommendation included that could not be accomplished by presently available techniques and equipment. Consideration is given in all cases to the safety of personnel, compliance with existing regulations, and prevention of pollution.

This document has been developed with the help and extensive contributions from industry experts of different areas of expertise.

The document contains 14 Sections plus a Commentary and covers various types of FPSs that are in use by the industry as offshore production systems. These include systems supported by column stabilized units (semi-submersible vessels), ship-shaped vessels, deep draft caisson vessels (also known as spars), and other hull shapes, and different materials (steel, concrete, and other non-metallic materials). Conversion to and reuse of existing floating structures as offshore production systems are also addressed.

Note that Tension Leg Platforms (TLP) are addressed in API RP 2T, "Planning, Designing, and Constructing Tension Leg Platforms". In order to ensure consistency between similar API RP documents, this API RP 2FPS makes extensive cross references to certain sections of API RP 2T and to API RP 2A-WSD, "Planning, Designing, and Constructing Fixed Offshore Platforms – Working Stress Design".

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Recommended Practice for Planning, Designing, and Constructing Floating Production Systems

0 Abbreviations

ABS	American Bureau of Shipping
ACI	American Concrete Institute
ALP	Articulated Loading Platform
ANSI	American National Standards Institute
API	American Petroleum Institute
ASD	Allowable Stress Design
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BOP	Blow-out Preventer
CALM	Catenary Anchor Leg Mooring
CBM	Conventional Buoy Mooring
CMPT	Center for Marine and Petroleum Technology
COW	Crude Oil Washing
DDCV	Deep Draft Caisson Vessel
DNV	Det Norske Veritas
DP	Dynamic Positioning
ESD	Emergency Shut Down
FMEA	Failure Modes and Effects Analysis
FPS	Floating Production System (includes FPSO, FPSS)
FPSS	Floating Production Storage System
FPSO	Floating Production Storage and Offloading System
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HDWL	High Design Water Level
HES	Health, Environment, and Safety
HHP	High Holding Power
HIPPS	High Integrity Pipeline Protection Systems
IACS	International Association of Classification Societies
ICLL	International Convention on Load Lines
IGS	Inert Gas System IMO International Maritime Organization
ISO	International Organization for Standardization
LDWL	Low Design Water Level LNG Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LRFD	Load and Resistance Factor Design
MARPOL	International Convention for the Prevention of Pollution from Ships
MODU	Mobile Offshore Drilling Unit
MPI	Magnetic Particle Inspection
NACE	National Association of Corrosion Engineers
NDT	Non-Destructive Testing
NFPA	National Fire Protection Association
NORSOK	NORsk SOkkels Konkuranseposisjon; organization to assist the competitive standing of the Norwegian offshore sector
NPSH	Net Positive Suction Head
NTS	Norwegian Technology Standards institution
OCIMF	Oil Companies International Marine Forum
OCS	Outer Continental Shelf
OREDA	Offshore Reliability Database
P&ID	Piping and Instrumentation Diagram
PLEM	Pipeline End Manifold
RCS	Recognized Classification Society or Societies
ROV	Remote Operated Vehicle
RP	Recommended Practice
S&W	Sediment and Water
SALM	Single Anchor Leg Moorings
SNAME	Society of Naval Architects and Marine Engineers
SOLAS	International Convention for the Safety of Life at Sea
SOPEP	Shipboard Oil Pollution Emergency Plan
SPM	Single-Point Mooring
STL	Submerged Turret Loading
TLP	Tension Leg Platform
USCG	United States Coast Guard
UT	Ultrasonic Testing
VCG	Vertical Center of Gravity
VIV	Vortex Induced Vibration
WOAD	Worldwide Offshore Accident Databank
WSD	Working Stress Design

1 Planning

1.1 PURPOSE AND SCOPE

This Recommended Practice (RP) provides guidelines for design, fabrication, installation, inspection and operation of Floating Production Systems (FPSs). The basic function of a FPS is to receive hydrocarbons from the wellhead, process the hydrocarbons, and store and/or offload the product to a shuttle tanker or convey it to a pipeline system. A FPS may be designed with the capability of one or more stages of hydrocarbon processing, as well as drilling, well workover, product storage, and export. This RP addresses only floating systems where a buoyant hull of some form supports the deck, production, and other systems. The buoyant hull can be of a column-stabilized, ship-shaped, or other form, that is maintained on location by a suitable station keeping system. Bottom-fixed components, such as self-supporting risers, and station keeping systems, such as turret mooring, Catenary Anchor Leg Mooring (CALM), Single Anchor Leg Mooring

(SALM), etc. are considered as ancillary components and are addressed in more detail in other API recommended practices.

Tension Leg Platforms (TLP) and Fixed Offshore Platforms are not addressed in this document. These platform types are defined and addressed in API RPs 2T and 2A, respectively. Production systems supported by self-elevating platforms (jackups) and submersibles (bottom sitting) are also excluded.

FPS technology is evolving rapidly, with new system configurations and component designs appearing frequently. Several different types of FPSs have been installed and many more have been proposed. Consequently, this RP does not address specific FPS configurations. Instead, design guidance for various common system components is provided in this document.

1.2 APPLICABLE CODES AND STANDARDS

The Responsible Party (see Section 1.3m) shall determine the applicable codes and standards. The Responsible Party shall reconcile any differences between the codes and standards and shall insure that the codes and standards are not mixed inappropriately.

This document provides the design guidance based on Working Stress Design (WSD) method. This is also known as the Allowable Stress Design (ASD) method. Although a user may choose Partial Factor Design or Load and Resistance Factor Design (LRFD) approach, it is not addressed in this RP.

This recommended practice relies heavily on existing design practices, and references many existing codes and standards, including:

- API RP 2, RP 14, and RP 17 Series
- IACS Recognized Classification Societies (RCS) Rules
- U.S. Coast Guard (USCG) regulations where applicable
- Minerals Management Service (MMS) regulations where applicable
- International Maritime Organization (IMO) codes and conventions

The General Commentary provides a listing of several recommended practices, rules, standards, and specifications. Additionally, the General Commentary lists references related to the topics covered in each section.

Alternative internationally accepted codes and standards may be utilized in lieu of those outlined in this standard including Load & Resistance Factor Design (LRFD) based methods; however, the user must ensure that the design philosophy intended in API RP 2T is met and a consistent safety level is applied. API RP 2A-LRFD and NORSOK N- 004 are examples of a LRFD based document.

Specific structural requirements for concrete FPSs are not within the scope of this RP, but this is not intended to restrict or prevent the use of such materials. For specific requirements, the following concrete LRFD based codes and standards are referred to for additional guidance.

- American Concrete Institute (ACI); Guide for the Design and Construction of Fixed Offshore Concrete Structures (ACI 357). For structural design, this guide refers to the ACI Building Code Requirements for Reinforced Concrete (ACI 318).
- Norwegian Petroleum Directorate; Regulation For Load Bearing Structures, Guidelines For Structural Design of Concrete Structures. For structural design this regulation refers to the Norwegian Standard NS 3473; Concrete Structures – Design Rules.
- Det Norske Veritas; Rules for Classification of Fixed Offshore Installations; Part 1, Chapter 3, Section 8, Design of Concrete Structures.

The methods for calculating loads referred to in this RP are considered for these concrete standards, but the designer should consider additional conditions appropriate for concrete structures as applicable. Special attention should be given to corrosion protection in exposed zones and the use of adequate concrete cover over the steel reinforcement and post-tension ducts.

1.2.1 Flag and Registration. The decision to seek (or avoid) registration of a FPS as a "ship" or "vessel" can have a significant impact on the operation and potential re-use of a FPS. This decision will determine whether a flag state's regulatory requirements must be considered, both in the design and during operation. Neither flagging nor classing of a FPS is required by this RP.

1.3 DEFINITIONS AND TERMINOLOGY

The key terms used in this RP are defined below:

a. anchoring and foundations: Includes drag anchors, piles (driven, drilled and grouted, or suction) or gravity bases used in platform mooring systems and piles or gravity bases used in riser and well system bases.

b. column-stabilized hull: Consists of a combination of buoyant columns, pontoons (or lower hull), and intermediate structural bracings, in addition to a deck structure (or upper hull) to accommodate processing equipment and other systems. These vessels usually have superior wave induced motion performance in comparison to ship-shaped hulls with similar displacement.

c. deck structure: A deck structure for a column-stabilized hull or a spar hull is designed as a single or multilevel structure consisting of box beams, trusses, stressed- skin girders, deep girders, and deck beams for supporting operational loads. Deck structures for ship shaped and other hulls are usually a part of the hull structure.

d. mobile offshore drilling unit (MODU): A vessel that is capable of engaging in drilling operations for exploration or exploitation of subsea petroleum resources.

e. other hulls: Other buoyant hulls that have unconventional hull form, and are not ship shaped, column-stabilized, or spar.

f. platform: Refers to a floating platform (in this document) consisting of a buoyant hull, deck structure, and station keeping system.

g. recognized classification society (RCS): A classification society that is a member of the International Association of Classification Societies (IACS), with recognized and relevant experience with offshore petroleum activities and established rules and procedures for classification/certification of installations used in petroleum activities.

h. responsible party: The legally recognized responsible party of the production lease or leases, concessions, grants, etc., usually the designated operator of the field, e.g., Owner, Duty Holder, Concession Owner, etc.

i. risers: Includes drilling, production, injection, workover, subsea systems control umbilical, and pipeline risers.

j. ship shaped hull: Consists of a single continuous buoyant hull with its internal structure having a geometry similar to that of ocean-going ships, barges, etc.

k. single point mooring systems: Permits weathervaning of the moored platform about the center of the mooring to minimize environmental loads. The mooring system may consist of Catenary Anchor Leg Mooring (CALM) lines or a Single Anchor Leg Mooring (SALM). The catenary lines can be connected directly to the platform at an internal or external turret system, or to an anchored buoy to which the platform is moored. The connection between the platform and the CALM mooring buoy could be through chain, wire rope or synthetic lines (soft yoke), or through a rigid yoke. The platform connection to the articulated leg of a SALM is usually through a rigid yoke. When a rigid yoke is used, it is common practice to permit vessel rotations by introducing articulating joints at the ends of the yoke structure.

l. spar: Consists of a floating facility that is held in place by a permanent mooring system, has a center of gravity below its center of buoyancy, and has a deep and narrow underwater shape designed to reduce wave induced vessel motions and excursions. It may also be called a Deep Draft Caisson Vessel (DDCV).

m. spread mooring system: Consists of multiple mooring lines (catenary or semi-taut) attached to the platform in a manner that limits the horizontal excursion of the platform. The mooring lines may consist of one or more mooring segments, with or without an in-line buoy or weight. The spread mooring system includes platform-mounted components such as windlass, winches, wildcats, stoppers, and fairleads, and off-platform components such as cable, chain, clump weight, piles or drag anchors, submerged buoys, various fittings and connectors.

n. subsea production system: Includes all submerged well completion, production control and gathering equipment, and riser equipment, plus the surface platform-based equipment for installation, maintenance, and control of this equipment.

o. weak link design: For a FPS, a design approach to ensure that the overload of an ancillary component (such as mooring line or riser) does not jeopardize the floating integrity of the FPS.

1.4 FLOATING PRODUCTION SYSTEM CONFIGURATION

FPS designs vary considerably regarding configuration. Configuration decisions are driven primarily by the need to meet functional requirements, project schedule, and cost competitiveness against other viable configurations. Risk to personnel, environment, and investment is a vital consideration for all decisions. Risks should be managed in accordance with Section 14.

Because of the multiplicity and diversity of possible FPS configurations, conceptual engineering is a complex task with numerous options to consider. Usually several iterations are necessary in the screening process. Significant differences regarding operability, safety, and economic performance between various FPS configurations can be revealed by a thorough conceptual engineering process. These differences generally become apparent only through this process.

1.4.1 Initial Configuration Decisions Some of the key parameters influencing the selection process of a FPS configuration are:

- Water depth
- Environmental conditions
- Production rate
- Product export method
- Preferred hull type(s) and construction material(s)
- New-build vs. conversion
- Drilling and well maintenance requirements
- Transportation and installation
- Well system configuration
- Service life
- Hydrocarbon storage requirements
- Regulatory requirements for re-use

Each of these parameters are described below.

a. *Water depth* impacts the horizontal excursion of the mooring system and different mooring systems have different depth capabilities. Some hull types may have a minimum water depth requirement.

b. *Environmental Data:* Performance of different concepts depends on the harshness and characteristics of the environment. For example, a FPS with long natural periods would exhibit less wave-induced motion than one with shorter natural periods and, therefore, would have less downtime due to weather. A FPS with a low natural period may experience a large number of cyclic loadings in normal environmental conditions, which may result in significant fatigue damage.

Vortex induced motions may also influence the design of some systems. Thus, in the selection process, the performance characteristics of various concepts in a site specific environment should be evaluated and considered in the design process.

c. *Production rate:* Processing equipment design depends on the production rate, the quality of the produced hydrocarbons, and the reservoir characteristics. Larger production rates typically result in higher payloads, and consequently a larger floating platform.

d. *Product export method:* The method selected for product export influences the general arrangement of the platform significantly, and thus the design of the FPS. A FPS designed to offload oil to a shuttle tanker or barge generally requires oil storage capability. Export systems utilizing a pipeline reduce the need for oil storage capacity associated with the FPS, and may permit the export of the gas with the oil (multiphase or high vapor pressure) or by a separate gas pipeline.

e. *Preferred hull type and construction material:* Based on a FPS's functional requirements, design environmental conditions, preferred well system configuration, capability and availability of fabrication facilities, consideration of new-build vs. conversion, and project economics, the owner/operator may have preference of one hull type over the other. Although the hull construction material is very likely to be steel, its properties may vary depending on the type of application. For example, steel used for a ship hull designed for operating in warm Gulf of Mexico climate may not be suitable for use in the colder environment of the North Sea.

f. *New build vs. conversion:* There are situations where reusing an existing ship or column stabilized vessel may provide an economically viable alternative. In many cases, schedule and cost considerations may lead to the decision of converting an existing vessel to a FPS. There are other situations where a new purpose-built FPS may prove to be economical in the long run.

Both new purpose-built facilities and converted existing facilities are valid options for FPSs. The following are some of the considerations for deciding whether to convert or build a new vessel:

1. *Field-specific considerations*
   - Expected field life
   - Field development schedule
   - Coastal governmental regulations
   - Mission requirements
   - Environmental conditions

2. *Overall economic considerations*
   - Availability of a suitable existing vessel
   - Construction/modification and installation cost
   - Operating cost
   - Delivery time
   - Functional capability
   - Expected service life
   - Environmental and personnel safety issues

In general, the decision to convert or build a new vessel is affected by the site and reservoir characteristics, intended service life and economic climate of the fabrication industry, as well as the availability and market price of existing vessels. A FPS designed to offload oil to a shuttle tanker (or barge) may require a FPS hull having the capability to store large volumes of oil, or a separate platform for storage.

g. *Drilling and well maintenance requirements:* Field development requirements for drilling and well maintenance capabilities are major factors in the selection of the type and configuration of the FPS. These capability requirements range from:

- No drilling or well maintenance (i.e., production-only FPS)
- Limited well intervention (i.e., wireline capability)
- Minor well workover (i.e., coiled tubing/concentric workover capability)
- Full well workover (i.e., tubing pulling and gravel pack replacement)
- Full development drilling

These requirements will impact the selection of the hull type, size and arrangement of the floating structure, and the requirements of the mooring and drilling/production riser systems.

h. *Transportation and installation:* Fabrication location, distance to the offshore location, and available marine installation equipment are all factors that should be taken into account when selecting the hull type.

i. *Well system configuration:* The well system provides the interface between the reservoir and the FPS. In selecting a well system configuration for economically maintaining the desired production rate, consideration should be given to reservoir and fluid characteristics, wave induced platform motions, drilling and well maintenance programs, and service life of the FPS.

j. *Service Life:* This can affect environmental design return periods and fatigue performance requirements, outfitting for corrosion protection, in situ inspection philosophy, etc. Some configurations may be better suited for long service lives in harsh environments. Some configurations are also better suited for relocation and reuse.

k. *Hydrocarbon storage requirements:* If hydrocarbon storage is required as part of the field development plan, this will have a major impact on the hull selection. One of the most critical aspects to be considered is the quantity of crude oil that must be stored.

l. *Regulatory requirements for re-use:* The regulatory requirements of the coastal state for a re-used FPS may impact the hull selection. Issues such as any special requirements for cleaning of crude oil storage tanks may be a significant factor.

1.4.2 FPS System Interfaces The FPS is likely to face issues related to equipment interfaces between dissimilar systems, both for conversion and new-build FPSs. An example of this is the interface between the electrical systems on a ship and that of the production equipment, well control equipment, and connections to a platform. Some of the major interface areas are:

- Electrical
- Production piping
- Cargo handling systems
- Air, water, and drainage utility systems
- Ballast and bilge systems
- Fire protection/gas detection
- Lighting
- Fuel system and source
- Emergency shutdown systems
- Life saving appliances
- Personnel safety equipment
- Production risers

Note: This is not an all-inclusive list of interface areas to be considered in the FPS configuration.

The design basis of a project should clearly define how interfaces are to be handled and indicates the necessity of compatibility for specifications of interfacing items. The designers may have to develop special details to accommodate these interface issues.

2 Categorization and Design Criteria

2.1 INTRODUCTION

This section outlines guidelines for selecting FPS design criteria. A consistent set of design criteria and codes/standards shall be used for structural, sea-keeping, and station-keeping system design of a FPS. Using a mixture of design criteria and codes/standards may result in a reduced level of reliability in the design. The hydrodynamic analysis should also be based on the site-specific environmental criteria, as outlined in this section.

2.2 GENERAL

FPS functional missions and physical configurations vary widely. Design criteria for various FPS applications vary accordingly. Since it is not possible to individually identify and address every potential FPS configuration and application, this section addresses FPSs by category whenever possible.

2.3 CATEGORIZATION

The Responsible Party shall determine the Category. Mission and duration of operation are the primary FPS application characteristics used for categorization. Category durations are not intended to be definitive and may vary depending on the characteristics of the well, field, equipment, or location. If the intent is to obtain well and reservoir data for a stated period of time, then it is probably a MODU. If the intent is to produce the reservoir or to produce the reservoir(s) for an indefinite period of time while obtaining well and reservoir data, then it is a FPS. Items to consider when determining the category can include, but are not restricted to, those listed below:

- Adding additional production equipment to the rig
- Flowing more than one well
- Permanent downhole well completion
- Providing additional storage or converting existing storage for production
- Connection(s) to pipelines
- Removal or mothballing drilling equipment
- Local government restrictions

Any one or a combination of these items may greatly influence the selection of the proper Category.

Three basic FPSs, or FPS application Categories, are defined and used for reference in this section. These are:

Category 1: Field Development Systems.
Category 2: Early, Pilot, or First-Stage Field Development Systems.
Category 3: Drill Stem Test Systems and Extended Well or Reservoir Test Systems.

The mission and typical duration of operations of the above categories of FPSs are described below:

Category 1: Field Development Systems
Mission - To profitably produce reservoir fluids until the economic depletion point is reached.
Duration - Typically greater than 5 years.

Category 2: Early, Pilot, or First-Stage Field Development Systems
Mission - To produce reservoir fluids to provide production experience and data necessary to reliably predict long-term reservoir productivity and ultimate recovery. Field depletion with this category of system is not the initial intention.
Duration - Typically from less than 60 days to two years and not normally exceeding 5 years.

This document does not apply to a RCS Classed MODU used for early, pilot or first-stage field development which would otherwise fall within category 2 if an acceptable level of safety is confirmed by operation within the specific MODU design criteria and a site specific risk analysis has been performed according to this standard.

Category 3: Drill Stem Test Systems and Extended Well or Reservoir Test Systems
Mission - To collect data regarding well productivity, fluid properties, producing formation properties, reservoir size and drive performance, production problems, reservoir continuity, well maintenance, and short term reservoir maintenance.

Duration - Typically up to 120 test days.

This document does not apply to a RCS Classed MODU, with or without built-in crude oil storage capabilities, engaged in drill stem tests, extended well or reservoir tests, or short term reservoir maintenance, which would otherwise fall under Category 3.

2.4 DESIGN CRITERIA

2.4.1 General

This section outlines the design criteria to be used for overall system design. Design criteria requirements for specific types of FPS components are described in the following subsections.

Design and analysis of the FPS and the associated subsystems require that a series of design cases be specified. This requires that each life cycle phase (e.g., construction, transportation, installation, operation and removal) be coupled with appropriate design environmental events, associated allowable stresses, and adequate safety factors. Statistical procedures involving probabilistic predictions of environmental parameters and FPS responses should be established in order to select design cases. Specification of design conditions requires establishing return periods and associated values of wind, wave, current, and tidal effects together with the range of operating conditions and loading conditions that maximizes the combined load effect for this period, for each of the various phases of the project and for its overall service life. Other environmental conditions, including long-term data for fatigue analyses, etc. are also needed.

2.4.2 Regulatory Requirements

2.4.2a National Regulations: The design of a FPS shall comply with the requirements specified by the coastal State (or Administration) having jurisdiction over the location where the unit is to operate.

In cases where the FPS is to be "flagged" (registered in a specific country, as though it were a merchant vessel) the relevant requirements of the flag state authorities must also be met.

2.4.2b Recognized Classification Societies (RCS): FPS owners may choose to obtain classification by one of the RCS to provide a third party technical verification of plans, and attendance to survey construction, testing, installation and commissioning of various components. The services of a RCS may also be necessary to obtain, or to expedite issuance of, flag State certificates.

2.4.3 Operational Requirements

Design criteria dictated by operational requirements should be reviewed during each iteration of the design spiral. The operational consequences of these requirements should be fully established before a final design decision is made. Some examples of such requirements usually involve:

- Projected field life
- Simultaneous drilling and production
- Production, storage, and off-loading matrix
- Processing equipment performance
- Consumables resupply procedure and frequency
- Possible changes in FPS configuration for extreme environment
- Maintenance procedures and frequency
- Staffing schedule and rotation
- Personnel comfort and safety

2.4.4 Hydrostatic Stability Requirements

2.4.4a General: Hydrostatic stability requirements should be met for all pre-service and operating conditions for both intact and damaged conditions of the floating structure. See relevant paragraphs of sections 3 - 7 for stability criteria.

2.4.4b Weight and Center-of-Gravity Determination: A lightship survey and inclining experiment should be conducted when construction is as near to completion as practical to accurately determine the lightship weight and position of the center of gravity.

For a floating structure with unusual configuration, it may not be feasible to incline the structure. In such case, the lightship weight and its center of gravity should be determined by a combination of a thorough lightship survey and calculations.

Any changes subsequent to the lightship survey and/or inclining experiment should be accounted for and included in the final documentation and updated during service.

2.4.5 Environmental Criteria

2.4.5a General: The following sections briefly describe the environmental criteria required in design. For guidance on actual values to be used in design, refer to data collected at the intended site, to appropriate meteorologic and oceanographic numerical models, and to API RP 2A.

In general, the design response should be based on the maximum response within a minimum return period of 100 years for FPSs of category 1. The user should refer to Section 2.4.6d for further details.

FPSs belonging to Categories 2 or 3 may use a lower return period. Use of lower return period shall be justified by appropriate risk analysis taking the consequences of failure into account for the environment and personnel safety.

2.4.5b Wind: Wind plays a significant role in the design and analysis of stationkeeping systems and in the analysis of intact and damaged stability. Depending on the category of the FPS, both steady and gust wind components may have to be used for mooring system design. See API RP 2A for further guidance.

2.4.5c Waves: Wind-driven waves are a major source of environmental forces on FPSs. Such waves are irregular in shape, can vary in height, length, and period, and may approach a FPS from one or more directions simultaneously. Sea swells should also be considered.

The development of wave criteria should generally be done in accordance with API RP 2A. Describing a design sea state in terms of an energy distribution or power spectrum, rather than a deterministic design wave height and wave period combination, is generally more applicable to FPSs due to the random nature of the sea surface and the dynamic response of FPSs. Wave spectra are defined by several statistical parameters such as the significant wave height, spectral peak period, spectral shape, and directionality. Other parameters of interest can be derived from these. API RP 2T discusses methods that can be used to predict the statistical extreme dynamic responses of FPSs. Duration of the storm during which the statistical properties of the sea state remain stationary, is usually also specified.

2.4.5d Current: Current data should be established for the site and included in the design criteria. Currents should include wind-driven, tidal, and background circulation components. In deep water the currents might produce large system loads. Near boundary currents (e.g., the Gulf Stream, meanders, and eddies) should also be considered. The current profile throughout the water column and current scatter diagram should be determined.

2.4.5e Tide and Water Level: Tidal components for design include astronomical, wind, and pressure differential tides. A High Design Water Level (HDWL) and Low Design Water Level (LDWL) should be established for each design event. The tidal range could affect the mooring system and riser design.

2.4.5f Joint Probability Statistics: Environmental data such as wind, tide, wave, swells, and currents can have specific relationships related to their interaction and simultaneous occurrences. The commonly used assumption of taking the combined expected maximum of each parameter might not always produce the worst design condition. When collecting data or performing analytical work, the various relationships should be included, if possible. Of particular importance are wind/wave, wave height/wave period, wave/current, wind/current, and wave/tide relationships, and the relative directions.

2.4.5g Physical Properties: Various seawater physical properties, such as temperature, salinity and oxygen content, is important for steel material requirements, corrosion, and buoyancy calculations. Further guidance can be found in API RP 2A.

2.4.5h Ice: Floating ice or atmospheric icing can affect the loading, floating stability, and operability of the FPS. See API RP 2A and API RP 2N.

2.4.5i Marine Growth: Identifying the type and accumulation rate of marine growth at the design site is necessary for determining design allowances for weight, hydrodynamic diameters and coefficients. Refer to API RP 2A for guidance.

2.4.5j Seismic Action/Earthquake: Seismic activity at the offshore location should be taken into account in establishing the design criteria for the FPS.

2.4.5k Subsidence: The likelihood and resulting impact of seabed subsidence should be accounted for in the design criteria for the FPS.

2.4.6 Design Cases

Defining a design case requires identification of the following parameters and establishing their relevancy based on their functionality and overall design objective:

a. Component description
b. Project phase
c. System condition
d. Environmental events
e. Safety criteria

2.4.6a Component Description: The major components of a FPS requiring special consideration for the various project phases should be first identified. In some designs, these major components may require unique consideration only for the initial fabrication and installation phases, while in other designs they may require special consideration for all project phases including operational.

2.4.6b Project Phases: The primary phases of a project should be identified for all major components of a FPS. Project phases typically include fabrication, transportation, installation, in-place (operating), and removal. Other possible project phases may include loadout, mating of one or more components, inspection, testing, etc. Each phase may have different loading conditions that should be examined. Examples of typical considerations that would be examined for different project phases are as follows:

- *Fabrication*: Loading conditions imposed on the various components of the FPS during fabrication could control their structural design. For example, the hull of a FPS, if it floats freely during any stage of fabrication, should always have adequate hydrostatic stability.
- *Transportation:* FPS components are subjected to dynamic loads during transportation to the installation/mating site. The transportation of FPS hull and/or components may be carried out in either wet-tow or dry-tow mode. The dynamic loads during transportation due to wave induced motion responses may in some cases be more severe than those experienced during in-service use. Hydrostatic stability, motions, and structural integrity of the FPS component and the transport vessel (for

dry-tow) need to be evaluated for all transportation operations for both intact and damage conditions, when warranted. The damage condition could be a compartment flooded on the FPS component (for wet-tow) or on the transport vessel for dry-tow. Fatigue of FPS components should be considered during transportation.

- *Installation/Mating:* During the various phases of installation and mating of two or more components of the FPS (where appropriate), the FPS components will be subjected to varying severities of external pressure and environmental loading depending on season and duration of exposure. For each installation phase, appropriate design cases should be developed and the designer may consider using risk analysis to determine the safety level of the design.
- *Commissioning:* During the commissioning phase, all utility systems may not yet be available for normal usage (such as power generation systems needed for normal ballast control operations). The sequence of construction and commissioning activities should be carefully planned so that the safety of the FPS is never in question.
- *In-place (Operating):* During its service life, the FPS will be subjected to many operating cases involving various combinations of environmental conditions, processing, offloading, storage levels and special conditions of the vessel. These operating case needs are to be defined, and realistic design cases examined for each major component for normal events as well as low-probability events such as collision, dropped object, damage, fire and explosion, etc. Major considerations for selecting appropriate operating cases include:
  - Mode of operation of FPS: Fixed configuration for all conditions or variable configuration.
  - Staffing: Remain staffed or personnel evacuated in extreme weather.
  - Riser/Flowline connection: Remain fully connected, release subsea connection and hang off, or release connection at the surface unit of the FPS.
  - Station-keeping systems: Remain connected without adjusting catenary mooring line tensions, maintain station with DP system, adjust mooring line tensions, release a portion of the spread to allow weather-vaning or relocate to a safe distance away from the wellheads.
- *Inspection:* Periodic inspection of the various major components and ancillary components of a FPS will be required during its service life unless specifically designed for no inspection, with a corresponding higher fatigue life. Some inspection procedures may be carried out without affecting normal operations, such as tank inspections, while others may require suspension of normal operations and/or alteration of the FPS configuration. Inspection requirements and procedures should be considered in the design stage. Design cases addressing changes in the FPS configuration due to inspection procedures should be identified early in the design stage. For example, operating a FPS with one or more mooring lines retrieved for inspection would temporarily reduce the mooring system's station-keeping ability. Adequate safety factors for the mooring system should be maintained by developing operating procedures that restrict inspection of the mooring system to mild weather seasons. Special inspection considerations should be given to existing vessels being considered for re-use in site-restricted mode for varying periods of time, and originally designed assuming that the hull would be periodically inspected in a drydock. Underwater inspection in lieu of drydocking may be considered when drydocking is not possible, and should include removal of marine growth prior to inspection.
- *Decommissioning:* Arrangements for decommissioning including cleaning, and possibly ultimate dismantling of the FPS, require consideration during design and fabrication. Any special arrangements should be documented for future reference.

2.4.6c System Condition: System condition defines the conditions of the various components of the FPS and is described below:

- *Intact, Normal:* The FPS with all components intact and exposed to normal operating environment.
- *Intact, Extreme:* The FPS with all components intact (or reconfigured) and exposed to extreme environment.
- *Damaged, Normal:* Partial loss of buoyancy or structural damage to a FPS component and exposed to normal operating environment.
- *Damaged, Reduced Extreme:* Partial loss of buoyancy or structural damage to a FPS component and the FPS reconfigured and exposed to a reduced extreme environment.
- *Reduced Station-Keeping Capacity, Normal:* Partial loss of station-keeping ability of the FPS due to removal of one mooring line for inspection or replacement and exposed to normal operating environment.
- *Reduced Station-Keeping Capacity, Reduced Extreme:* Partial loss of station-keeping ability of the FPS due to removal of one mooring line for inspection or replacement and exposed to reduced extreme environment.

2.4.6d Environmental Events: The environment should be defined quantitatively in terms of wind, wave, swells, current, and tide data. Typical environmental events used to design FPSs are summarized below.

1. *Extreme Environment:* An extreme environment is defined as that combination of wind, swells, waves, and current resulting in an extreme environmental load

effect, for which the system components are to be designed. The criteria for the extreme environment should be developed from the environmental conditions at the site and should include a risk analysis where prior experience is limited. The risk analysis may account for historical experience, the planned life and intended use of the FPS, the risk to human life, potential for pollution, cost, and the probability and consequences of events more severe than the extreme environment. More than one combination of extreme wind, waves, and current may need to be investigated for a typical FPS.

Category 3 (see Section 2.3) applications are similar to current MODU practice, and the environmental criteria applied in MODU design and in developing MODU operating guidance may generally be used. RCS rules and API RP 2SK provide guidance for choosing these environmental criteria.

The extreme environment for a Category 2 FPS may be chosen to reflect the months during which it will be on location. The environmental data reflecting the appropriate return period for those specific months may be used in the design.

For Category 1, experience with fixed platforms in the Gulf of Mexico supports the use of a design environment with a 100-year recurrence interval. Risk analysis may justify either longer or shorter recurrence intervals.

If it is planned that the facility personnel will be evacuated during the extreme environment condition, and if safety assessment indicates that there is acceptably low risk of pollution if a failure should occur, and if the service life is substantially lower than those of permanent installations, a shorter recurrence interval may be justified. In such a case, the recurrence interval should be determined by a risk analysis taking into account the consequences of failure.

However, not less than a 100-year environment should be considered where the extreme environment may occur without adequate warning while the platform is staffed, or where the failure of any system component can result in environmental pollution.

In defining the extreme environment for a FPS, the designer must consider the characteristics of the components and configuration of the system. Extreme design events for a FPS can usually be identified by the following groups:

a. *Extreme Environmental Events:* These events represent environmental conditions corresponding to the most severe sea states expected at the site with the selected design recurrence interval. Due to the dynamic nature of the global responses of FPSs, a range of sea states with joint probabilities of equal to or less than the design return period should be investigated. For a 100-year return period criteria, a range of sea states having probability of exceedance of 0.01 per year, with associated wind and current conditions, should be examined.

b. *Extreme Load Events:* These events represent combinations of environmental conditions producing extreme structural, mooring, and riser load cases. For 100- year return period criteria, these environmental conditions would produce extreme design loads having probability of exceedance of 0.01 per year. The environmental conditions generating these extreme design loads may not necessarily correspond to the 100-year storm. For example, in the Gulf of Mexico, for one or more components, these may result from combined wind, wave, and loop current conditions rather than a severe hurricane.

c. *Extreme Motions Event:* These events represent combinations of environmental conditions producing extreme motions and/or relative motions of the components of the FPS. For a 100-year return period criteria the environmental conditions would produce extreme design motions having a probability of exceedance of 0.01 per year. The environmental conditions generating the extreme motions may not necessarily correspond to the 100-year storm (i.e., may be caused by a storm of lesser intensity than the 100-year storm but containing a more adverse distribution of wave energy inducing larger first and/or second order resonant excitation of one or more compliant degrees of freedom of the FPS). For a FPS with a mooring and riser system that permits rapid disconnection of the production vessel from the mooring, the maximum design condition for the production configuration is the threshold environment for the vessel to stay connected or perform disconnecting operations. The vessel will be disconnected from the mooring when the threshold environment is reached. Design and operating procedures should ensure that disconnection could be accomplished prior to design level, loads, and/or motions being exceeded.

2. *Normal Environment:* A normal environment is defined as the combinations of environmental conditions expected to occur frequently during the pre-service and service life of the FPS. Since different environmental parameters and combinations affect various responses and limit operation differently (e.g., installation, crane usage, etc.), the designer should consider the appropriate environmental conditions for the design situation.

3. *Reduced Extreme Environment:* Reduced extreme environmental conditions are those which have low probability of being exceeded when the FPS is in a special condition such as a compartment flooded, one or more

mooring lines removed for inspection/replacement, local structural failure, etc. Joint probability statistics may be used to determine a return period, which when combined with the FPS in a special condition, has a risk level equal to or less than that of the extreme event with the FPS in intact condition.

4. *Threshold Environment:* Specification of a threshold environment is appropriate for FPSs that are capable of changing their configurations in preparation for an extreme event. A threshold environment is the limiting environmental condition that the FPS is capable of sustaining in its normal operating configuration, but with normal operations suspended. The FPS must be able to perform the reconfiguration operations in the threshold environment. Once the threshold environment is reached, the FPS would be reconfigured to allow survival of its components in more severe weather. Typical examples of reconfiguration could be partial or complete disconnection of the mooring system, riser system, etc. Once the FPS has reconfigured, all components of the FPS should be able to withstand the appropriate extreme environment. Risk and consequences of failing to reconfigure should be assessed for all FPSs designed to be reconfigured to survive extreme environments. These should be captured in the Marine Operations Manual.
5. *Calm Environment:* There are certain operations that are performed only under calm weather conditions. Calm environmental conditions may be used for these design cases.
6. *Transportation Route Environment:* Transportation design environment should be established to represent the transportation route. As a minimum, a 10-year return period for environmental condition should be considered for the transit design criteria. Reductions due to routing plans and seasonality restrictions can be considered.

2.4.6e Safety Criteria: Safety criteria are classified as categories A, B or C, where safety factors are related to the probability of loading occurrence. Others may also be considered, such as criteria corresponding to ultimate survival or damaged redundancy design cases. Specific recommendations for safety factors for each FPS component are given in their respective sections of the RP. The safety criteria Categories A, B and C are defined below:

- *Category A:* These safety criteria are intended for those conditions that exist on day- to-day basis (frequently occurring.)
- *Category B:* These safety criteria are intended for rarely occurring design conditions.
- *Category C:* These safety criteria are intended for the design of the structure against fatigue failure. Increased factors of safety should be considered for areas that are not inspectable.

2.4.7 Load Types.

Loading type categories are:

2.4.7a Dead Loads: Fixed static weight of the platform structure and any permanent equipment that does not change during the life of the structure.

2.4.7b Live Loads: Variable static loads, which can be changed, moved or removed during the life of the structure. Maximum and minimum payloads should be considered to determine the most critical live load patterns. Mooring and riser loads should be considered in this category.

2.4.7c Environmental Loads: Loads on the structure due to the action of wind, wave, swell, current, tide, ice, or earthquakes. Green water effects on deck loading should be considered.

2.4.7d Inertial and Drag Loads: FPS motion-induced loads that are consequences of the environmental loads.

2.4.7e Construction Loads: Loads built into the structure during the fabrication and installation phases, or applied during fabrication/installation.

2.4.7f Hydrostatic Loads: Buoyancy of, or external hydrostatic pressure on, submerged members.

2.4.7g Accidental Loads: Refer to Section 2.5.

2.4.7h Mooring and Riser Loads: Refer to section 2.4.7b.

The combination and severity of loads should be consistent with the likelihood of their simultaneous occurrence.

2.4.8 Design Recommendations

2.4.8a Station keeping Systems

- *Passive Mooring System:* API RP 2SK "Design, Analysis of Stationkeeping Systems for Floating Structures" provides criteria and procedures for designing passive mooring systems. Mooring systems, which provide weathervaning capability, often incorporate buoys with soft or rigid yokes, turntables and universal joints, or articulated towers. These components should be designed utilizing appropriate codes and guidelines. For the structural design, these codes generally incorporate the safety category concept. Category A is appropriate for the operating condition and Category B is appropriate for the extreme environment condition.
- *Thruster-Assisted and Dynamically Positioned Systems:* Thruster power may be used to dynamically position a vessel or to assist the passive mooring system. In the latter case, the system is called "thruster assist"

when the thrusters are manually controlled or "DP assist" when they are automatically controlled. These systems require adequate redundancy against station-keeping failures. The guidelines for the design of these systems are provided in API RP 2SK and IMO MSC Circular 645, "Guidelines for Vessels with Dynamic Positioning Systems," 1994.

2.4.8b Process System: Section 10.1 provides guidance regarding the impact of FPS motions on process system design. A threshold operating case for the process should be established defining motions and wind that permit continued safe and effective operation of the system. Extreme conditions should be defined as per the operating scenario discussed in Section 2.4.6. The design is recommended to be based on Category B criteria, including live loads where applicable. The process system will also be subject to motions during transit to the installation site. Structural analysis for the transit condition should be based upon Category B for the appropriate extreme and reduced extreme events.

2.5 ACCIDENTAL, FIRE, AND BLAST LOADS

2.5.1 General

FPSs may be subject to various accidental loads such as: collision from service vessels; impact from dropped objects; explosion or fire from process, riser, and well events. Consideration should be given to the design of the structure, and to the layout and arrangement of facilities and equipment, to minimize the effects from these loads.

The floating platform structure in the vicinity of the waterline, in locations likely to be subject to impact from service vessels, should be protected. Protection should be considered for externally located appurtenances such as pipeline risers or wells. Certain locations of the deck, such as crane loading areas and areas near masts or derricks, are more likely to be subject to dropped objects under normal operating modes. The location of equipment and facilities below these areas should be arranged in such a way so as to minimize the possibility of damage from dropped objects under normal operating modes.

In the operating life phase of a floating structure, it can be expected that the damage resulting from accidental loads will be repaired after the occurrence. It is not anticipated that the damage would occur simultaneously with design extreme environmental loads or that the damaged structure would be subjected to the design extreme environmental load.

Critical components should be designed under a weak link design philosophy, such that a mooring/riser failure shall not compromise the integrity of the unit. See section 1.3 (Definitions) for further details of the definition of weak link design philosophy.

2.5.2 Accidental Impact Loads

Floating structures may be subject to extreme load effects other than those covered by the specifically defined environmental loadings. These include impact from service vessels and dropped or swung objects.

Analysis of this damage should be performed to determine the extent and necessity for structural repair. Such analysis will also identify, for the operating manual, conditions under which the installation should be shut-in and evacuated.

Provision of fenders, deck planking, grating, and timbers has been found to be adequate to withstand these in all but extreme circumstances. Provision of aids to navigation, observation of safe operating practice, and development of detailed procedures when major lifts or marine operations are to be undertaken will limit risk to offshore personnel and the environment; however,; however, mechanical failures in these circumstances may cause significant structural damage that requires detailed analysis.

2.5.3 Accidental Fire and Blast Loads

FPSs processing hydrocarbons have a potential, however small, for either fire or explosion or both. The result of an explosion from a structural sense is an overpressure that tends to dissipate with increasing distance. Any object in the vicinity of this explosion interacts with the overpressure. Fire causes a thermal loading on nearby objects, which in turn causes both deformation and stress. Prolonged thermal loading can also result in changes in material elastic modulus, yield point, and strength. The design of a FPS should include a systematic treatment of these adverse loadings and decreased load bearing capacity.

Other API and industry guidelines, codes and specifications cover fire protection precautions.

3 Floating Structure Design and Analysis Column Stabilized Units

3.1 INTRODUCTION

3.1.1 Purpose and Scope

This section addresses the design and analysis of main and secondary deck and hull structure of a column-stabilized Floating Production System (FPS).

The column-stabilized FPS evolved from the Semi-submersible Mobile Offshore Drilling Units (MODUs). Column stabilized FPSs may support a full drilling facility or a workover facility in addition to the production and utility facilities and accommodations. Early column stabilized FPSs were converted from MODUs, which were designed according to the rules of Recognized Classification Societies (RCS). For conversion and re-use of existing column stabilized units, reference is also be made to Section 7 of this RP.

Purpose-built FPS hulls usually have four or more stability columns mounted on either twin pontoons connected by braces or a ring pontoon. The columns are interconnected by an integrated deck structure. The integrated deck, columns, and pontoons together constitute the FPS global structural framework, while providing the required stability and global performance. Moorings for such systems should be designed according to Section 8.

3.2 GENERAL STRUCTURAL CONSIDERATIONS

3.2.1 Project Phases

The hull and deck structure should be designed for loadings that occur during all project phases as defined in Section 2.4.6b.

3.2.2 Damaged Conditions

The structural design should consider the possibility of accidental events including collisions, dropped objects, fire, explosion, and accidental flooding as described in Section 2.5. The design should consider the damaged condition with reduced structural capacity and higher hydrostatic pressure due to damaged waterline.

Hydrostatic stability of the structure in the damaged condition should also be investigated.

3.2.3 Redundancy and Reserve Strength

Global structural integrity of a column stabilized FPS depends on the design of primary structural elements, e.g., column, pontoon, deck, and braces as well as the critical structural connections between pontoon-column, column-deck, and the connections at the braces ends. These connections should be designed to possess satisfactory ductility to safely redistribute loads without premature brittle failures in the event of local failure of a structural member. Special attention should be given to providing reserve strength following the loss of a critical brace member or main load bearing structure in deck or hull.

3.2.4 Interfaces with Other Systems

The structural design of the deck and hull should consider interfaces with other systems such as the mooring line and riser termination points, mooring system and riser installation equipment, moon pool requirements, drilling and production equipment, and hull marine systems.

3.2.5 Safety

Arrangement of main structural deck elements should be coordinated with topside facilities equipment and operational requirements. The structure should allow adequate ventilation of hazardous areas, access for fire fighting, fire protection, and escape routes. Similarly, manned spaces in the columns and pontoons should be provided with escape routes.

3.2.6 Air Gap

Considerations for calculating the air gap are provided in API RP 2T, Section 7.2.8 (Deck Clearance). Due to the floating nature of the FPS, roll and pitch should be considered in addition to the factors for deck clearance listed in API RP 2T.

3.2.7 Corrosion Allowances and Corrosion Protection

A corrosion protection system and/or additional scantling thickness appropriate for the environment and design life of the platform should be provided. Protection should be designed following the guidelines of Section 13.3. Special attention should be paid to corrosion protection in ballast tanks.

3.2.8 Vibrations

The effect of vibrations from machinery, such as gas turbines and diesel engine-generators, should be given consideration in the design.

Members subjected to Vortex Induced Vibration (VIV) should be designed for fatigue and/or VIV mitigation. Long, slender members are especially susceptible to VIV.

3.2.9 Inspection and Maintenance Program

A comprehensive in-situ inspection and maintenance program of the critical hull and deck members over the FPS service life should be developed following the guidelines described in Section 7.6 or guidelines provided by the RCS.

3.3 DESIGN CASES

3.3.1 General

A design case is a combination of loads for each project phase (construction, transportation, installation, in-place, etc.), system conditions (intact or damaged) and environment (normal, reduced extreme, extreme, etc.) with the appropriate safety criteria described in paragraph 2.4.6e. The designer should carefully and systematically prepare a list of design cases which will induce maximum loads for each structural member in the platform, as defined in Section 2.

3.3.2 Design Loading Conditions

In addition to the recommendations in Section 2, the following aspects should be considered.

For FPSs designed for drilling and production operations, loads from simultaneous drilling and production operations should be considered.

Variations in ballast distribution and consumables should be considered to determine the maximum design stress in structural members.

As applicable, in-built deformations, and/or stresses result from special or unique fabrication sequences should be included in the structural design of the unit.

When the deck structure is envisioned to be buoyant in a mode of operation, or to meet stability requirements, appropriate consideration should be given to the structural design for such loadings.

3.4 GLOBAL RESPONSE AND STRUCTURAL ANALYSIS

3.4.1 Hydrodynamic Analysis

Environmental forces acting on a FPS should be developed using the methods presented in Section 6 (Environmental Forces) of API RP 2T with the exception of “superharmonic” wave forces discussed in paragraph 6.4.5 of that document which are not applicable. Current loads on mooring lines and risers should be considered.

Development of hydrodynamic loads acting on the FPS hull should be in accordance with Section 6 (Environmental Forces) of API RP 2T. These hydrodynamic loads should be used to compute the vessel motion responses using methods presented in Section 7 of API RP 2T and Sections 4 and 5 of API RP 2SK. Dead weight, live loads, buoyancy forces, and mooring/riser loads should be included in these loads. Current loads and damping of risers and moorings should be included in the hydrodynamic response analysis.

3.4.2 Global Structural Analysis

All hydrodynamic loads developed in addition to the mass inertia loads, should be applied to the structural model. The structural modeling, strength and fatigue analysis methods should be in accordance with Paragraph 8.4 of API RP 2T. Several design seastates (varying wave height and period) from several directions should be analyzed to ensure that the wave causing the highest dynamic loads in a primary strength member is bracketed. Linear harmonic wave theory can be used to investigate the variations in dynamic loads due to passage of a wave. An example procedure to determine design wave cases is provided in the commentary.

Redundancy analysis should be carried out to ensure that there is adequate ductility to allow redistribution of overloads to other components in the event of local failure of highly stressed members and critical connections.

When analyzing the compartment flooding design cases, all hydrodynamic loads should be developed with the FPS floating in the damaged draft, trim and heel condition. The lateral component of gravity should also be included in the analysis.

3.5 STRUCTURAL DESIGN—HULL

As given in Section 1.2, the design basis utilized is based on a Working Stress Design (WSD) methodology and safety factor criteria as defined in API RP 2T.

Consistent with this methodology, the following references should be utilized when calculating the appropriate allowable stress or resistance.

Tubular members	API RP 2A (WSD)
Non-tubular beam-columns members	AISC (ASD)
Stiffened flat plate structures	API BUL 2V
Stiffened shell structures	API BUL 2U
Nodes and transition joints	API RP 2A and API RP 2T*
Fastening and for cases not covered by the above references	AISC (ASD)

*API RP 2T Paragraph 8.5.5.2 (Pontoon to Column and Deck to Column Joints) and Paragraph 8.5.5.3 (Transition Joints and Stiffened Plate Intersections).

If an alternative methodology is to be used from that listed above, the user shall ensure that the safety levels and design philosophy intended in API RP 2T are met. See Section 1.2 for further discussion on alternative codes and standards.

3.6 FABRICATION TOLERANCES

Guidance on fabrication tolerances for steel structures is given in API RP 2T supplemented with additional guidance given in the references in Section 3.5 Any change in these tolerances as a consequence of specific fabrication methods should be considered in the design. Special attention should be paid to interfaces between separately constructed sections.

3.7 STABILITY AND WATERTIGHT INTEGRITY

3.7.1 General

Hydrostatic stability of the vessel in the pre-service and in-service phases of the project should be assessed for both intact and compartment damage or flooded conditions. All free-floating pre-service phases of the FPS should be investigated for stability. Examples of pre-service phases are:

- Fabrication and outfitting
- Float-on and float-off from the deck of a transportation vessel
- Wet tow of the FPS
- Hull/deck mating operation
- FPS ballasting down/up from the pontoon draft to a specified column draft.

3.7.2 Intact and Damaged Stability

The intact and damaged stability of the vessel during its pre-service and in-service phases should satisfy the requirements of applicable national governmental regulations. As an example, a FPS located in the United States OCS waters must meet the stability rules applicable to MODU, as promulgated by the USCG. Many governments do not have their own rules and in general accept the applicable MODU Code or RCS Rules.

The extreme storm and operating conditions differ by restrictions in deck load and/or draft. Two scenarios of damage should be considered: external damage (e.g., collision) and inadvertent flooding (e.g., saltwater system failure).

As a minimum, the design should provide adequate stability according to the criteria presented in the appropriate rules for all pre-service and in-service phases of the FPS, and for both intact and damaged conditions. The maximum anticipated VCG in each condition should be compared against the allowable VCG for that condition for compliance.

3.7.3 Watertightness and Weathertight Integrity

External openings whose lower edges are below the levels defined by the applicable codes for weathertight integrity in intact or damaged conditions are to have suitable weathertight closing appliances. These appliances must effectively resist ingress of water due to intermittent immersion of the closure.

All openings in watertight bulkheads whose lower edges are below the levels defined by the applicable codes for watertight integrity in intact or damaged conditions are to have suitable watertight closing appliances.

Where watertight bulkheads and flats are necessary for damage stability, they are to be made watertight throughout. Where individual lines, ducts or piping systems serve more than one compartment or are within the prescribed extent of damage, satisfactory arrangements are to be provided to preclude the possibility of progressive flooding through such systems.

3.7.4 Weight Management

It is of vital importance that the weight and center of gravity of all items be rigorously and continuously monitored throughout the design, construction and operating phases of the project. Local and global design of deck and hull structure as well as platform response to the environment is dependent on weight distribution, which should be documented and tracked during the design, construction, and operating phases.

At the start of the design phase, appropriate contingencies should be defined to account for weight growth during the project. This may be in the form of reserve ballast.

4 Floating Structure Design and Analysis—Ship Shaped

4.1 INTRODUCTION

4.1.1 Purpose and Scope

This section covers the structural design of new-build conventional ship shaped FPSs. It is intended to highlight modifications to standard ship design considerations. The design of this type of FPS generally follows the rules and standards of RCS, the vessel's flag state as appropriate, and the coastal authorities of the sovereign state in whose waters the FPS is intended to operate. Moorings for such systems should be designed according to Section 8.

Ship shaped FPSs differ from configurations covered in other sections in that they most often provide for storage and transfer facilities for produced oil as well as support for oil processing facilities. It is important therefore to consider in the design the variations in loading accompanying different levels of crude inventory and the impact of additional systems and equipment necessary for the safe storage and transfer of crude oil.

Existing practices or codes should apply, such as the rules and regulations for the design and construction of site specific FPS by one of the RCS.

FPSs designed, constructed, and maintained using alternative rules and standards may be acceptable for production service, providing that these rules and standards are fully documented and can be verified as equivalent to one of the RCS rules and standards.

4.2 GENERAL STRUCTURAL CONSIDERATIONS

4.2.1 Project Phases

The hull and deck structures should be designed for loadings that occur during all project phases as defined in Section 2.4.6b. Ship shape FPSs would be either permanently moored on site or have a disconnectable mooring system. In the latter case, the FPS will disconnect from its moorings and leave the site either under its own power, or assisted by tugs, to avoid severe storm or other limiting design conditions.

4.2.2 Weight Distribution and Mooring Loads

Careful monitoring of weight and center of gravity should be performed during all phases of the project. Also, various cargo loading/unloading sequences anticipated during service and their effect on stability and hull stresses should be investigated.

The ship shaped FPS may be kept on site by various methods, depending on site specific criteria and operational goals. These methods include several different types of station-keeping systems, such as an internal turret, external turret, CALM buoy, spread mooring, thruster assisted and/or dynamic positioning. Each mooring system configuration will impose loads into the hull structure which are characteristic of that system. These loads should be addressed together with riser loads in the structural design of the FPS.

4.2.3 Subdivision and Damaged Condition.

Subdivision of the hull should be made with regard to strength and stability requirements. FPSs should meet the as amended Load Line requirements defined in the 1966 International Convention on Load Lines (ICLL) and subsequent protocols.

Hydrostatic stability of the structure in the damaged condition should also be investigated. The extent of damage to be addressed can be found in Chapter 3, Section 4 of the IMO MODU Code, and RCS rules. Host country and flag state (if applicable) stability and pollution requirements should also be considered during the design stage.

4.2.4 Corrosion

A corrosion protection system and/or additional scantling thickness appropriate for the environment and design life of the platform should be provided. Protection should be designed following the guidelines of Section 13.3. Special attention should be paid to corrosion protection in ballast tanks.

The corrosion protection system must account for both internal and external hull steel wastage. The possible corrosive effects of H_2S, CO_2, and other gases given off by the cargo oil in the storage tanks, and their possible combination with small quantities of water in the tanks, should be investigated and accounted for as well as the effects of any microbial action that may effect horizontal surfaces.

4.2.5 Sloshing

Due to the nature of the cargo operations of FPSs, there will be slack tanks at almost all times. Sloshing of the fluid within a partially filled tank may occur when the natural period of the contents is near that of the period of the wave-induced vessel motions, i.e., "close to resonance". Sloshing results in fluid pressures that may exceed the design pressures for the boundary members within the cargo or ballast tanks. Therefore, the effect of sloshing should be considered in the design.

"Close to resonance" refers to the natural period of the fluid in the tank being within 20 percent (plus or minus) that of the period of the motion of the vessel. Sloshing should be addressed for both the longitudinal and transverse directions as well as filling heights in increments of 10 percent. The determination of the natural period of the fluid within the tank should take into account the restriction to free flow of the fluid that may be imposed by the structures within the tank itself. Long swell waves should also be checked. RCS rules contain provisions for quickly determining natural periods of fluids within tanks and should be referred to for guidance.

Common methods of controlling sloshing in FPSs are the inclusion of swash bulkheads, controlling tank length, and/or reinforcement of boundary structures. Should reinforcement of boundary structures be pursued, calculations should be made to determine what filling height induces the greatest impact loading and the structural boundary members should be designed accordingly. The sloshing loads may either be determined from RCS rules or by direct computational fluid dynamics.

4.2.6 Green Water Effect

The Green Water Effect is the overtopping of seawater on or above the main deck of a vessel due to severe wave conditions. It is a result of relative response of the ship with respect to sea waves in severe sea conditions. Green water on deck can be harmful to personnel on the vessel, and may cause severe damage to the equipment on deck as well as damage to the vessel's structure itself. The tendency of a hull to amass green water on deck should be investigated during the design stage, and is recommended to be confirmed by model tests. Should green water on deck be found to be a problem, remedial action should be taken to protect the crew and vessel by such means as additional or redesigned bulwarks and/or strategically placed breakwaters.

The Green Water Effect would especially apply to a permanently moored FPS. The disconnectable-moored FPS should be designed based on model tests or appropriate design methods, and for threshold environmental conditions (see paragraph 2.4.6d). A permanently moored FPS should be designed to meet the extreme conditions presented in paragraph 2.4.6d.

4.2.7 Slamming

An effect which can be described as the emergence of the keel from the water and the subsequent slamming of the keel as it re-enters the water. This event occurs generally in severe weather conditions. This may also occur either at light operational draft or during transit conditions when the vessel experiences a severe weather condition. The design loads should include slamming as appropriate.

4.2.8 Fatigue

Established RCS methods for fatigue strength assessment should be followed, based on a site specific assessment. Detailed structural (finite element) models of complex joints and other complicated structures may be needed to develop local stress distributions. Fatigue of primary hull girder in and around turret or moon pool structure should be analyzed in areas of high cyclic bending stresses. Structural members that transmit mooring system and riser system loads into the vessel hull should be carefully detailed and analyzed for fatigue damage. See Section 4.5 for further details on fatigue.

4.2.9 Vibration

The effect of vibrations from machinery, such as main and auxiliary engines, propeller excitation, slamming, rotating machinery, processing equipment, or other sources should be considered in the design.

4.2.10 Process Equipment Support Structure

The deck support frame for process equipment, including the connections to the hull frame, should include provisions for movement of the process skid due to hull deflection. These support structures should be designed to withstand inertial/green water loading experienced by the process equipment due to wave induced motion responses, in addition to dead load in upright, heeding, and trimming conditions.

4.2.11 Inspection and Maintenance Program

A comprehensive in-situ inspection and maintenance program of the critical hull and deck members over the FPS service life should be developed following guidelines described in Section 7.6 or guidelines provided by the RCS.

4.3 DESIGN CASES

4.3.1 General

A design case is a combination of loads for each project phase (construction, transportation, installation, in-place, etc.), system conditions (intact or damaged) and environment (normal, reduced extreme, extreme, etc.) with the appropriate safety criteria described in paragraph 2.4.6e. The designer should carefully and systematically prepare a list of design cases which will induce maximum loads for each structural member in the platform, as defined in Section 2.

4.3.2 Global Loads

The total hull girder loads, consisting of wave-induced bending moments and shear forces plus the still water bending moments and shear forces should be calculated in accordance with RCS Rules considering environmentally induced loads from the design cases of 2.4.6d. Depending on the expected environmentally induced loads at the FPS installation site, the wave induced loads at the installation site may be higher or lower than those used by an RCS as the basis of acceptance of a tanker (unrestricted service classification).

An on-board load monitoring system may be installed similar to the ones typically used on tankers.

4.3.3 Hydrodynamic Loads

Typically, two dimensional, linear, ship motion theory, which considers the hull as a rigid element, is adequate to determine the hydrodynamic loads acting on the hull girder; however, for special hull forms or for hulls susceptible to slamming, more sophisticated analysis and/or model tests that consider nonlinear wave effects may be required.

When the analytical means may not adequately predict the hull girder hydrodynamic loads, model tests should be carried out in wave basin to measure hull girder loads. Measurements should be taken at critical sections of the hull, such as at midships and at one-quarter vessel length (L) from either end.

4.3.4 Design Loading Conditions

Sufficient loading conditions for all anticipated pre-service and in-service conditions should be determined and analyzed to evaluate the critical design cases for the hull girder longitudinal strength. This should include fully laden, light ballast, and a mix of representative operational conditions. Operational conditions should also include, as appropriate, unsymmetrical tank loading cases. The loading conditions should include riser and mooring loads. The adequacy of the hull structure for all combinations of static and dynamic loading are to be evaluated. Consideration should be given to static and dynamic loads induced by process and utility equipment on the deck.

4.4 STRUCTURAL DESIGN

4.4.1 Hull Strength Analysis

The hull girder and scantlings should be designed in accordance with RCS rules.

In the evaluation of the hull girder strength, the selection of local scantlings, and the design of the hull's main supporting members, the following factors should be considered:

1. The dynamic components of the loads produced by the various on site loading conditions described in 2.4 may produce dynamic loading components higher or lower than those used in RCS rules for a tanker. Adjustments of the rule criteria applicable to a tanker may be needed (or allowed) depending on the conditions at the particular installation site. Some RCS's have published Rules specifically for ship shaped FPS.
2. The impact of wet and dry weights of process equipment and full range of mooring and riser loads.
3. Utilization of segregated ballast tanks for control of the still water bending moments, shear forces, draft and trim.
4. Local structural loads imposed by mooring system, and by drilling and production riser equipment.

4.4.2 Local Strength Analysis

The procedures outlined in RCS rules, (supplemented by AISC, API RP 2A and API BUL 2V), including the effects of dynamic loading on the structure, should be followed for local strength analysis.

Special considerations should be given to the following:

- The structure supporting the components of the mooring system such as fairleads, winches, etc. should be designed to withstand the stresses corresponding to a mooring line loaded to its breaking strength.
- Support structure for the riser system.
- Consideration should be given to the scantlings necessary to maintain strength in way of large hatches.
- Process equipment supports should be analyzed for all applicable combinations of the following loads:
  - Process support reactions due to equipment weight, wind loads, vessel motions, etc.
  - All applicable combinations of hydrostatic loads on the hull frame imposed by liquids in tanks and the sea;
  - All applicable combinations of hydrodynamic loads on the hull frame imposed by liquids in tanks and the sea.
  - Differential movement between the process deck & hull due to stillwater and wave induced and thermal deflections.
- For a turret-moored FPS or a FPS with a moonpool well, the plating of the well should be suitably stiffened to prevent damage when the FPS is in transit. The required strength of the FPS should be maintained, and particular attention should be given to the transition between fore-and-aft members.
- For yoke-moored FPSs and external turrets, finite element analysis results of attachments to the hull should be used to ensure even stress distribution of concentrated mooring reactions, into the hull structure.
- The effects of Green Water on the affected local hull structure, or the design of a breakwater used to deflect water away from equipment on the deck.
- Flare boom support structure, especially in the case of overhanging (non-vertical) flare booms.
- Crane support structures and supply boat landing areas.
- Helideck Supports.
- Loads imposed by either side-by-side or tandem offloading.

4.4.3 Structural Details

The user should follow the structural design guidelines of the RCS. Consideration should be given to the following:

- The thickness of internals in locations susceptible to excessive corrosion.
- The proportions of the built-up members should comply with established standards for buckling strength.
- The design of structural details such as noted below, against the harmful effects of stress concentrations and notches:
  - Details of the ends and intersections of members and associated brackets.
  - Shape and location of air, drainage, or lightening holes.
  - Shape and reinforcement of slots or cut-outs for internals.
  - Elimination or closing of weld scallops in way of butts, "softening" bracket toes, reducing abrupt changes of section or structural discontinuities.
- Proportions and thickness of structural members to reduce fatigue damage due to engine, propeller or wave-induced local and overall cyclic stresses, particularly for higher strength steel members.
- Structural details in areas of high vibration should be designed to reduce the effect of resonance and local member fatigue.

The design of the process equipment support structure and other superstructures should conform to the provisions of RCS rules and API RP 2A and API BUL 2V. Guidance for sizing beam brackets and spacing of panel stiffeners can be found in the rules of the applicable RCS.

Finite element analyses may be required to check the adequacy of the hull framing and associated process equipment support structure. RCS requirements for the various combinations of vessel draft and tank loadings typically applied to the design of tanker framing, should be considered when selecting load conditions. The methodology and details of the finite element analyses should meet RCS requirements.

The user should consult the Ship Structure Committee references (see Commentary) to review some history of service performance of typical structural details used on ocean- going ships.

4.5 FATIGUE

4.5.1 Fatigue Analysis Methodology

The possibility of fatigue damage due to cyclic loading should be considered in the design. Methodology should follow the RCS Rules. A fatigue analysis using site-specific environmental data should be performed.

The full history of the vessel should be accounted for in the fatigue analysis. Note that this is especially important for vessels that are converted to floating production system service.

At minimum, the fatigue analysis should consider the following:

- For a turret moored vessel, the effects of weathervaning should be considered to account for slow drift and occurrence of waves in off head seas.
- For spread moored vessels, the environmental parameters probability of distribution should reflect the actual site and mooring conditions.
- Load conditions during operations.
- Site specific wave data and vessel response.
- Consideration should be given to the effects of end-of-life corrosion on the stress range.
- Fatigue damage during transit.

- As applicable, previous fatigue damage.
- Inspection and Repair philosophy. Economic considerations may increase RCS rules requirements, which are typically based on a safety level assuming periodic inspection with corresponding repairs as necessary. Design considerations should include plans for dry dock vs. in-service repairs.
- Evaluation of fatigue limit states should include consideration of significant actions contributing to fatigue damage in all design conditions.

All critical details in the FPS should be documented to have sufficient fatigue strength. Particular attention should be given to connection details of the following:

- Integration of the mooring system with the hull structure.
- Main hull bottom, sides, longitudinal bulkheads and deck.
- Main hull longitudinal stiffener connections to transverse frames and bulkheads, because of the relative deflections.
- Openings in main hull.
- Transverse frames.
- Flare tower and attachment to hull.
- Riser interfaces.
- Major process equipment supports.

4.5.2 Selection of Fatigue Requirements

The target fatigue life of a structural component should be selected based upon the intended life, component inspection and repair requirements, and RCS rules (if applicable).

4.6 WEIGHT AND STABILITY

4.6.1 Stability Criteria

In general, stability requirements of IMO, RCS and/or applicable flag state administration should be used to assess the stability of the FPS.

4.6.2 Stability and Loading Manual

A stability and loading manual should be prepared which shows the stability limitations and allowable hull girder bending moments and shear forces. This manual should include all pertinent information regarding tank loading arrangements, as well as loading and unloading sequences necessary to maintain hull girder longitudinal bending and shear stresses and vessel stability within the allowable limits for all conditions including transient conditions of loading. It is recommended that the ship shape FPS be equipped with a computer system for monitoring of the vessel stability and hull strength.

4.7 TRANSIT

The transit condition from the shipyard completing the construction of the vessel should be established in the design. The transit condition should be analyzed for longitudinal strength using appropriate loading along the length of the ship, and wave condition representing the environment for the transit route and the time of the year. The total of still water and wave induced bending moment should be assessed for structural strength of the ship during transit condition.

Special attention should be paid to items such as the flare boom, crane pedestal, etc. which will be subject to motion induced loading and/or slamming that may occur during transit. Motions and accelerations during transit should be calculated and process and topside equipment supports should be verified against the forces generated by these motions and accelerations.

If fitted with an internal turret, special consideration should be given to bottom slamming to preclude damage to the turret supports and bearings. In many cases, this may require adjustment of the transit draft to reduce motion responses of the vessel.

4.8 FABRICATION TOLERANCES

Guidance on fabrication tolerances for steel structures is given in the appropriate RCS rules. Any changes in these tolerances as a consequence of specific fabrication methods should be identified to incorporate them in the design.

5 Floating Structure Design and Analysis—SPAR

5.1 INTRODUCTION

5.1.1 Purpose and Scope

This section addresses the design and analysis of the deck and hull of a FPS using the configuration of a Deep Draft Caisson Vessel (DDCV), also known as a “spar”. In this document, a FPS with such configuration will be called a “spar”.

A spar platform is a large diameter deep draft floating structure. Figure 5.1.1-1 shows a representative spar platform. Other variations of spar configuration exist for different applications.

A spar platform may include a full drilling facility or a workover facility in addition to the production equipment and accommodations. The structural and stability design of this type of FPS is covered in this section. The moorings for such systems should be designed according to Section 8.

5.1.2 Description of a Spar Based Platform

A definition of spar is given in Section 1.3.c with an illustration of a typical spar platform shown in Figure 5.1.1-1. It primarily consists of a hull, a deck, production equipment, and a mooring system.

The hull structure provides the buoyancy to support the weight of hull, deck, living quarter, process equipment, utility system, mooring system, riser system, stored oil (for platform with storage capability), etc. The deep draft spar concept reduces heave responses significantly, and surface trees can be used for such concept. For a spar based platform without oil storage capability, the hull is designed to have hard tanks at upper hull to provide the necessary buoyancy, while the rest of the hull resembles an open can entrapping a large mass of water inside. In such case, the hull design also incorporates soft tanks at the bottom of the hull (in upright condition) which provides temporary buoyancy necessary during transportation, upending and installation. The following tank definitions are provided:

- *Hard Tank:* is the tank of a spar which provides for adjusting the platform's center of gravity and operating draft, and is designed for full hydrostatic pressure.
- *Soft Tank*: is a tank normally located at the spar keel and provides buoyancy during the towed condition. Flooding the soft tank upends the spar platform. In certain designs, fixed (or solid) ballast is installed in the soft tank.

The top deck structure is a multilevel facility which may consist of trusses, deep girders and deck beams for supporting equipment, and operational loads. The mooring system consist of chain jacks/winches, chain stoppers, fairleads, mooring lines and anchors. The riser system consists of top tensioned or catenary risers. Other variations of riser configurations may be developed for different applications.

A spar hull is functionally divided into a number of sections as shown in Figure 5.1.1-2, and are described below:

1. An upper buoyant section to support the weights of hull, deck, equipment, mooring system, variable trimming ballast, etc. This buoyant section consists of compartments which are designed to withstand hydrostatic pressure in addition to hydrodynamic loading. The compartmentation should be arranged to meet the intact and damaged stability. A double wall section (cofferdam) may be provided at the waterline for damage control against vessel impact.
2. The mid-section can be designed as a stiffened cylindrical shell structure (which could be either flooded or used for storage) or a truss hull form which may contain a series of structural plates that trap water mass and provide hydrodynamic damping to limit heave motions.
3. The soft tank section on the bottom provides temporary buoyancy during tow, which is flooded during spar upending. The soft tanks may hold fixed ballast when needed to lower the spar center of gravity for adjusting stability as well as motion characteristics.
4. A centerwell or moonpool may run through the entire depth of the hull to accommodate drilling, production, and export risers.

5.2 GENERAL STRUCTURAL CONSIDERATIONS

5.2.1 Project Phases

The hull and deck structures should be designed for loadings which occur during all project phases including construction, transportation, installation, inplace and decommissioning phases as defined in section 2.4.6b.

5.2.2 Damaged Conditions

The structural design should consider the possibility of accidental events including collisions, dropped objects, fire, explosion, and flooding. Damaged conditions shall include consideration of reduced structural capacity and higher hydrostatic pressure for the waterline at damaged configuration. Section 2.4.6c further describes damage considerations.

5.2.3 Reserve Strength

The design of the structure should include details that provide reserve strength in areas that are critical to the structural integrity of the hull.

5.2.4 Safety

Arrangement of the main structural deck elements and top of hull should be coordinated with topside facilities equipment lay out and operational requirements. The deck structure and the spar hull should allow adequate ventilation of hazardous areas, access for fire fighting, fire protection, and escape routes. Facilities such as, quarters, production equipment, etc. should be arranged based on safety considerations.

5.2.5 Air Gap

Considerations for calculating the air gap are provided in API RP 2T, Section 7.2.8 (Deck Clearance). Due to the floating nature of the FPS, roll and pitch should be considered in addition to the factors for deck clearance listed in API RP 2T.

5.2.6 Interfaces with Other Systems

The structural design of the deck and hull should consider interfaces with other systems such as mooring line and riser termination points, mooring system and riser installation equipment, moon pool requirements, drilling and production equipment, and hull marine systems. For spars with storage, the storage compartmentation and its offloading system should be considered.

5.2.7 Riser System

Risers are used for drilling, production, water injection, subsea umbilicals and export. Risers could be top tensioned and supported by the spar itself or by separate buoyancy cans. They could also be catenary risers. Riser/hull interface locations should be selected based on consideration of hull structure arrangements, riser installation, inspection requirements and riser entry, riser stress and wear effects. Riser loads should be included in spar structure design. The structure supports around the riser/spar interface may need to be reinforced. The spar hull design should consider the relative motions of the riser buoyancy cans and the hull at all conditions.

5.2.8 Tank Subdivision

The subdivision of tanks utilized for providing buoyancy is normally based upon requirements for damaged stability, operational flexibility and inspection.

Strength of internal structure in watertight compartments (e.g., ballast tanks) should include consideration of actions resulting from damage or accidental flooding of the compartments in question. The tank bulkhead scantling should be designed to withstand hydrostatic pressure for damaged waterline. Progressive collapse should not occur in the event of accidental flooding of a watertight compartment.

5.2.9 Corrosion Allowances and Protection

A corrosion protection system and/or additional scantling thickness appropriate for the environment and design life of the platform should be provided. Protection should be designed following the guidelines of Section 13.3. Special attention should be paid to corrosion protection in ballast tanks.

5.2.10 Vibrations

The effect of vibrations from machinery, such as gas turbines and diesel engine-generators, should be given consideration in the design.

Members subjected to Vortex Induced Vibration (VIV) should be designed for fatigue and/or VIV mitigation. Long, slender members are especially susceptible to VIV.

5.2.11 Inspection and Maintenance Program

A comprehensive in-situ inspection and maintenance program of the critical hull and deck members over the FPS service life should be developed following guidelines described in Section 7.6 or guidelines provided by the RCS.

5.3 DESIGN CASES

5.3.1 General

A design case is a combination of loads for each project phase (construction, transportation, installation, inplace, etc.), system conditions (intact or damaged) and environment (normal, reduced extreme, extreme, etc.) with the appropriate safety criteria as described in paragraph 2.4.6e. The designer should carefully and systematically prepare a list of design cases which will induce maximum loads for each structural member in the platform, as defined in Section 2.

5.3.2 Loading Conditions

For each design case, the spar should be designed for the loading conditions that will produce the most severe local and global effects on the structure. Applied loading combinations to be considered for structural design should include, but are not limited to the following items:

- Loads due to wind, wave, and current.
- Gravity Loads of the structure and installed equipment with appropriate components due to platform heeling and trimming.
- Operational Loads due to drilling, production, and export
- Loads from mooring and riser systems.
- Loads specific to marine operations, e.g., loadout, transport, upending, lifting, mating, etc.
- Dynamic loads.

For spars designed for drilling and production operations, loads from simultaneous drilling and production operations should be considered. When the platform is designed for crude storage, and offloading, the loads specific to such operations should be considered.

Variations in ballast distribution and consumables and the locations of movable equipment (e.g., drilling substructure) should be considered in order to determine the maximum design stress in the structural members.

When significant in-built deformations, and/or stresses result from the chosen fabrication and installation sequences, these should be included in the structural design of the platform.

5.3.3 Installation Loads

Spar structure design should consider the loads encountered during assembly and installation phase of the spar. These loads include loads exposed during assembly of the spar hull section on land and/or in water, transport (wet or dry), launch, connecting pieces, upending, and during ballasting and deballasting operations when the top deck is being installed.

5.4 GLOBAL RESPONSE AND STRUCTURAL ANALYSIS

5.4.1 Global Responses

In predicting the global responses of a spar platform, environmental forces acting on the spar should be developed using established methods. These loads could then be used to compute the spar global motions. Environmental loads should include wind, wave, swell, and current effects.

Spar responses depend on the platform characteristics, e.g., damping coefficients, added mass, entrapped mass of water, environmental loading, loading from the mooring system, etc. The heave damping of the platform can be adjusted by designing the platform with mass/damping plates. Incorporation of such plate is very critical to a design of a spar with truss sections in the mid-section and/or bottom of the hull.

Mooring line tensions obtained by using methods presented in Section 8 should be applied for global structural analysis.

Maximum acceptable spar global responses depend on operations, e.g., drilling, well production, etc., and nature of load conditions, such as, routine operation, survival condition, etc. These acceptable global response limits should be developed based on operational philosophy and response limits of other spar components, e.g., riser stresses, mooring line tensions, etc.

Air gap as described in Section 5.2.5 should be determined as part of the spar global response analysis accounting for the relative motions between the spar platform and water surface due to combined effects of wind, current and waves. Global response analysis should provide the inertia loads required for the design of the deck structures.

5.4.2 Vortex Induced Vibration (VIV)

In areas with a strong current extending deep into the ocean it is necessary to assess the spar for the possibility of vortex induced vibrations. A spar may oscillate in the transverse direction to the flow of current caused by vortex shedding behind the spar. VIV is a function of the current speed and the natural period of the spar system.

Analysis of spar VIV can be made with established methods published in the industry or using model tests. Helical strakes or other VIV suppression strategies may be employed on the spar hull to suppress the VIV. In that case the effects of the chosen strategy on the inertia and drag of the spar should be considered.

5.4.3 Structural Analysis

All appropriate loads should be transferred to the spar structure model for stress analysis. Mooring line load should be considered in the structural analysis. The structural model and strength and fatigue analysis methods should be in accordance with established procedures. Several design environments with varying wave heights, wave periods, wind speeds, wind directions, current speeds and current directions accounting for their joint probability occurrence should be analyzed to ensure that the combination cases include the case with the highest dynamic loads in a structural member.

Redundancy analysis should be performed to ensure that there is adequate redistribution of stress in the event of a local failure of a highly stressed member or critical connections.

When analyzing the compartment flooding design cases, all hydrodynamic loads should be developed with the spar floating in the damaged draft, trim and heel condition. The lateral component of gravity should also be included in the analysis.

Some spar structural component design could be governed by fabrication, assembly, transport, upending and installation loads. These loads should be determined based on established procedures and stress analysis to ensure that their sizing is adequate. Fatigue analysis should include all loading history of the spar including fabrication, transport, upending, and in-place operation phases.

For spar hull appurtenance design, local water velocity around the spar hull should be determined for the design loads to ensure that the attached appurtenance structures are designed properly.

5.5 STRUCTURAL DESIGN—SPAR HULL AND DECK

5.5.1 Design Basis

As given in Section 1.2, the design basis utilized is based on a (WSD) methodology and safety factor criteria as defined in API RP 2T.

Consistent with this methodology, the following references should be utilized when calculating the appropriate allowable stress or resistance.

Tubular members	API RP 2A (WSD)
Non-tubular beam-columns members	AISC (ASD)
Stiffened flat plate structures	API BUL 2V
Stiffened shell structures	API BUL 2U
Nodes and transition joints	API RP 2A and API RP 2T*
Fastening and for cases not covered by the above references	AISC (ASD)

*API RP 2T Paragraph 8.5.5.2 (Pontoon to Column and Deck to Column Joints) and Paragraph 8.5.5.3 (Transition Joints and Stiffened Plate Intersections).

If an alternative methodology is to be used from that listed above, the user shall ensure that the safety levels and design philosophy intended in API RP 2T are met. See section 1.2 for further discussion on alternative codes and standards.

5.5.2 Fatigue Design

Fatigue damage due to cyclic loading is to be considered in the design of the structure. A fatigue analysis should be carried out using an appropriate loading spectrum in accordance with the accepted theories in calculating accumulated damage. API RP 2T can be used for fatigue analysis. All significant stress cycles imposed on the structure during its entire service life should be accounted for, including those induced during assembly, fabrication, transport, installation and in-service phases.

Increased safety factors should be considered for the areas that are not inspectable.

5.6 FABRICATION TOLERANCES

Guidance on fabrication tolerances for steel structures is given in API RP 2T supplemented with additional guidance given in the references specified in Section 5.5.1 of this RP. Any changes in these tolerances as a consequence of specific fabrication methods should be considered in the design. Special attention should be paid to interfaces between separately constructed sections.

5.7 STABILITY AND WATERTIGHT INTEGRITY

5.7.1 General

Hydrostatic stability of the spar in the pre-service and in-service phases of the project should be assessed for both intact and compartment damaged conditions. All free-floating pre-service phases of the spar should be investigated for stability. Examples of such pre-service phases are:

- Fabrication and outfitting.
- Float-on and float-off from the deck of a transportation vessel.
- Wet-tow of the spar on its own hull.
- Dry tow of the spar on a transport vessel.
- Hull launch/upending.
- Hull/deck mating operation.
- The spar ballasting down/up condition.

5.7.2 Spar Hull Configuration

The upper part of the spar hull is divided horizontally by watertight decks and vertically by radial watertight bulkheads. These compartments or "hard" tanks of the hull are designed to resist the hydrostatic pressure of seawater on the outer hull and centerwell. The radial bulkheads extend the full length of the spar hull from the upper deck to the bottom of the hard tank. These tank subdivisions regarding number and dimensions of tanks are based on both the intact and damage stability requirements. The tanks in the lowest level of the hard tank section are generally used as variable ballast tanks for controlling trim of the platform. All the other tanks in the hard tank section are void spaces, and they are primarily for providing buoyancy.

The soft tanks at the keel of the spar may provide room for fixed ballast when necessary for lowering the center of gravity. These soft tanks are also used for buoyancy during towing of the spar and also during upending of the spar hull. A double hull may be built at the waterline to provide protection from flooding by collision damage from boats or other vessels.

The freeboard of the spar influences the down flooding angle which is one of the important parameters in the stability assessment of any floating platform.

5.7.3 Intact and Damaged Stability

The intact and damaged stability of the spar during its pre-service and in-service phases should in general satisfy the requirements of coastal government regulations. As an example, a spar located in the United States OCS waters must meet the stability rules applicable to MODU, as promulgated by the U.S. Coast Guard. Many governments do not have their own rules and in general accept the applicable Rules of IMO or RCSs.

The Extreme Storm and Operating Conditions may have to be imposed with restrictions in deck load and/or draft. Two scenarios of damage should be considered: external damage (e.g., collision) and inadvertent flooding (e.g., saltwater system failure).

As a minimum, the design should provide adequate stability according to the criteria presented in the appropriate rules for all pre-service and in-service phases of the FPS, and for both intact and damaged conditions. The maximum anticipated VCG in each condition should be compared against the allowable VCG for that condition for compliance.

5.7.4 Watertightness and Weathertight Integrity

External openings whose lower edges are below the levels defined by the applicable codes for weathertight integrity in intact or damaged conditions are to have suitable weathertight closing appliances. These appliances must effectively resist ingress of water due to intermittent immersion of the closure.

All openings in watertight bulkheads whose lower edges are below the levels defined by the applicable codes for watertight integrity in intact or damaged conditions should have suitable watertight closing appliances.

Where watertight bulkheads and flats are necessary for damage stability, they are to be made watertight throughout.

Where individual lines, ducts or piping systems serve more than one compartment or are within the prescribed extent of damage, satisfactory arrangements are to be provided to preclude the possibility of progressive flooding through such systems.

5.7.5 Weight Management

It is of vital importance that the weight and center of gravity of all items be rigorously and continuously monitored throughout the design, construction, and operating phases of the project. Local and global design of deck and hull structure as well as platform response to the environment is dependent on weight distribution, which should be documented and tracked during the design, construction, and operating phases.

6 Floating Structure Design and Analysis—Other Hulls

6.1 INTRODUCTION

6.1.1 Purpose and Scope

This section covers the design of FPSs which are not covered by Sections 3, 4 and 5 of this document. The station-keeping systems for such FPSs are covered by API RP 2SK.

For an unconventional FPS design, a readily available design practice or design standard may not be suitable. The designer must define the methodology to ensure that all sig-

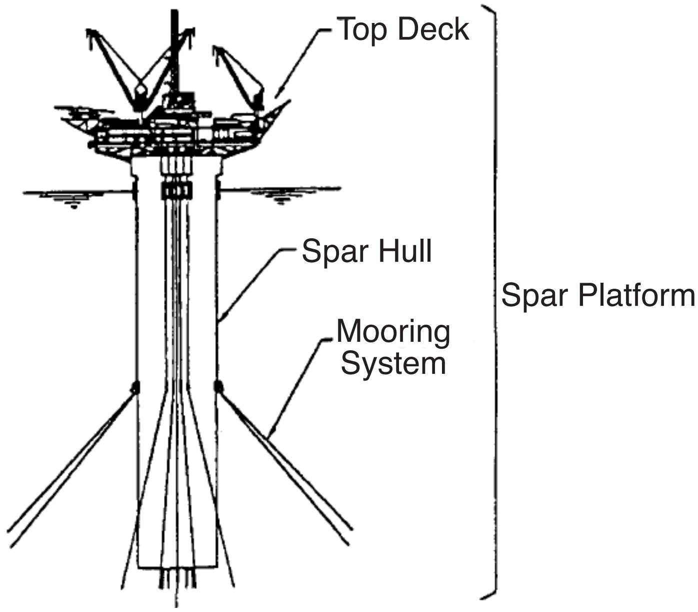


Figure 5.1.1-1—"SPAR" Platform

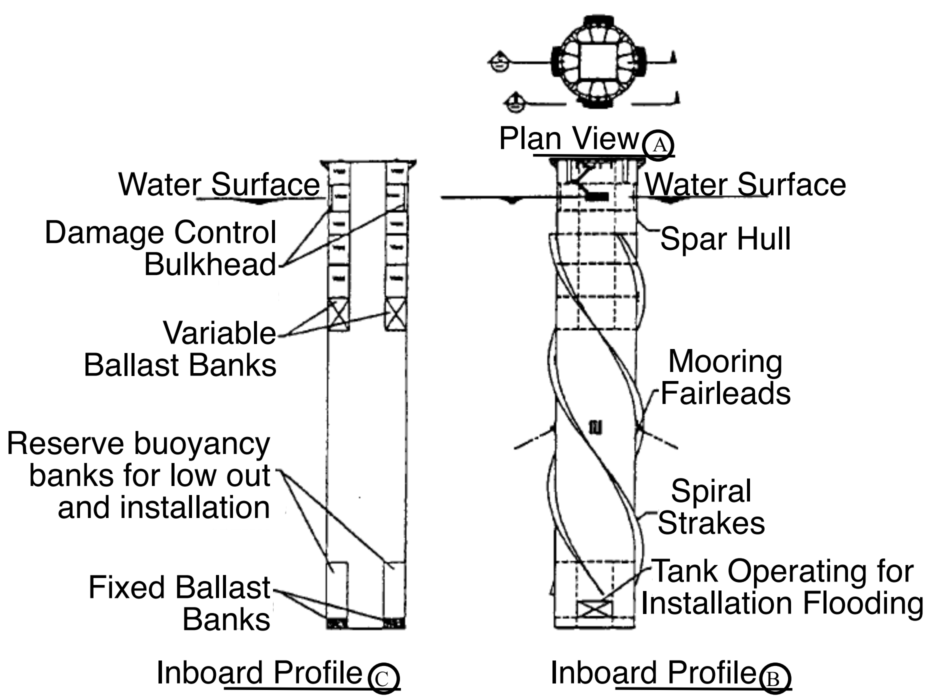


Figure 5.1.1-2—Typical Compartmentation of a "SPAR" Platform

nificant features of the behavior of the FPS are accounted for in its design and that it conforms to sound engineering practices. It is recommended that any proposed design practice be discussed with appropriate regulatory and/or RCS at early design stages.

Existing practices or codes may apply to parts of such a FPS. The selection of existing codes should be carried out with special attention regarding their compatibility with each other and their compliance with standards of safety and reliability accepted by the offshore industry. The use of formal reliability analysis may be considered for their appropriateness to establish the design criteria and/or the standard for the proposed design (See Section 14).

For concepts with unique configuration, the environmental effect calculations should be verified by conducting model tests.

6.2 STRUCTURAL DESIGN USING STEEL

Existing codes for structural design listed in Section 3.5 should be used as the basis for the design of the structure. These are generally based on the use of the WSD method, and designer may refer to API RP 2A, API RP 2T, API BUL 2U and API BUL 2V. Alternative rational design methods may be used, as appropriate.

The user should ensure that the requirements used are relevant to the form of the structure, the materials used, its purpose and the types of loading and environment it will be subjected to. If sections from different design codes are used, their compatibility and level of industry acceptability should be confirmed. The design methods selected should be reviewed to establish that they meet the overall system reliability requirements.

Structural details peculiar to a specific FPS design should be given careful attention, to establish that all significant loading components are properly represented. Selection of a design code or standard for such components should be reviewed to ensure that the selection is applicable for the intended design.

6.3 FABRICATION TOLERANCES

Guidance on fabrication tolerances for steel structures is given in API 2T, API BUL 2U, and the RCS rules. Any change in these tolerances as a consequence of specific fabrication methods should be evaluated for its acceptability.

6.4 STABILITY AND WATERTIGHT INTEGRITY

Stability and watertight integrity of the FPS should be adequate at all stages of its life cycle to meet applicable regulatory requirements as well as host and flag state requirements.

The requirements by other agencies, such as IMO and RCS are similar and addresses the issues of capsizing of floating platform against overturning moments due to wind and any other external or operational loading in intact condition. In general, the discussion on stability in Section 3.8 and Section 4.6 are valid for platforms with unconventional configurations. Additionally, special consideration should be given to resolve any unconventional stability issues that may be specific to new configuration.

The concepts of requirements for righting/heeling moment curve area ratio should be considered judiciously for application to unconventional floating platform.

6.5 SYSTEM SAFETY AND LOSS CONTROL

The safety provisions incorporated into the FPS should be designed to suit the features of the FPS with unconventional configurations and layout with the objective of achieving appropriate safety to minimize the damage and loss of life, environment and property.

The ability of ballast, fire fighting, escape and other safety systems to operate in upset conditions (e.g., large heel angle of the vessel, under emergency power, etc.) should be verified to ensure that onboard personnel will have adequate resources to respond, escape, and evacuate from a large range of possible events.

7 Conversion and Reuse of Existing Floating Structures

7.1 GENERAL

FPSs may be built by converting or re-using existing floating structures. Examples of the types of existing floating structures likely to be converted (or modified to) production service include:

- Column stabilized structures, such as semi-submersible MODUs, construction and accommodation vessels, multi-service vessels, etc. as defined in Section 1.3.
- Ship-shaped structures, such as drillship MODUs, ocean going tankers, barges, etc. as defined in Section 1.3.

This section provides general guidance on special considerations associated with the selection and conversion of an existing floating structure to production service. Areas addressed include design and construction standards, effects of prior service, corrosion protection and material suitability, inspection, and maintenance. This section is intended to supplement the RPs provided in other sections.

Major considerations for the selection, conversion or reuse of an existing floating structure are the vessel's original basis of design (i.e., design criteria, methodology, codes), age, condition, maintenance, and operational history, as well as the design, inspection, maintenance, and repair requirements for the intended production service. The relative importance of these considerations are influenced by the converted structure's intended mission (as defined in Section 2), strength, fatigue, and redundancy requirements and regulatory/certification requirements.

A key consideration related to converting an existing floating structure for long-term production service (Category 1 as defined in Section 2.3) is the design philosophy for inspection, maintenance, and repair (when required) of the converted structure with minimal disruption to normal operations. Ships and/or other floating structures are usually designed to be drydocked for inspection, maintenance, and repair at regular, (typically 4–5 year) intervals, commonly known as special/continuous survey. These inspection and maintenance activities emphasize structural crack detection and repair, corrosion and wastage determination (typically by plate thickness gauging) and plate repair and replacement, coating/anode replacement, and miscellaneous damage repair. A FPS is not designed for such drydocking, and should be designed such as to avoid such maintenance and repair.

A FPS can be designed as disconnectable which requires a system for disconnecting the vessel from its mooring and riser system to allow the vessel mainly to ride out severe weather or seek refuge under its own power or towed away by tugs when needed. For a FPS with such disconnectable system, it could be envisioned to disconnect the vessel for inspection, maintenance and repair. Nevertheless, it is not a desirable option because of loss of production. It is strongly recommended to develop an on-site inspection and monitoring program for a FPS and incorporate this into the conversion design of the existing structure. Specific examples of this program include providing internal access to critical structural areas for inspection and maintenance, using enhanced corrosion protection systems, etc.

7.2 DESIGN, CONSTRUCTION AND MAINTENANCE STANDARDS

A site specific structural evaluation using the results of a current condition survey or planned condition after modifications shall be performed to determine the adequacy of the floating structure to be used in the conversion. Acceptance criteria shall be based on RCS rules applicable for such conversions.

Existing floating structures likely to be converted to production service typically would have been designed, constructed, and maintained, (collectively referred to as "classed") under the rules and standards of a RCS.

Floating structures classed using alternative rules and standards may be acceptable for conversion to production service, providing that these rules and standards are fully documented and can be verified as equivalent to one of the RCS rules and standards.

The RCS and regulatory rules and standards used to design, construct, and maintain the existing floating structure may have been subsequently revised or superseded. Depending on the intended mission, the converted floating structure should comply with part or all of the current rules and standards. The recommended level of compliance with the current rules and standards will vary and depend on the intended production service.

The mooring system should be designed in accordance with Section 8.

7.3 PRE-CONVERSION STRUCTURAL SURVEY

The existing vessel to be converted to a FPS should be subjected to a comprehensive structural survey prior to, or during, the vessel's conversion. This "pre-conversion" survey should establish the actual condition of the structure, including the existence of fatigue-related problems, such as cracking, etc., scantling dimensions and the level of corrosion wastage. The survey results should be used as the basis for any site-specific structural analyses of the converted unit and should also provide the "baseline" condition for future in-service inspections.

To the extent practical, the pre-conversion structural survey should cover all structural components and details considered part of the main or primary structure. The existing vessel should be subjected to a "close and thorough visual" inspection in accordance with the Renewal (or "Special") Survey requirements of an RCS. This survey should also include a significant level of non-destructive testing (e.g. magnetic particle inspection [MPI], eddy current [EC] testing, ultrasonic testing [UT]) to identify fatigue-related problems, and to determine the actual scantlings. Structural components and details having previous service problems (e.g., fatigue-related cracking, corrosion wastage) should be inspected in detail using non-destructive testing to establish the adequacy of the prior repairs or modifications.

7.4 EFFECT OF PRIOR SERVICE

7.4.1 General

Existing floating structures typically considered for conversion to production service may have been in previous service for an extended period of time, possibly up to 20 years (or more). During this period, the structure may have been subjected to environmental loads that caused accumulation of fatigue damage. Additionally, structural material wastage due to corrosion (or wear), and miscellaneous structural damage may be present. Damage and wastage should be addressed during the conversion of the existing floating structure to production service. The extent of the repair or replacement of the damage and wastage will depend on the converted structure's intended service life, function, and operating environment.

Any significant structural damage and wastage should be repaired or replaced during the conversion of the existing structure to production service. Guidance for determining the extent of fatigue-related damage and corrosion wastage associated with column stabilized and ship-shape structures can be provided in the RCS Rules.

7.4.2 Column Stabilized Structures

The primary structure of column stabilized floating structures comprises multiple columns, pontoons, braces, and primary load- carrying deck structural members. The areas where these structural components intersect are typically highly stressed and/or fatigue prone. These areas critical to the overall integrity and reliability of the floating structure should be subjected to detailed strength and fatigue assessments, and periodic inspection, and monitoring during service.

The extent of fatigue damage from prior service should be included in the site-specific fatigue assessment.

Fatigue analysis should consider the following:

- Prior service damage reflecting the age and operational history of the vessel.
- Previous repairs and modifications.
- Results from a comprehensive structural inspection, prior to conversion.
- Site-specific wave data and vessel response.
- Modifications to improve fatigue performance and renewal efforts.
- Target fatigue life.

In addition to fatigue-related damage, the existing floating structure should be inspected to establish the extent of material wastage due to corrosion. This inspection should include non-destructive (typically ultrasonic) testing to determine the thickness of the existing plating on the pontoons, columns, braces, and deck structure. Areas of significant wastage should be repaired or replaced. Other miscellaneous structural damage should also be repaired.

7.4.3 Ship Shaped Structures

Fatigue damage, structural inspection, maintenance and repair is very important for ship shaped structures converted to long-term production service, as described in Category 1 in Section 2.3. Additionally, the converted structure may have a significantly different configuration, such as incorporating an internal turret or a drilling "moonpool." Therefore, a site-specific fatigue assessment is recommended using the guidance provided in Section 4. The structure should also be checked for arrangement specific loads, e.g., higher or lower loads for a weathervaning vessel. It should also be noted that the still water loads for the converted FPS can be larger than those used for the original design and the structural adequacy in the new condition should be considered. Finally, tanker ships are normally designed either for empty or full (pressed) tanks. Therefore, sloshing of the FPS as discussed in Section 4 may need to be checked.

The strength and fatigue of the converted FPS should be calculated for FPS specific items not considered in the original tanker design. Examples are:

- permanent moorings
- riser system
- production and additional topside equipment

Fatigue analysis should consider the cumulative fatigue damage during prior service life. This cumulative fatigue damage should be calculated based upon the operating parameters (e.g. general trading routes, effective speed, percentage occurrence of environmental headings, load conditions, etc.). This damage should be combined with the expected fatigue damage of the converted vessel on site during her service as FPS, to obtain the total expected fatigue life of the floating structure. The calculated total fatigue life should be compared against the remaining fatigue and service life as a FPS to decide on the adequacy of the remaining fatigue life of the structure. In cases where the trading history is not known, unrestricted service wave statistics could be applied.

7.5 CORROSION PROTECTION AND MATERIAL SUITABILITY

Wastage of steel due to corrosion is a major consideration for structures operating in the marine environment, and requires special consideration for existing structures to be converted for long-term production service. The suitability of the existing steel to meet the requirements of the intended production service at a specific location should be taken into consideration. For example, steel used for Gulf of Mexico operations may not be suitable for North Sea use because of different ductility and impact energy (charpy) requirements for colder and more hostile environment.

Potential for corrosion wastage depends on the fluid (i.e., sea water, fuel oil, cargo oil, etc.) steel is exposed to, the type of corrosion protection system used, and its associated maintenance. Specific structure areas that are to be considered for corrosion protection are:

a. External surfaces, including:
   - Underwater hull (pontoons, columns, braces, bottom and side shell, etc.)
   - Waterline area (splash zone)
   - Above waterline hull
   - Deck areas
   - Topside facilities and superstructure

b. Internal surfaces—dry, including:
   - Void spaces (open and closed)
   - Machinery and equipment spaces
   - Storage spaces
   - Accommodations

c. Internal surfaces—wet, including:
   - Ballast tanks (active, passive, and reserve [dry])
   - Cargo and slop tanks (tankers, barges)
   - Fuel tanks
   - Fresh water tank
   - Drill water tanks

Three primary corrosion protection systems are:

- Coating (paint) systems
- Cathodic protection (anodes, impressed current) systems

- Corrosion thickness allowance

These systems are typically used in combination to provide a complete corrosion protection system for the entire structure.

Condition of the existing floating structure's corrosion protection system may require it to be replaced, upgraded and/or supplemented for conversion to production service. The specific requirements depend on the system's previous performance history and present condition, the condition of the structure, the refurbishing and repair performed, and the maintenance program to be conducted during the conversion and throughout the production service. Recommendations for the corrosion protection system replacement, upgrade, and refurbishment are provided in Section 13.

Impressed current systems, independent or in combination with sacrificial anodes, are considered feasible alternatives to upgrade a corrosion protection system. An existing coating system may need to be replaced and/or upgraded to protect the external plating or internal tanks and void spaces. Coating system selection should consider the floating structure's service life and inspection program, in terms of personnel access and cleaning requirements.

The protection system and requirements for a specific surface or tank will depend on the type of service and the duration of exposure. For example, the system requirements may vary for an active ballast tank (i.e., tanks having continuous changing of sea water), passive ballast tanks (i.e., tanks maintaining a constant amount of sea water), cargo oil tanks, and drill water tanks.

In general, the steel used in the existing floating structure will be considered acceptable if the structure meets the minimum standards provided in Section 7.2; however, conversion of the structure for production service may result in some of the existing material not meeting requirements in areas, such as highly stressed and/or fatigue prone components and structural details. In these areas, the material may need to be replaced or reinforced if found not meeting specific fracture toughness and ductility requirements, and through-thickness (i.e., "z"-direction) properties, and weldability.

Margins on the scantlings should be considered during the design stage to accommodate intended service life.

7.6 INSPECTION AND MAINTENANCE

A comprehensive in-situ inspection and maintenance program of the critical hull and deck members over the FPS service life should be developed following guidelines described in this Section 7.6 or guidelines provided by the RCS.

The program should be developed in conjunction with and incorporated into the structure's design. The program should provide for periodic monitoring of the floating structure's integrity throughout its production service life. The scope of the program should provide for inspection of all critical areas of the primary structure over a specific time interval, typically 4–5 years. Personnel and equipment access to the inspection areas should be considered in the design. A program for maintaining and, if indicated, repairing the structure and its corrosion protection system should also be developed.

Development of the structural inspection program should consider the results of the structural strength, fatigue and redundancy analyses discussed in Sections 3-6 for various structure types, and consider the previous inspection history (including the inspection results of structures of similar design). Additionally, the plan should incorporate the specific inspection requirements of the appropriate RCS, regulatory and certifying agencies.

It must be borne in mind that inspection of tanks will require emptying, cleaning, and gas freeing these spaces. This may affect the loading on both the global and local structure of the vessel.

Since drydocking of the FPS may not be practical or economically feasible during its service life, underwater inspection capability may have to be incorporated into the inspection and maintenance program. Methods of inspecting and maintaining the corrosion protection systems should be developed. Consideration should be given to minimizing through-hull fittings. If this is not possible, covers for seachests and similar components must be provided. Adequate identification markings (taking into consideration the coastal states language) to assist in underwater survey and/or repair should be provided.

Guidelines should be developed for repair acceptance criteria. As an example, underwater welding should be limited to secondary structure items unless it can be demonstrated that welding can achieve the strength used in the design. The effects of welding on the corrosion protection system (painted surfaces) and the repair of such surfaces must be considered.

Methods of inspecting and maintaining the corrosion protection systems should be developed. Where, due to lack of accessibility, it is not considered practicable, or possible, to inspect, maintain or replace corrosion protection systems, such systems should be designed taking this factor into account and should, as a minimum, be designed for twice the service life of the floating structure.

7.7 HYDROSTATIC STABILITY

It is recommended that the stability requirements of a FPS be in accordance with Section 3.7 or 4.6.

8 Station Keeping and Anchoring Systems

8.1 GENERAL

The term "station-keeping" refers to maintaining a Floating Production System over a specified location within certain offset limits. This may be achieved using a passive mooring system, a dynamic positioning system, or a combination of the above.

A passive mooring system normally consists of multiple lines spreading around the structure with each mooring line consisting of composite sections consisting chain and steel wire or fiber rope with or without in-line buoys. The mooring system can be either a conventional spread mooring (catenary) system or a taut mooring system anchored at the sea bed with conventional anchors, anchors with high holding power, or with piles. With taut mooring lines, the anchors are subjected to significantly higher vertical loads than those of conventional spread mooring system.

Mooring line fairlead locations should be decided based on considerations of hull structure arrangements, interference with other structures, supply boat landing spaces, inspection requirements, etc. Mooring line loads are to be included in the structure design, specially in the vicinity of mooring fairleads.

All aspects of station-keeping systems for FPSs are covered by the API RP 2SK. This section does not intend to repeat the information provided in the RP 2SK. The primary purpose of this section is to provide additional recommendations to supplement RP 2SK.

8.2 DIFFERENCES BETWEEN FPS AND MODU MOORING SYSTEMS

An FPS mooring system serves a stationkeeping purpose similar to that for a MODU, while the design philosophy for the two systems differ. First, a FPS mooring focuses on the more permanent nature of the in-service phase, while a MODU mooring emphasizes mobility and the constant need for keeping the MODU within a tight watch radius in support of the drilling operations. Secondly, the consequence of a FPS mooring system failure would usually be more severe than that of a MODU mooring failure. Finally, a MODU mooring can be frequently inspected during retrieval or deployment, but retrieving a FPS mooring for inspection can be very expensive.

API RP 2SK recognizes these differences and emphasizes that the FPS mooring should be more reliable and requires a demonstrated acceptable fatigue life. API RP 2SK requires that line dynamic calculations be carried out for a FPS mooring, in addition to quasi-static analyses. The latter usually suffices for a MODU mooring. API RP 2SK also recommends a more severe maximum design condition and more stringent criteria for FPS mooring in terms of anchor holding power, anchor proof test load, and allowances for corrosion and abrasion.

8.3 DESIGN CRITERIA

8.3.1 Environmental Criteria

Design criteria are closely related to the nature of the operation and the category to which the FPS belongs. Table 8.1 outlines environmental criteria to supplement requirements specified in API RP 2SK. The designer should note that local regulatory requirements may exceed those specified.

For a permanent operation with a mooring system that permits rapid disconnection of the production vessel from its mooring, the extreme environmental condition is the maximum environment in which the production vessel remains moored (with due consideration of disconnect operation requirements); however, the mooring alone (without the production vessel) should be able to withstand the maximum design environment specified for permanent moorings.

Table 8.1—Environmental Criteria

FPS Category	Extreme Environmental Condition
1. Field Development Systems	100-year return period, to be applied to both intact and damaged mooring.
2. Early, Pilot, or First-Stage Field Development Systems	Return period shall be 10 times the expected time on location, but not less than 5 or more than 50 years, to be applied to both intact and damaged mooring.
3. Drill Stem Test Systems and Extended Well or Reservoir Test Systems	
• Near Other Offshore Installation	10-Year return period storm, to be applied to both intact and damaged conditions.
• Away From Other Platforms	5-year return period storm, to be applied to intact mooring.
• Away From Other Platforms, Riser Disconnected and Unmanned	Less than 5-year return period to be justified by risk analysis

8.3.2 Environmental Design Cases

In addition to the maximum design condition, the user must define the station keeping performance requirements for the maximum threshold and normal conditions. The following types of environmental events need to be defined depending on meteorological and oceanographic (metocean) climate:

- Cyclonic storms (hurricanes and typhoons)
- Snowfalls and thunder storms
- Loop current and soliton
- Ice
- Earthquakes and tsunamis
- Joint frequency data of wave height, wave period and wind for fatigue assessment

It is important to note that the mooring system response could be sensitive to a number of environmental parameters, such as:

- Weather directional pattern
- Current profile
- Range of wave periods to be associated with the design wave heights
- Wind spectrum

The environmental conditions should include a wide range of wind, wave and current combinations with return periods of 100 years or less to ensure that the combinations producing maximum responses are identified.

8.3.3 Safety Factors

The safety factors proposed in API RP 2SK should be used as appropriate for the design case. The failure mode of the anchor system should be considered in the design. Refer to API RP 2SK for drag embedment anchors, API RP 2T for driven pile anchors, and the commentary of this document for suction pile anchors. For other anchor types, the safety factors should be chosen considering failure modes and prior industry experience.

8.4 ANALYSIS METHOD

The general methodology for the analysis and design of station-keeping systems is described in detail in API RP 2SK. The use of dynamic analysis is strongly emphasized. It is now well recognized that the percentage contribution from "line dynamics" increases with increasing water depth. Slow drift response is identified as a major contributor to the total offset and line tension. The resonant nature of the slow drift response requires particular attention to the slow-drift damping. As mentioned earlier, the technology in this area is still developing. The estimated damping should include viscous effects on the hull, wave drift damping, and the damping contributions from the mooring system and the risers. In carrying out the dynamic analysis, the designer is faced with the choice of a time-domain or frequency-domain analysis to account for the FPS system's non-linearities. Each analysis method has its advantages and disadvantages, and the designer should choose the analysis methodology most appropriate for his specific design case. The use of hydrodynamic model tests and wind tunnel tests is also recommended for final design verification.

8.5 INNOVATIVE DEEP WATER MOORING SYSTEMS

As exploration of oil and gas moves into deeper waters there is an ever-increasing demand for efficient mooring systems. The conventional catenary mooring system encounters several performance challenges in large water depths. These challenges are primarily related to payload limitations, mooring system efficiency, footprint constraints, installation logistics and equipment limitations.

Weight of the mooring system increases with water depth. This increased weight has to be supported by the floating system, and may have serious design implications for units, which are payload sensitive. The increasing vertical angle (steepness) of the mooring lines makes the mooring system relatively inefficient providing less horizontal restoring force for the same level of line tension. The footprint of the mooring system tends to occupy a large area on the seabed. In ultra deepwater the mooring and anchor footprint can be as large as several miles in diameter, posing problems for sub-sea system layout and anchor placement, since the anchors can extend into adjacent blocks in some cases. Finally, the increase in hardware sizes and the increase in water depth, puts a high demand on the installation vessels pushing them to their capacity limits. The deployment and proof-loading of the anchors in deep water imposes serious demand on the installation vessels.

The emerging solutions to meet these challenges can be classified into the following three categories:

- *Mooring configuration:* Taut mooring or semi-taut mooring for higher mooring efficiency and reduced footprint.
- *Anchoring systems:* Vertically loaded anchors able to withstand substantial uplift load. System types include both drag and suction embedded systems. Driven piles are also a potential solution for anchoring systems.
- *Mooring line material:* The use of lightweight synthetic mooring lines to reduce weight and yet provide sufficient compliance combined with steeper departure angles.

In general, the design of these mooring systems can be rationalized based on API RP 2SK coupled with specific performance requirements.

API RP 2SM provides a comprehensive guideline for design, analysis and testing of synthetic mooring lines.

Industry experience in the use of innovative deepwater mooring systems has still not attained sufficient maturity to provide design guidelines. Thus, it is emphasized that the reliability of these new concepts be carefully investigated in terms of component performance and dynamic response.

The current state of technology is further described in the station keeping commentary.

8.6 SPECIAL CONSIDERATIONS FOR MOORING DESIGN

8.6.1 Effects of Current

The methodology for computing current loads on a FPS is outlined in API RP 2T Section 6.3 (Current Forces). Additionally, consideration should be given to the effects of current on the mooring and riser system itself and/or on the performance of the thruster system, as outlined below. It should be recognized that the current has a direct influence on the static offset of the vessel, the wave mechanics, the mean and low-frequency excitation forces and the low-frequency damping, hence, on the total offset.

The technology in this area is still evolving. The pertinent issues involved include:

- Current loads on moorings and risers
- Current effects on thruster performance
- Effect of drag coefficient on FPS response

These are discussed in the Station keeping Commentary.

8.6.2 Mooring System Influence on Wave Frequency Response

The analysis of mooring systems has classically evolved under the assumption that wave frequency motions of the body are not influenced by the mooring system (except for tethered structures such as Tension Leg Platforms). This is a fairly valid assumption for the majority of FPS systems. For most of the catenary moored systems, the inertial and damping forces (for wave frequency motions) far exceed the mooring stiffness related restoring force of the system. Thus the system responds to wave frequency motions generally unaffected by the mooring system. Under these conditions the wave frequency motions of the free floating body can be used to define the top end motions of the mooring system.

The above scenario can be significantly altered with deepwater mooring systems, especially when the vessel is not massive or the mooring and riser system have substantial mass that can no longer be ignored in comparison to the vessel mass. In this case, the moorings can have significant influence on the vessel motions. This influence can be further accentuated by the presence of semi-taut or taut mooring systems.

Use of a fully coupled analysis should be considered for deepwater systems with large numbers of risers and moorings, taut moored systems, or whenever the mass of the risers and moorings can no longer be considered insignificant compared to the vessel mass. The fully coupled analysis should consider the entire system from the surface vessel to the seabed, and analyze the whole system together, as opposed to the traditional analysis of decoupled moorings and vessel. The intent of the above section is to focus attention to strive towards a fully coupled analysis, as far as practicable.

8.6.3 Impact of Riser

In mooring analysis for drilling operations, where the vessel is equipped with a single drilling riser, riser loads, stiffness, and damping are normally ignored. This may also be acceptable for shallow water production operations with small numbers of production risers; however, in deepwater operations with large numbers of production risers, the interaction between the vessel, mooring system and the production riser system becomes significant. For this case mooring system design should take into consideration the riser loads, stiffness, and damping.

8.6.4 Weathervaning Mooring System Considerations

Weathervaning mooring systems are a common choice for ship based floating production systems in moderate to harsh environments. The system allows the FPS to weathervane and align itself in the direction of minimum loading. Analysis of turret moored systems needs special attention to some unique issues.

First, the collinear environment (wind, wave and current all coming from the same direction) may not be the most critical design case. Thus a careful consideration of the environmental factors with possible directionality is required to capture the most critical design cases. A shift in the wave heading from head on to some oblique heading angle can significantly increase the design loads.

Secondly, the prediction of the mean heading of the vessel is of critical importance to the prediction of the maximum tension or offset. The traditional mooring analysis examines the floating structure dynamics about the mean offset position in its mean orientation. It is recommended that the user investigate the sensitivity of the floating structure dynamic responses to the predicted mean heading by undertaking parametric studies of the mean heading.

Finally, the accurate prediction of the yaw response in the dynamic simulation is critical in predicting the total system response. The prediction of yaw response for some analysis tools may not have received the same degree of benchmarking as the other degrees of freedom (e.g., pitch, surge, and sway response).

Turret moored vessels can fall into two groups: Freely weather vaning units and units with heading control. Units with heading control try to keep the bow into the waves in order to minimize the roll motion. An important aspect with these units is the need for redundancy in the thruster system. Another difference is that some units have a lock turret, which either have to be unlocked by active intervention or start rotating when a certain moment is obtained. These design assumptions are important to know, in order to decide how the mooring system is to be designed.

8.6.5 Special Design Considerations for Synthetic Mooring Systems

Synthetic mooring materials are usually deployed for taut or semi-taut mooring systems and pose additional design challenges. The increased elasticity of the synthetic moorings can potentially introduce new dynamic behavior not encountered in the traditional steel moorings (see API RP 2SM).

The dynamic tension contribution for conventional steel catenary moorings arises from the hydrodynamic loads on the mooring lines trying to "freeze" the catenary configuration against fairlead motion driven response. These hydrodynamic loads resisting the catenary configuration change may exceed the gravitational loads (which provide the catenary shape) by an order of magnitude. This "freezing effect" on the catenary configuration forces the mooring line to stretch elastically as they must comply with vessel motions. This change in response mode (from catenary to elastic elongation mode) results in amplified tension compared to the response of a static catenary calculation. This tension amplification of the wave frequency contribution can be as high as a factor of ten for deep water moorings.

For synthetic mooring systems, a new type of behavior can contribute significantly to the dynamic tension variation. An axial dynamic response of the mooring line itself can be introduced by the floater motions from wave frequency response. Also, the introduction of chain segments at the end of the synthetic ropes (provided for handling purposes) could potentially introduce some dynamics. Finally, any form of vortex induced vibration can also set up an axial dynamic response. The effects of the above could set up some resonant response, with potential for snap loads in the lines (see API RP 2SM).

8.6.6 Impact of Mooring System on Air Gap

The deck height of column stabilized units and spars are selected to provide adequate air gap under extreme storm conditions to prevent major wave impact loads on the structure. The analysis of the air gap needs to adequately account for the effects of mooring system loads in addition to the environmental loads on the FPS. The platform tilt angle and the platform set-down effects are more pronounced for small waterplane area units and deserve careful attention at the design stage.

8.6.7 Special Considerations For Spar System Response

The spar platforms will typically be restrained by spread-moored systems. The standard analysis procedures for spread mooring system design apply, with one exception as noted below. If the mooring system for the spar is taut or semi-taut, then it can significantly influence the heave natural period of the spar. For this case, the mooring restoring forces in the vertical direction could have significant contribution to the total heave restoring force, and the heave natural period.

8.6.8 Dynamic Positioning Systems

Guidance on dynamic positioning systems is given in API RP 2SK and IMO MSC Circular 645 (See Commentary).

9 Well and Production Fluid Control and Transport Systems

9.1 PURPOSE AND SCOPE

This section is intended to provide guidance for the planning, design and analysis, component selection and procurement, and operating of elements and subsystems involved in conveyance and control of well and production fluids in conjunction with the FPSs.

As shown in Figures 9.1a-i, a FPS may be used for production from subsea wells or surface wells. For surface (dry tree) wells, the wellheads and trees may be supported on the deck of a simple jacket structure, on dry land or a man-made island, on the FPS itself or on a dedicated buoyant structure, such as a self-standing buoyant riser. a FPS may be equipped for well drilling or workover operations and may be located above the wells for direct access through either subsea or surface wellheads.

In many cases, there is existing API RP documentation that covers elements and systems addressed in this section. To avoid duplication and conflict, the reader is directed to the appropriate RP for guidance. In particular, this section addresses elements of subsea production systems associated with floating production installations. The section does not intend to replace API RP 17A. The designer is directed to the comprehensive outline and contents of RP 17A, which is intended to cover all subsystems and components of subsea production systems associated with the fixed or floating platform installations; however, the designer is reminded that subsea production systems may vary extensively from the few simple cases depicted in the sketches provided in RP 17A, Section 1.

9.2 GENERAL

Systems for well and production fluids control and transport must safely convey fluids from the wells that are fixed in the ground to the production equipment on moving platform. These systems must, therefore, be carefully matched with the type of platform(s) selected for the FPS development scenario and the metocean conditions affecting the site.

Surface wellheads allow drilling and/or workover from the FPS and direct surface control of wellhead trees. These systems require integral design of the tieback riser system and the FPS due to interaction of loads and motions.

Subsea well production systems are generally considered independent from the floating production facilities covered in this RP; however, designers should be aware that the components and functions of the subsea production systems are strongly influenced by the water depth for each particular application. Success of a subsea production system design depends on reliable connections between the subsea components (wells) and the host platform supporting the controls and process facilities. Full integration of the total system design (reservoir through product delivery point) is an important design consideration.

9.3 PLANNING

Planning should include consideration of the number and distribution of well completions to determine efficient means for tying wells back to the production facility. Designers must consider relative motions between the FPS and the wells and/or trees. Planning should also include consideration of reservoir characteristics, drilling program, and well maintenance requirements. A means for limiting the amount and complexity of equipment on the seafloor (or below the sea surface) is recommended. Even with this guidance in mind, for many field developments there could be strong incentives to employ subsea completions.

Surface-completed subsea wells are tied back to the FPS by top-tensioned near-vertical risers. These risers typically have a dry tree at their top and no valves at the seabed other than the subsurface safety valve at the well.

The basic system for production tieback and control of individual subsea-completed wells is individual flowline connections with direct hydraulic control functions. Reservoirs requiring a large number of subsea wells may need subsea manifolding and multiplexed control systems. The efficiency and reliability of manifolded and multiplexed systems are improving, such that the designer can make a decision to commingle flows and combine functions with increasing confidence.

Commingling of flows increases the complexity and range of cases that should be considered in evaluating reservoir productivity and flowline hydraulic performance. Flowlines designed to minimize back pressure on the reservoir, during peak commingled maximum flow conditions, may experience undesirable hydraulic (and thermal) performance under minimum flow conditions.

Reservoir, produced fluids, and ambient conditions may require the system to embody special features (e.g., exotic metallurgy, artificial lift, chemical injection, pigging, etc.) to maintain safe, efficient production. These factors will tend to increase complexity and expense of the subsea systems, flowpaths, and the field operating procedures. Certain combinations of production conditions may require frequent well and well system intervention operations that may render some subsea development approaches unattractive.

Flow characteristics throughout the flowpath can be affected by adopting different pressure management approaches. Pressure control by conventional choking or by High Integrity Pipeline Protection Systems (HIPPS) affects flowpath rating and sizing as well as reservoir performance. HIPPS is becoming an acceptable practice to limit design pressures in the flowlines, risers, and other flowpath components. Planning for use of these systems may reduce pressure ratings to realize system savings.

The planning phase of engineering for floating production facilities with producing well systems should strive to ensure that critical equipment and potential sources of pollution are effectively protected against maritime and offshore production hazards. Field facilities installation and operating procedures should provide for the safety of personnel. Testing of all critical subsystems and components should be planned to ensure that engineering design and fabrication accomplishes the objectives for safe, non-polluting field development.

9.4 WELL COMPLETION PROCEDURES AND SUBSYSTEMS

9.4.1 Well Control

Well control is a key aspect of system design, installation, and operational safety. Whether located at the subsea or the surface, for production or injection, wells provide pathways that can conduct high formation pressures and fluids to the surface. Uncontrolled release of these pressures and fluids may result in injury to personnel and damage to equipment or the environment. Accordingly, engineers and operators involved with well control have developed rigorous standards for equipment and procedures utilizing decades of experience and research. Much of this knowledge is reflected in API guidance documents, but the topic is being more fully explored in a continuously growing body of technical papers. The API documents noted in this section provide reference to a core of drilling and completion technology publications. Special well control practices for the exploitation of energy reserves in the marine environment have evolved in the last three decades as exploration moved beyond depths where conventional land practices are applicable. Well control is important at all times, but at certain times during drilling, completion, and workover, special attention to well control systems, and preparations is required. This section notes elements of a FPS that are involved in well control for drilling, completion, and production operations.

9.4.2 Drilling

In a number of the FPS scenarios, development drilling is not performed from the main production platform. The decision on whether or not to include drilling facilities on a specific FPS platform depends on:

- Need for drilling after production start-up
- Cost and utility of permanent drilling facilities
- Relative merit of vertical versus deviated wells

9.4.3 Drilling Risers

For deeper water installations, drilling is often done from a mobile drilling unit. In such situations, the drilling is usually conducted through a marine drilling riser. The marine drilling riser is a specialized system that consists of a number of pipes (a main pipe with various auxiliary lines attached), connecting facilities, and various functions at the surface with well control equipment at the seabed. The main pipe is assembled from an appropriate number of standard length segments (called joints, usually 50 to 75 feet long). These are connected in a manner that ensures fluid path continuity and structural integrity under the demands of operating service. The drilling riser serves to convey the drill string and drilling components into the hole, and to support the column of drilling fluids that circulates through the well. The circulating fluids contain formation pressures, remove drill cuttings, and may even provide power to the drill bit. Auxiliary pipes (such as choke, kill, and hydraulic control lines) are attached outside the main pipe by brackets. Additional appurtenances (such as buoyancy elements or fairings) may be attached to the main riser pipe joints in special operating circumstances.

API RP 16Q provides extensive guidance in the system definition and design of marine risers as used by mobile drilling rigs. The assessment of suitability of a mobile drilling rig and riser system for use as part of a FPS field development scenario should consider any special requirements for interfacing with the selected production equipment. Any potential interaction with existing equipment or with operations of a producing FPS (such as, mooring system interference between anchor lines and pipelines) should also be considered.

If the drilling is to be conducted from the FPS itself, the FPS may use either the marine drilling riser system described above, or alternatively, the FPS may tieback one or more casing strings to the surface and use surface well control equipment. Whichever design is used, a designer should consider that drilling or well completion activities may be in progress simultaneously with production operations. There may be situations where it is appropriate to shut in (and even remove) risers from the neighboring wells. For example, drilling riser design and operation should consider the influence and interference with adjacent risers. Adjacent production or export risers may have very different configurations and dynamic response characteristics than typical marine drilling risers. In such cases, refer to API RP 17D or API RP 2RD for Design of Risers for Floating Production Systems and Tension-Leg Platforms.

9.4.4 Workover and Limited-Duty Drilling Risers

Instead of being equipped for full drilling activities, a FPS may be equipped with less extensive facilities for direct well intervention and maintenance, including some limited drilling (e.g., side-track drilling) or completion work. In such cases, the riser in use may be considerably smaller and lighter than a conventional marine riser. The design should refer to API RP 17G for appropriate guidance.

9.4.5 Blowout Preventers

Well control practice requires the use of a blowout preventer (BOP) system to ensure that formation pressures exerted on and through the well bore do not cause uncontrolled release of well fluids when the normal drilling fluid hydraulic head is disrupted. The BOP system is comprised of a number of mechanical closing devices that are stacked vertically to provide redundant barriers to confine the formation pressures. The devices of the BOP stack are arranged to facilitate means for sealing on or cutting through the drill string, sealing above the wellhead, and controlled circulation of fluids into and out of the wellbore.

This BOP stack may be located at the surface or subsea, depending on the type of well being drilled or completed (and on the type of drilling system employed). A subsea BOP is generally more complicated, requiring extensive automation, and the ability to operate against hydrostatic pressures. It is run to and attached to the subsea wellhead by the marine drilling riser, or by a special completion/workover riser. It is connected to the riser by means of a Lower Marine Riser Package which provides a means for accommodating riser inclinations and allows emergency disconnection.

9.4.6 Well Completion (Wellheads and Trees)

Surface and subsea wellheads perform the same general functions. A wellhead supports and seals casing strings, as well as supporting the blow-out preventer (BOP) stack during drilling or completion, and the tree after completion. The functions of subsea and surface wellheads and trees are similar, but the designs are very different because subsea completions require that casing landing, sealing, and completion operations be performed remotely from the surface. Appropriate safeguards must be in place to ensure the proper placement of all these elements. The primary concern is the prevention of leaks that could result in the release of hydrocarbons.

The mechanical configuration of the well completion provides the key to efficient reservoir depletion and performance monitoring downhole. Well completion design must take into consideration the fluid characteristics and the well, field, and area conditions.

9.5 FLOWPATH SYSTEMS

There is a wide variety of equipment and components that may be employed in facilitating the transport of fluids throughout a FPS. Any or all of the many possible features may be necessary depending on the functional requirements of the system; however, beyond the basic conduits (e.g., tubulars) forming the core of the flowpath systems, any additions will tend to increase complexity and add costs. The following subsections discuss some of the design considerations for key equipment and components that may be employed in assembling the flowpath systems for a FPS.

9.5.1 Subsystem/Component Descriptions

9.5.1a Pipelines and End Connections. General system descriptions and guidance for pipelines in FPS scenarios is given in API RP 17A. FPSs for shallow water may have pipelines extending from surface wells and/or manifolds on shore (e.g., near shore pads), or small jacket structures. In the first case, pipelines must be designed for a shore approach. In the latter case, the flowpath will include risers (and downcomers) from the jacket deck to the subsea flowline.

Depending on distances, fluid characteristics, and seabed conditions, the user may need to evaluate the merits of flexible pipe solutions against conventional steel welded pipe. Refer to API RP 1111 for guidance in the design, construction, operation and maintenance of conventional offshore hydrocarbon pipelines and API RP 17B for flexible pipelines. Pipelines used for transport of injection fluids (gas or water) should follow these recommendations as well.

9.5.1b Risers.

General Functions: The function of a production riser is to provide conduit(s) for conveying hydrocarbons or injection fluids between the sea floor equipment and the FPS. The function of an export riser is to provide conduit(s) for the hydrocarbons between the FPS-mounted processing plant and the pipeline, tanker or other transport systems (see Section 11 for guidance). The risers and support structures may also provide support for auxiliary lines and control umbilicals. A complex, multi-path riser system may provide conduits for production to and export from the FPS (see Figure 9.l.b). For additional guidance on riser systems, refer to Section 11 (Riser Systems) of API RP 2T, Section 7 (Production Risers) of API RP 17A, and API RP 17B. For specific design guidance on risers for FPSs, refer to API RP 2RD.

Weathervaning and Disconnect/Reconnect Functions: To make the flowpath connection between risers and facilities on the FPS, a variety of links may be used depending on the types of riser and FPS. Typically, unless the riser itself is highly compliant, flexible jumper hoses are used to accommodate relative motions between the FPS and the top of the riser. Generally, the weathervaning rotation of turret-moored vessels is accommodated by a mechanical system. As an alternative, flexible pipe may be considered for accommodating weathervaning relative motion by employing a drag chain arrangement on the deck of the turret to allow specific ranges of rotation (Figure 9.2).

Turret connections (whether using swivels or flexible pipes to accommodate weathervaning) may be provided with a means to disconnect the FPS from the risers to allow it to move off site. This capability may be used to avoid extreme loads in the mooring and piping or swivel connections when infrequent extreme storm events (such as icebergs) can be expected.

If a flowline end connection is integral to a turret mooring design that embodies a disconnect feature intended to avoid extreme event mooring loads, then engineering calculations should demonstrate acceptable stress levels up to the conditions where disconnect and reconnect functions are intended. The flowline system should incorporate valves that prevent the outflow of produced fluids when disconnection is required.

If disconnection is required for the system to reconfigure to survive extreme storm events, then redundant independent means for providing power to the disconnect/reconnect function should be provided. Model testing is recommended to confirm functionality at the intended limits. Factory and field testing is recommended to demonstrate full-scale service functionality. After reconnection, the swivel system should be given full hydrostatic testing prior to restart of production through the swivel. Manual back-up disconnect/reconnect mechanisms should be designed to avoid exposure of operating personnel to unacceptable levels of risk.

9.5.1c Product Swivels

Description of Service: A product swivel assembly permits fluid transfer across the interface between the non-rotating portion of the riser or riser system and the rotating moored vessel supporting it. The moored vessel, whether a permanently or temporarily moored tanker or barge, is then allowed to weathervane (>360 degrees) around the centerline of the swivel, positioning itself in the direction of least resistance to the environmental forces.

Swivel Types:

a. *Axial:* The axial swivel provides a rotating connection between two parts of pipe. The swivel consists of a top and bottom ring, a bearing, and sets of internal and external seals. This type of swivel is usually limited to one flow path but is useful for large diameter pipe with high pressure, and/or piggable fluid transfer. Refer to Figure 9.3 for an illustration of a typical single product axial swivel. In most cases, axial swivels are used for a single product, however, multiple annular passages may be configured to pass multiple products through an axial swivel.

b. *Toroidal:* Depending on the method of mounting, the toroidal swivel usually consists of an inner non-rotating ring (stator) and outer rotating ring (rotor) which encloses a toroidal shaped chamber. A bearing provides the mechanical connection between the fixed and rotating parts. Seals around the periphery of the toroidal chamber prevent leakage of the fluid product at the interfaces where the inner and outer rings are held in registry by the bearing. Refer to Figure 9.4 for a cutaway view of a typical toroidal swivel.

Depending on the method of mounting, a multi-level swivel consists of a stationary inner core, a product chamber, and a rotating outer shell. Multiplicity is achieved by stacking multiple toroidal swivels. Multi-level swivels are frequently arranged to include well fluids, well treatment fluids, hydraulic power, fire-fighting water, utilities, electro/hydraulic control lines, electrical power and fiber optic instrumentation lines. Refer to Figure 9.5 for an illustration of a typical multi-level swivel.

c. *Full Service Production Swivel:* A full service swivel stack can be used to accommodate multiple external service requirements for a field development scheme. Such a swivel design would generally have a vertical stack configuration in which basic components of each individual service are combined. In general, these swivels are custom-designed to meet the specific development needs. Typical functions which may be included in this swivel include:

- Crude oil import/export
- Gas export
- Three phase production fluid transfer
- Water injection
- Gas injection/lift
- Hydraulic power and control circuits
- Electrical power and controls
- Electrical bonding
- Optical signals

Figure 9.6 shows a typical full service production swivel stack.

9.5.1d Lifting and Pumping Systems In cases where reservoir pressure-driven fluids must flow against significant head losses due to either hydrostatic back-pressure or losses in long, complicated flowpaths, pumping systems may be incorporated in the production system. Such equipment is intended to aid reservoir productivity by reducing the back-pressure at the reservoir. Pumping systems may also be used to ensure that desired fluid flow regimes exist in pipelines and risers. It may be advantageous or necessary to incorporate pumping facilities when producing from either subsea or surface wells.

For surface well developments, it is likely that gas-lifting facilities or electric submersible pumps may be included. In the case of gas lift, produced gas (or an inert gas) can be compressed and conveyed to an appropriate injection point and introduced into the flowstream reducing the density of the produced fluid. In deep water, the base of the riser section of the flowpath may be considered a convenient injection point. Subsea multiphase pumps may also be used to provide energy to the produced fluid stream.

9.5.2 Design Characteristics

9.5.2a Riser Design. Riser design is a complex undertaking in which the designer/analyst must be aware of the influence of a large number of parameters and conditions. The riser system of a FPS will change with time and production needs. The array of risers is likely to be such that interference between adjacent risers or risers and the mooring system will be a critical issue. Therefore, the designer must assess the integrity of individual risers and the influence/interference of other risers. It is recommended that the designer/analyst refer to API RP 2RD.

Riser system design for FPS service should be performed on a fully integrated basis to include both anchor legs and risers acting in combination when determining system loads and interference.

9.5.2b Swivel Design

1. Pressure/Temperature Rating: The fluid swivel should be designed to withstand the specified pressures and temperatures (while rotating) for the following cases:
   - Range of operating conditions.
   - Static shut-in pressure.
   - Pressure surge conditions.

Design standards are usually based on ASME Pressure Vessel Codes. (See reference list in the Commentary.)

2. Seals
   a. *Seal Design*: When designing the seals, the following should be considered:
      - All seals should be of one-piece (continuous), molded construction where possible. If welded seals are required, a qualified procedure should be developed for welding and testing the welded seal and material.
      - The swivel design should strive to prevent leakage. The swivel design should incorporate internal redundant seal sets. Leak detection and recuperation ports should be provided to collect leaking fluid and allow identification of the leak path.
      - External seal sets should also be provided to prevent the ingress of seawater into the swivel and bearing
      - The seal should be designed to seal over the full range of fluid compositions, operating pressures, temperatures, and load-induced swivel deformations.
      - Back-up anti-extrusion rings or equivalent should be considered for high pressure or temperature systems
      - Seal energizers should be considered where appropriate
      - For abrasive fluids, wiper seals or isolation systems should be considered to keep the abrasive material out of contact with the swivel seals.

   b. *Seal Material:* The seal material should be compatible with the working fluid. Common seal materials for hydrocarbon production include polymeric compounds, and synthetic rubber compounds. The seal material should be capable of withstanding the swivel's operational temperatures and pressures. The seal seats and traveling surfaces should be corrosion-resistant and of sufficient hardness to prevent excessive abrasion and wear. High grade alloys or stainless steels are commonly used in current designs.

3. Bearing System: The bearing should be designed to withstand maximum load conditions imparted on the swivel. The mooring system is normally designed to isolate the product swivel from the mooring loads. The bearing is subjected to loads resulting from the following

- Self-weight.
- Accelerations of the swivel assembly and attached piping or equipment.
- Unbalanced hydrostatic and thermal loads.
- Forces due to pressure effects and expansion in the pipes.
- High fluid velocities.
- Drive mechanism for rotation.

For multiple bearing systems, the loading effects between the bearings must be considered and should accommodate predicted deflections due to the complete range of loading conditions.

4. Dimensional Tolerances: The range of gaps between the inner and outer rings should not exceed a prescribed maximum to prevent seal extrusion (when subjected to high pressures and temperatures). Measured initial gaps are subject to change during internal pressure and temperature variations. The prescribed gap should provide for tolerances in machining, differential thermal growth, eccentricities, bearing clearances, register clearances, and deflections.

5. Piping: The design codes to be used for the swivel piping should be specified in accordance with API RP 14E. Pipe thermal expansion, pressure effects, eccentricities, and fatigue loading should be taken into consideration where appropriate.

6. Maintenance: The swivel configuration should be designed to facilitate lubrication, maintenance, and repair. The designer may consider spare paths, and means to remove individual seals or swivels, without disturbing other flow paths. A comprehensive maintenance program should be specified, which accounts for predicted durability and service loads of the unit. Maintenance programs should be evaluated after adequate in-service experience to judge differences, if any, between predicted and in-service degradation of the unit.

7. Pigging: In general, only the center path of the swivel is piggable with a full range of pigs. Other paths (toroidal) allow the passage of soft pigs only. Location of pig receiver, and choice of services for central flow path, may be affected by pigging requirements.

9.5.2c Jumper Flowlines: Jumper flowlines accommodate relative dynamic motions between the FPS and the top of the riser. If the top of the riser is supported remotely from the FPS (e.g., in a buoyant self-standing configuration), then the jumper flowlines may themselves be exposed to environmental loads, as well as loads due to vessel motions and service. If the jumper flowlines are protected within the confines of the vessel or turret then relative motion and well stream service loads will dominate design considerations. Drag chain systems should be designed to account for possible abrasion due to contact with the supporting structures (e.g., racks or decks). Jumper flowlines located in hazardous areas of the FPS may also be subject to explosion and fire, requiring appropriate protection and ESD isolation.

9.5.2d Exposed Fixed Flowline Piping: Dynamic riser jumper flowlines connecting to column stabilized FPSs will often be terminated at connections located below the water surface. A likely configuration would have a riser connection porch mounted at the pontoon deck level. Fixed, rigid piping is then used to complete flowpaths to/from the production facilities. If this rigid piping is run external to the hull and exposed through the water surface, it will be subject to wave loading and possible impacts from other vessels, as well as internal service-related loads. In such cases, the pipe bodies, end connections, and support fixtures should be designed to meet proper safety and serviceability requirements.

Such rigid piping may be attached to the platform hull structure by properly spaced supporting fixtures or may be supported vertically in tension between the pontoon and deck structures. This piping may be designed in the manner prescribed for rigid pipeline risers on fixed structures (see API RP 1111) with suitable measures to prevent or limit the consequences of boat impact.

9.6 CONTROL SYSTEMS, LINES AND FLUIDS

Refer to API RP 17A for guidance in applications for subsea production systems. For production from surface well systems, the operator has the option of using direct manual operating systems and controls, or of limiting manual intervention requirements by employing automated remote control. In situations where remote control is preferred, refer to API Specification 17E and API RP 17I for guidance.

9.7 TEMPLATE AND MANIFOLD SYSTEMS

Refer to API RP 17A for guidance in applications for subsea production systems. Simple spacing templates may be used for support and layout of pre-drilled, mudline suspended wells on shallow water jackets. These may be designed according to guidance in API RP 17A for the simplest class of templates. Guidance for manifold systems for surface wells can be found in API RP 14E.

Spacing between wells, risers, and wellhead equipment is an important issue for the design of templates for subsea wells or wells tied back by risers for surface completion. A designer should consider access requirements for maintenance, and possible riser interference concerns, when configuring layout and dimensions of the template.

9.8 OPERATION, INSPECTION AND MAINTENANCE

9.8.1 General

The user should ensure that the design of the subsea and fluids conveyance system accommodates all necessary field operating procedures. Refer to API RP 17A and API RP 2RD for discussions on appropriate measures and project activities related to establishing and maintaining safe, functional field facilities.

9.8.2 Disconnections

A key feature of some FPSs is the capability of the system to reconfigure for survival by disconnection. The disconnection allows the platform to be separated from subsea and mooring systems so that the separated systems will survive (endure or avoid) the event in a manner which matches their design capabilities. Key design aspects of this operational feature are discussed in preceding sections. Inspections confirming the integrity of the temporarily abandoned subsea equipment, riser, riser interface, and mooring systems should be undertaken prior to restarting production following a disconnection.

9.9 QUALITY ASSURANCE, MATERIALS AND CORROSION

9.9.1 General

Reference should be made to API RPs 17A, 17B, and 2RD for guidance on issues relating to procurement of equipment for subsea equipment, flowline, and riser systems. The following discussions are added to cover swivels, which are associated with floating production systems allowing the FPS to weathervane. Additional guidance may be found in API RP 14E.

9.9.2 Testing Requirements for Swivels

Testing procedures should be specified (and agreed with the owner/operator) to assure that castings, forgings, or other items used in the fabrication of the fluid swivel system housings are to sufficient quality standards fulfilling all functional and design code safety requirements. Special care should be given to all bearings and seal faces.

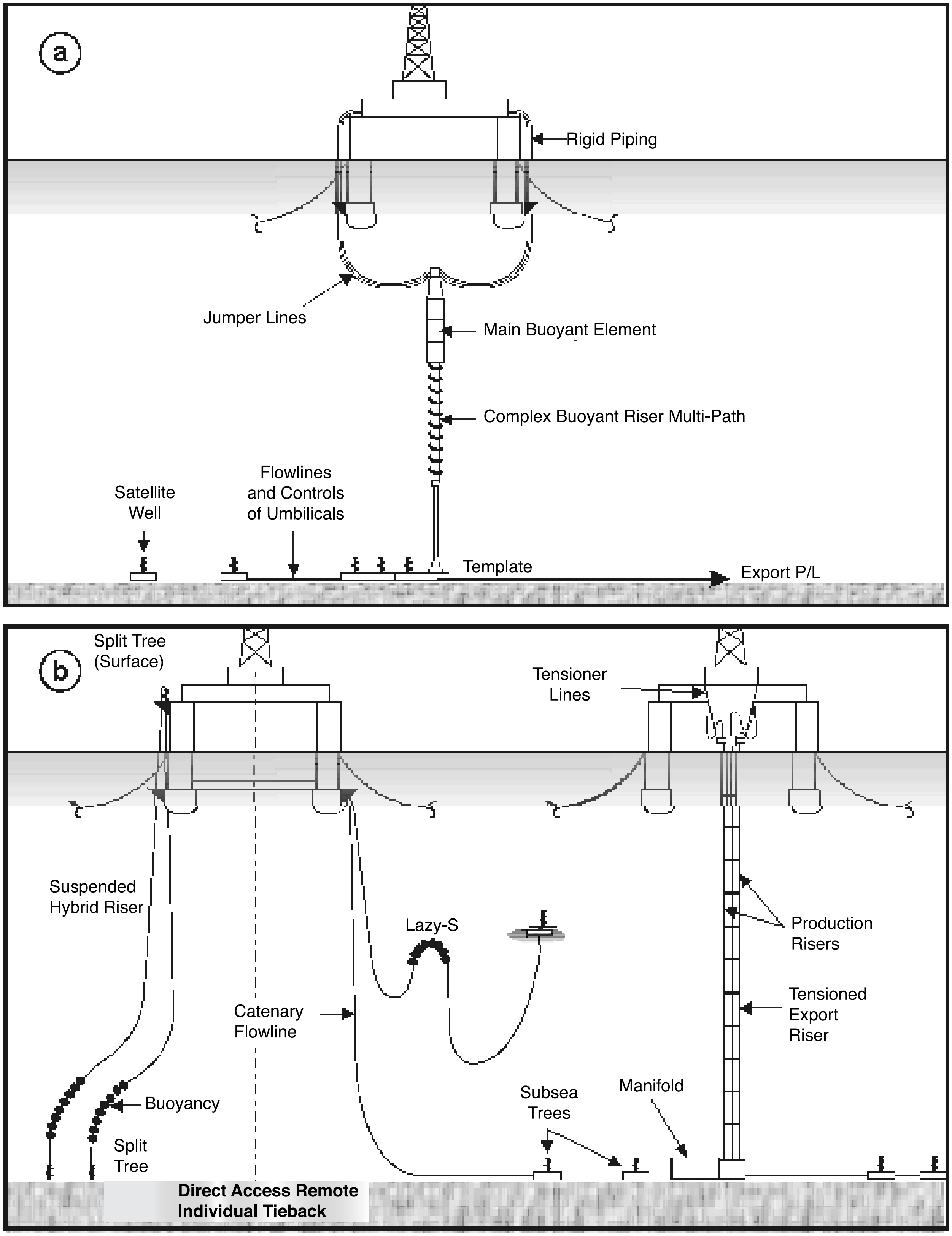
Seal designs and materials should be proven by dynamic tests which simulate a number of years of service under the conditions and with exposure to fluids representative of the design conditions and depressurization. The minimum number of years of successful service to be proven by testing should be agreed with the owner/operators.

The following swivel unit shop tests should be performed:

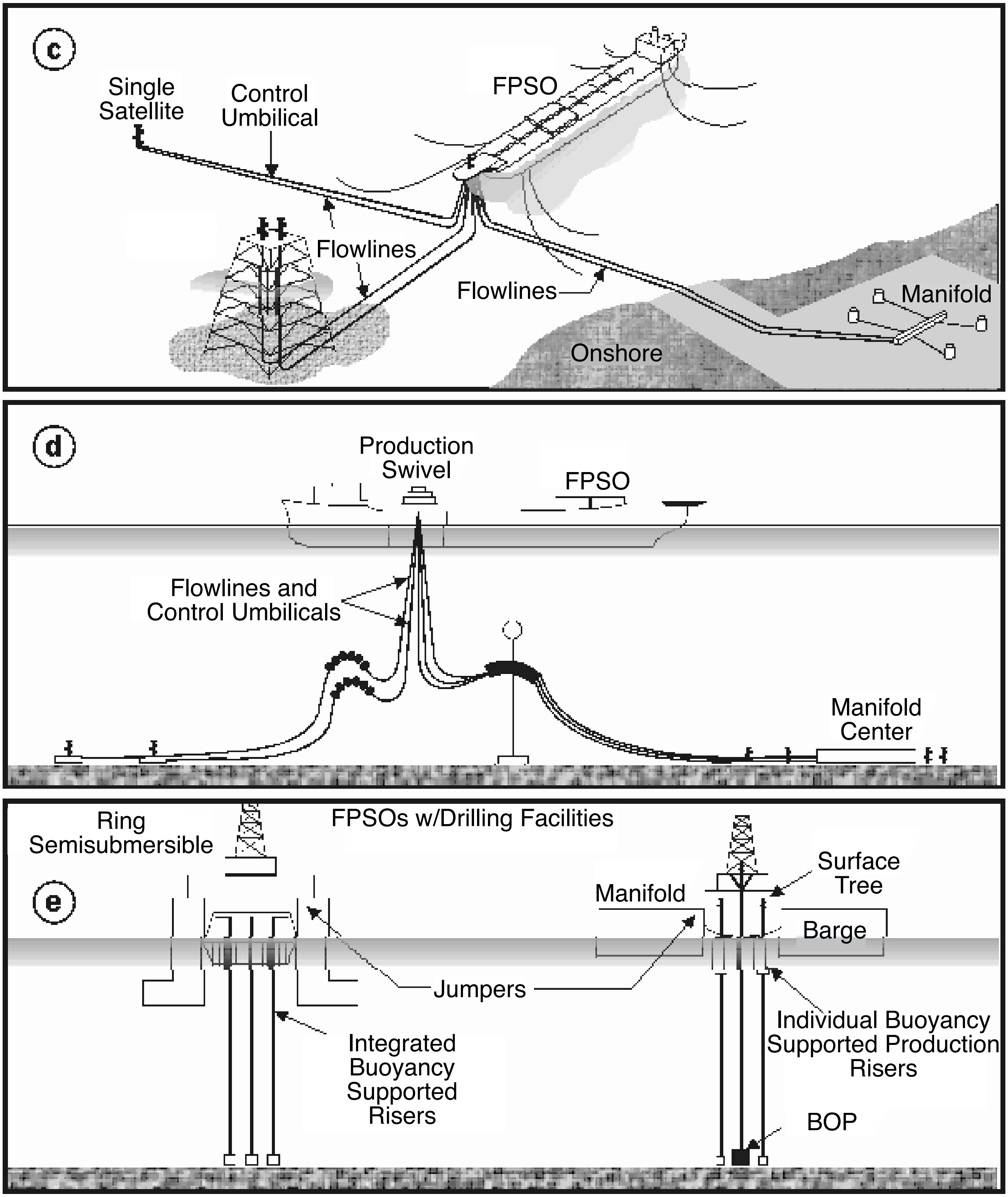
- Hydrostatic proof test of the body.
- Pressure fluctuation test.
- Rapid decompression tests (gas swivels only).
- Cyclical loading test.
- Test requirements should be according to manufacturer's recommendation and approved by owner/operator.

Full rotation tests in each direction and cyclic partial rotation tests should be performed at three (3) operating pressures. Rotation speeds should model real-time conditions to accurately represent the intended application and also to prevent damage to the seals.

Shipyard acceptance rotation testing should be performed at a range of operating pressures after mounting on the turret with all connections made .



Figures 9.1a and 9.1b—Components for Well and Flowpath System Configurations



Figures 9.1.c, 9.1.d and 9.1.e—Concepts for Well and Flowpath System Configuration

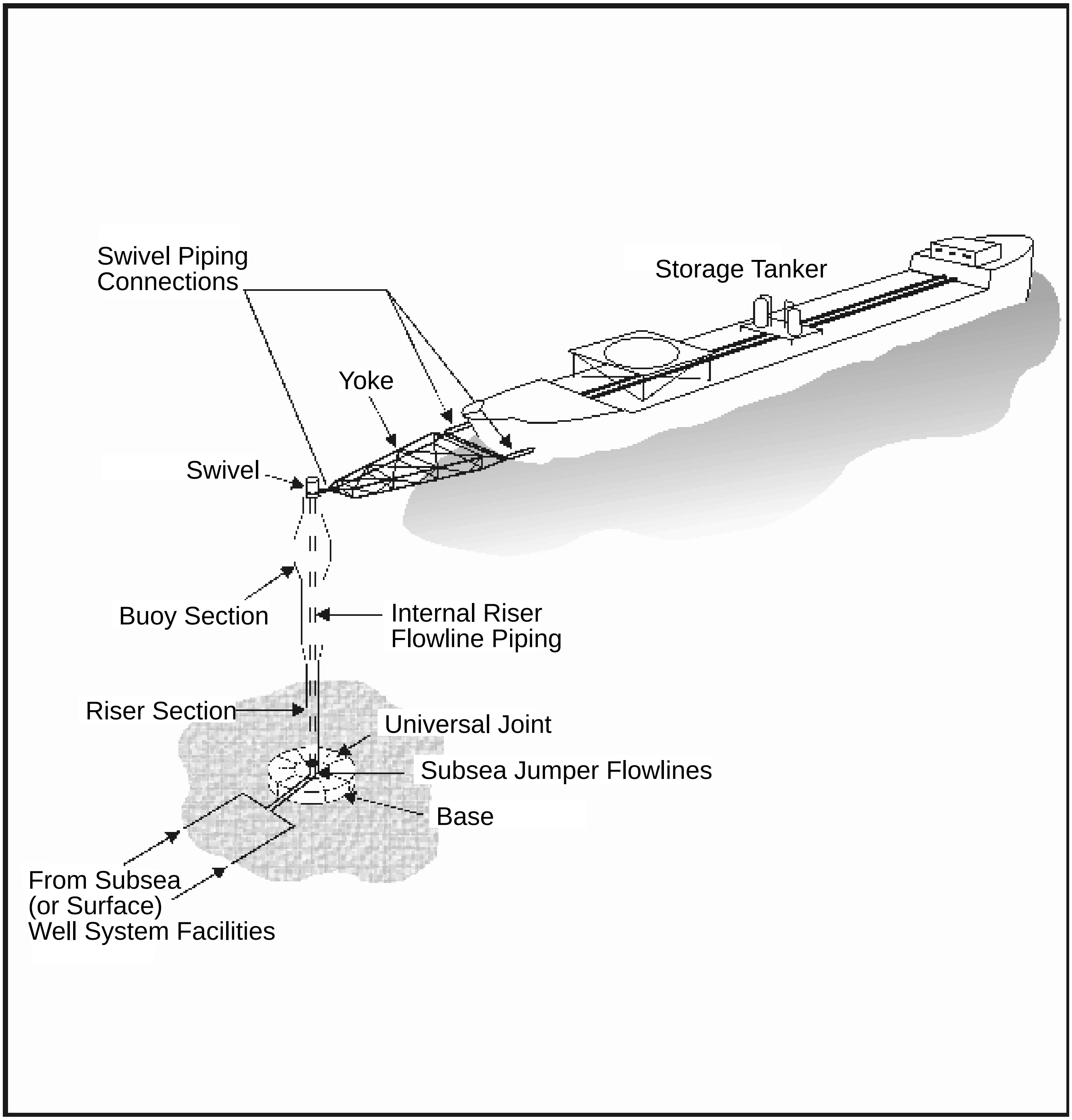
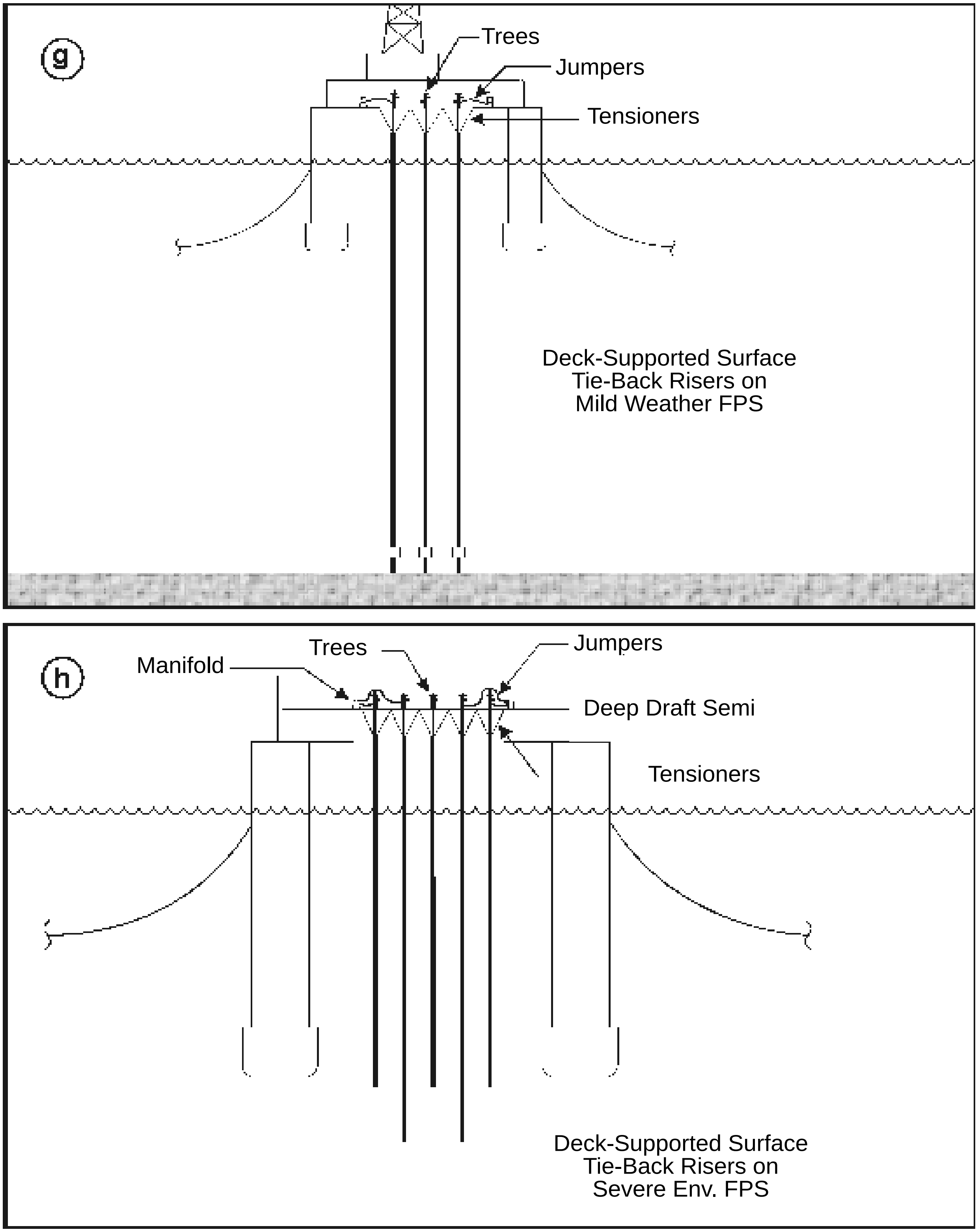


Figure 9.1.f—Single Anchor Leg Mooring (SALM) with Tubular Riser and Yoke



Figures 9.1.g and 9.1.h—Concept for FPS Well and Flowpath Systems Configuration

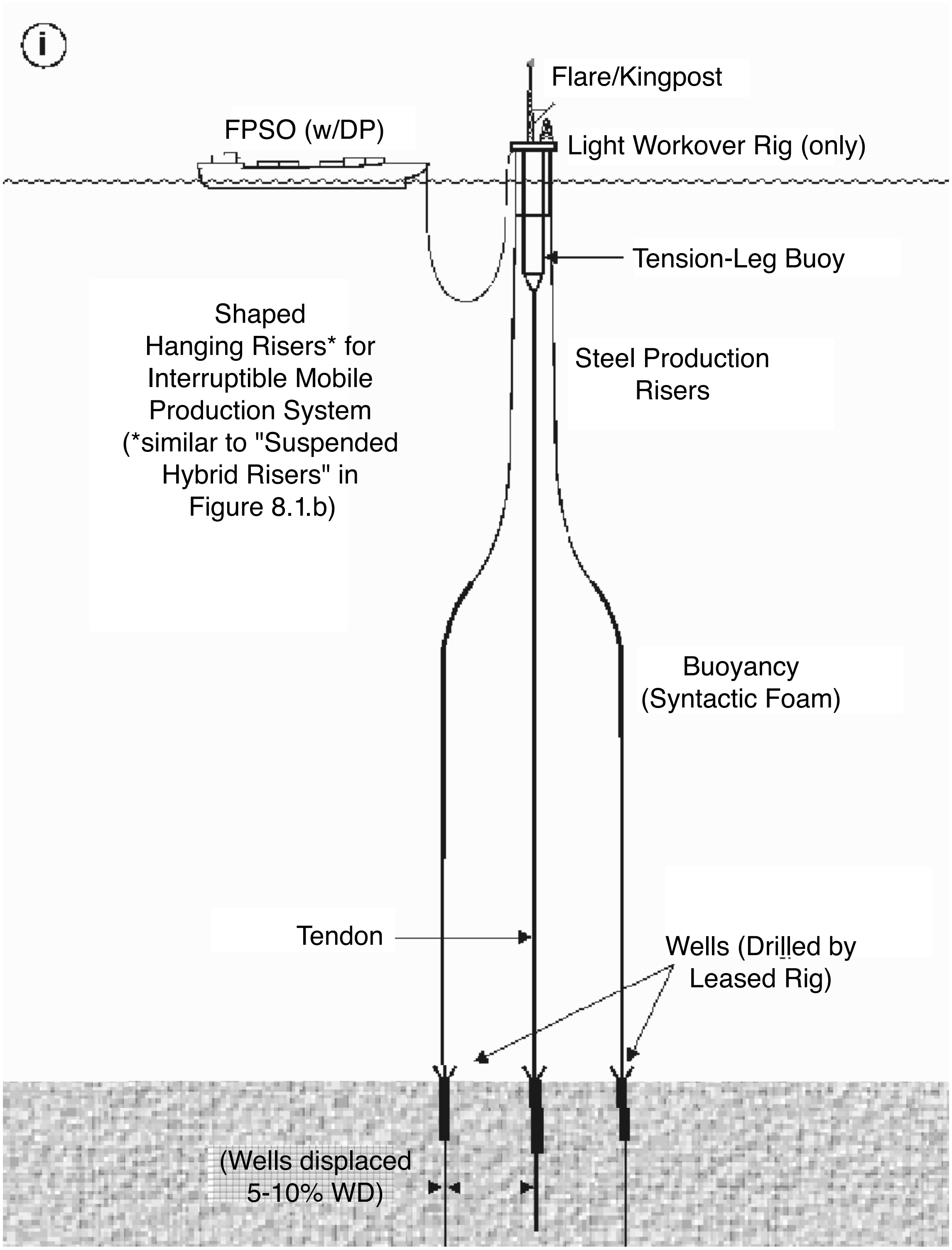


Figure 9.1.i—Concepts for Well and Flowpath System Configurations

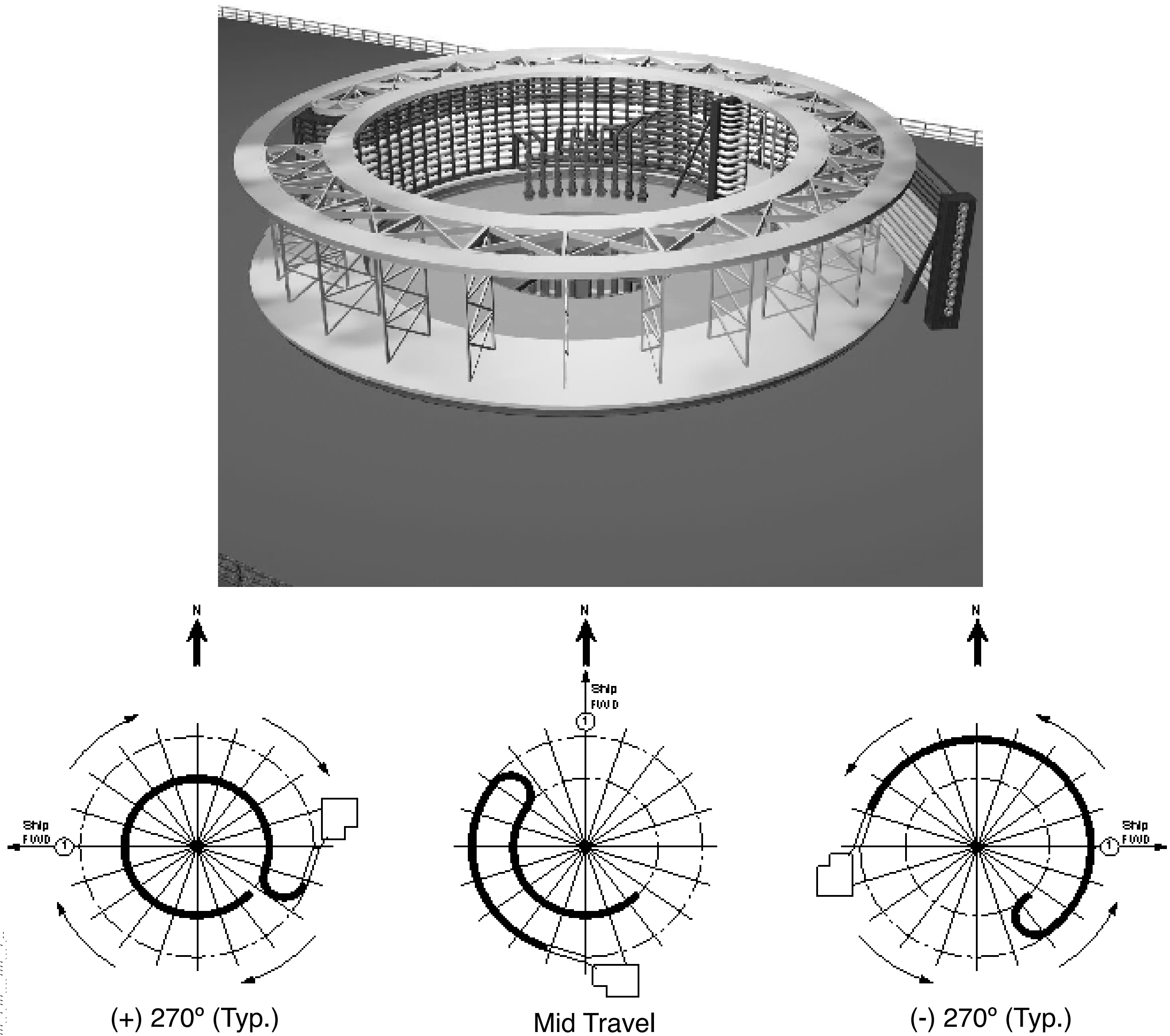


Figure 9.2—"Drag Chain" Concept

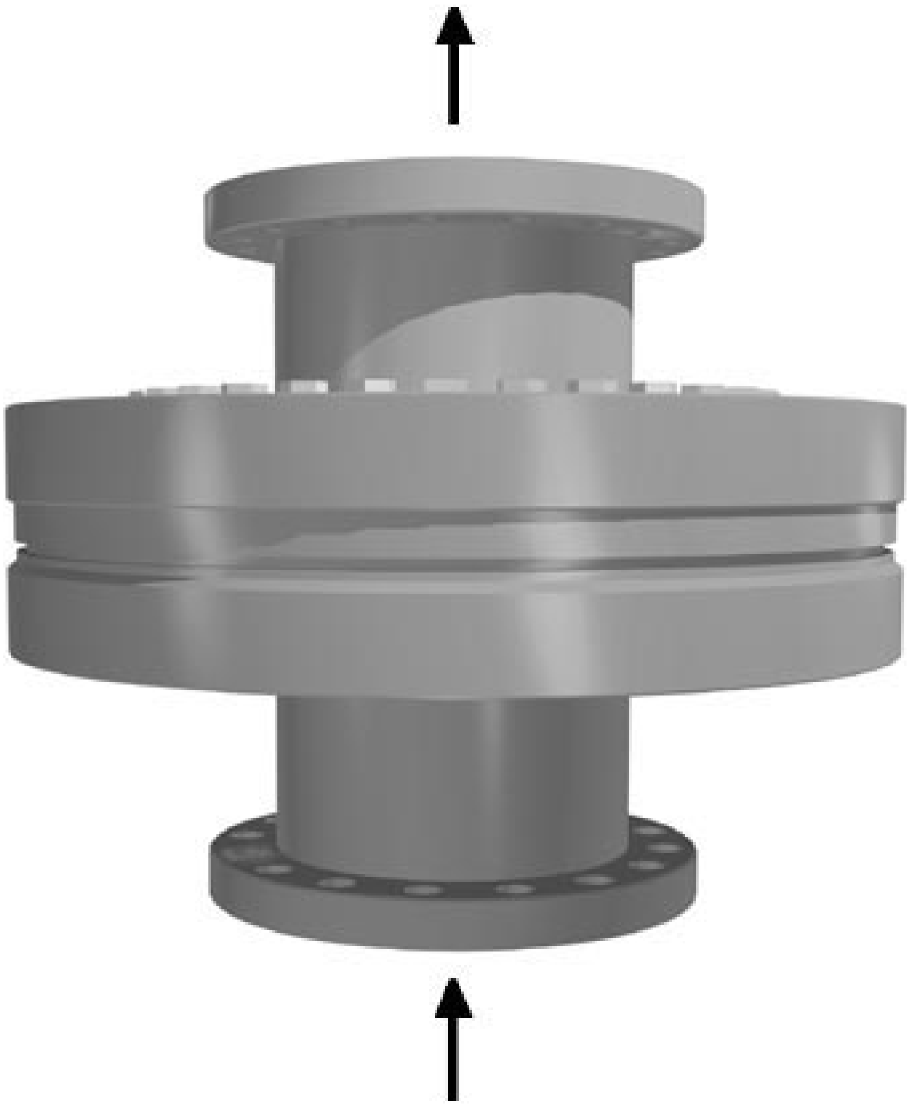
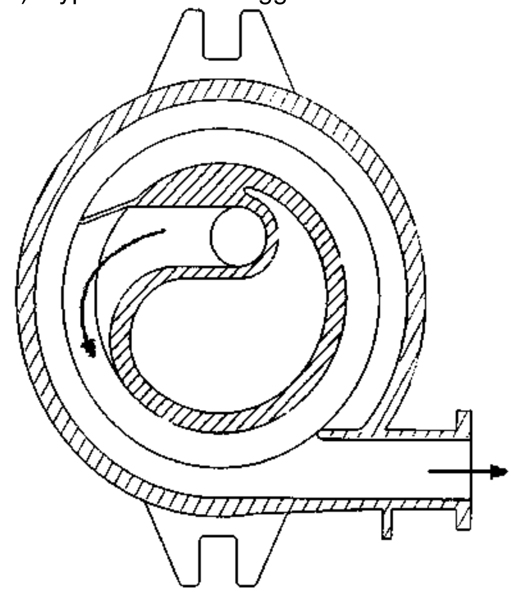


Figure 9.3—Typical Single Product Axial Swivel

a) Typical Torodial Piggable Swivel



b) Typical Torodial Non-piggable Swivel

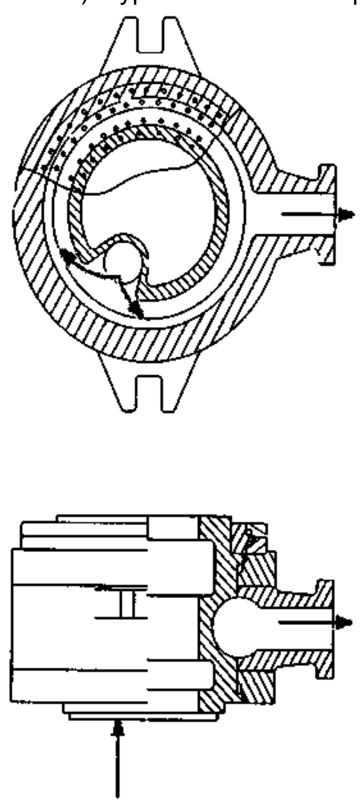


Figure 9.4—Typical Torodial Swivel Assemblies

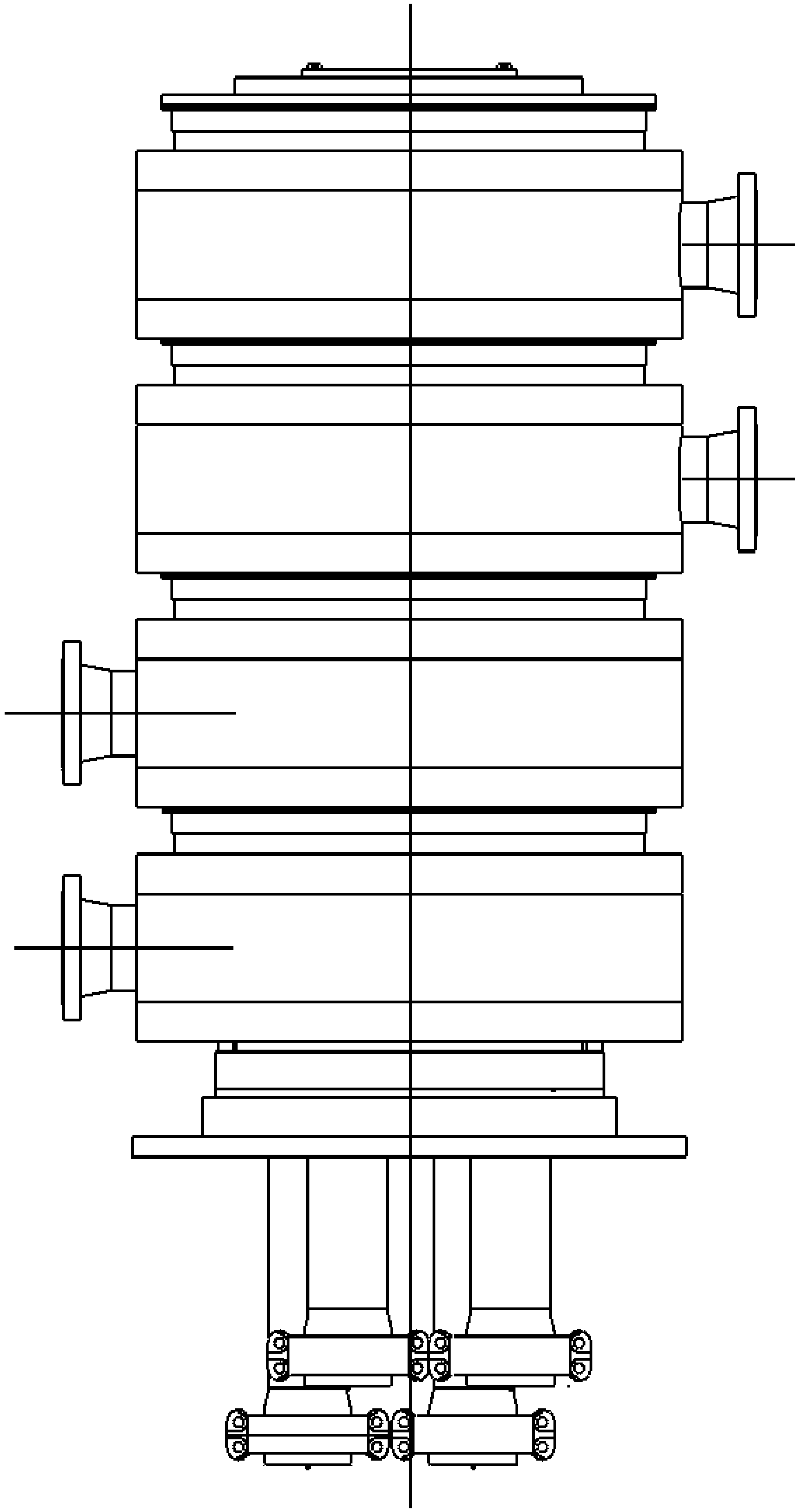


Figure 9.5—Typical Multi-Leve; Swivel

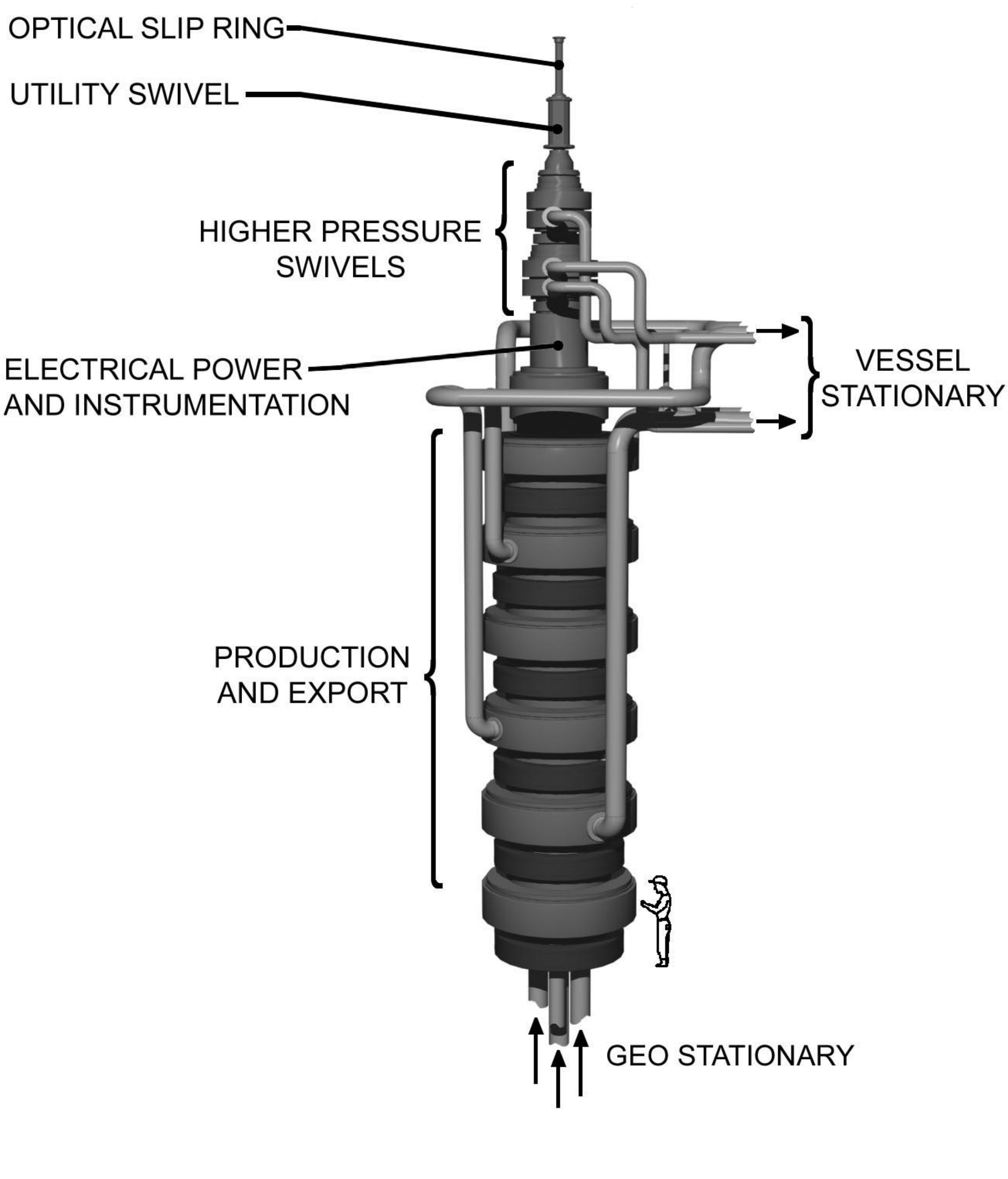


Figure 9.6—Typical Full Service Production Swivel Stack

10 Facilities

10.1 PROCESS FACILITIES

10.1.1 General Considerations

This RP focuses on unique capabilities that should be considered for production facilities and utility systems that are part of floating production systems. Other appropriate industry standards, such as API RP 14C, 14E, 14F, 14J, 75, 500, 505, etc. will apply regardless of the host and should be considered complementary.

Design and construction of FPSs process facilities must meet the requirements of all applicable regulatory authorities. The Owner is responsible for identifying all applicable requirements and regulations and to resolve conflicts between regulations. Notwithstanding applicable regulations, codes, standards, and RPs that may be required, additional consideration should be given to the following when designing floating systems:

1. Selection of design working pressure for surface equipment to meet the following objectives:
   - Satisfy necessary drive pressure in product transport lines (deferring pumps and compressors).
   - Achieve necessary gas lift operating pressures.
   - Provide appropriate safety protection in the event of hydrate formation and/or deposits (wax and/or solids) in certain piping segments.
2. A FPS's sensitivity to changes in weight and center of gravity.
3. Provisions for the application of heat to the process systems to treat the colder production streams. Where possible, waste heat transfer should be considered as a fuel conservation measure.
4. Valves to provide for proper and safe purging of piping systems and mechanical pigging.
5. Packaging of various components.
6. Gravity drain systems (open) should be separated between hazardous and non- hazardous areas.
7. Classification of areas. Reference should be made to current guidelines for both marine and process applications. Consideration will need to be given to any FPS hull hazardous areas/effects on the process facilities and vice versa.
8. When designing piping connections for FPSs, the following should be considered:
   - Allow for full working pressure of piping systems.
   - Maintain uniform inside diameter for mechanical pigging efficiency.
   - Provide adequate pressure relief systems and shutdown valves to avoid overpressure of storage tanks (See sections 10.2.6, 10.2.7, and 10.4.2b).
   - Interfaces between marine and process systems, and their differing design codes and practices.

10.1.2 FPS Motions Considerations

10.1.2a General Effect of Motions: Many components of a process facility rely on gravity separation. This can be the primary separation of oil, gas and water or the further refinement of these products in an oil, gas, or water treater. The gravity separation process, by its very nature, requires quiescence. Transmission of rigid-body FPS motions to the fluid in the pressure vessel may disturb this quiescence. There are five general effects of motion on process equipment. These effects shown in Figure 10.1, are discussed below:

- *Spirit level effect:* This is due to the liquid finding its own level when the FPS rolls or pitches in waves.
- *Resonant waves:* Resonant waves inside a process vessel result from the liquid's natural frequency inside the vessel approaching the excitation frequency induced by the horizontal motions of the FPS.
- *Primary turbulence:* Primary turbulence of the liquid is caused by the absorption of energy resulting from liquid motion caused by the spirit level effect and resonant and other motions.
- *Secondary turbulence:* Secondary turbulence of the liquid is caused by jetting of liquid through the holes of internal baffle plates installed to eliminate primary turbulence and resonant waves.
- *Process control effects:* Motions can have numerous effects on process control due to variation of liquid levels, vertical motion acceleration, hang up of floats and displacers, etc.

10.1.2b Severity of Motion Effect: Severity of the FPS motion effect on process equipment can be subdivided into three major categories:

1. *Motions have significant effect on performance:* Primarily refers to equipment with liquid/liquid interface such as:
   - Three-phase separators.
   - Oil treaters.
   - Water treaters.
   - Trayed contactor towers.
   - Produced water decanting tanks.
2. *Motions have less effect on performance:* Primarily refers to equipment with gas/liquid interface such as:
   - Two-phase separators.
   - Gas scrubbers.
   - Surge tanks.
   - Packed contactor towers.
   - Heaters.
3. *Motions have minimal effect on performance:* Primarily refers to equipment with single-phase or mixed two-phase fluids such as:
   - Heat exchangers.
   - Pumps.
   - Compressors.
   - Coolers.
   - Manifolds

Care must be taken to ensure that impacts on performance of machinery is fully evaluated. For example, the oil sump for a turbine or diesel requires special considerations to insure that there is always liquid available to the oil circulation pump. Motion must also be considered in the design of cranes and other material handling devices.

Additional discussion on this topic can be found in References 1 and 2.

10.1.2c Vessel Size and Internals Design: The pressure vessel size and the design of the internals have to be determined to ensure that the process performance requirements are met for a given set of motion conditions. Due to the complexity of motions and internal design, no comprehensive analytical approach exists. As a result, proper design should rely heavily on empirical and experimental results.

As mentioned earlier, the introduction of any baffle system reduces primary turbulence caused by the FPS motion, but thereby introduces secondary turbulence or eddy currents from the holes in the baffle plates. Consequently an optimum baffle system should be developed that minimizes total turbulence. This is represented graphically in Figure 10.2.

Reference 2 provides a practical example of how the internal design was modified on a TLP to improve the performance of the process equipment.

10.1.2d Arrangements and Layout: Safety is the main goal in the layout and arrangement of FPS process systems. It is recommended that API RP 14J and API RP 75 be consulted in the design phase of a FPS. RCS Rules also provide guidance for the arrangements and layout of the FPS.

In addition to the general guidance referenced above, the following specific items should be considered in the layout and arrangement of a FPS.

1. Personnel accommodation should not be located directly above or below produced oil or gas storage tanks, process vessels, pipelines, risers, or wellheads.
2. Personnel accommodations should be positioned at as great a distance as possible from the process facilities.
3. Process vessels, hydrocarbon storage tanks, or other items which could become a source of fuel in the event of a fire should be located as far as possible or otherwise protected from wellheads and potential ignition sources.
4. Arrangements and layout of the facilities, accommodations, control rooms, and life saving appliances should be such that a fire in a process area, hydrocarbon storage area, wellhead area, or other classified areas does not prevent or impede the safe exit of personnel from the accommodations through designated escape routes to boat landings or life boat locations.

10.2 UTILITY SYSTEMS

10.2.1 General

This RP should be regarded as complementary to already existing design rules and recommendations published by RCS and national authorities. These rules are well developed for ships and column stabilized vessels and to a somewhat lesser extent, for spars and other unique hull forms. In general this RP coincides with these codes and standards, and therefore mainly covers areas not already covered by other relevant rules, and emphasizes areas that deviate from these rules.

It should be pointed out that the recommendations contained in this section are based on current requirements for marine and utility systems from RCS and national/international codes, standards and regulations. Difficulties may arise when trying to apply these requirements to existing vessels undergoing modification to a FPS. Flag and/or coastal state administrations may grandfather existing systems and not require upgrade to current requirements; however, typically for systems that are critical to safety such as fire protection systems and ballast systems on column stabilized units, it is expected that the current requirements be met insofar as is reasonably practicable. Applicable regulatory agencies and/or RCS should be consulted as to the acceptability of *grandfathering* for specific FPS modifications.

10.2.2 Bilge System

10.2.2a Bilge System—General Considerations: Watertight compartments, passageways, and machinery spaces with the exception of ballast, cargo and consumable tanks should be serviced by a bilge or suitable drainage system. Hazardous and non-hazardous spaces should be provided with separate drainage or pumping arrangements. Hazardous spaces that typically require a bilge pumping system include: the cargo pump room, cofferdams adjacent to cargo tanks, and other watertight compartments considered hazardous either due to location or equipment and systems housed within. Adequate provisions should be made for removal of fluid accumulation in the bilges of these spaces. This should be accomplished by means of a separate bilge pump, eductor, or a bilge suction from a cargo pump or cargo stripping pump. The pump and associated piping should not be located in spaces containing machinery or in spaces where other sources of ignition are normally present, unless all electrical components, including explosion proof motors, are suitable for Class I, Division 1 or Class I, Zone 1 areas, and:

1. The space is continuously ventilated with no less than 20 air changes per hour.
2. Loss of ventilation is alarmed in a manned space.
3. Combustible gas detection is installed in accordance with Section 6.5.2 (Use of Combustible Gas Detection Equipment) of API RP 500 or Section 6.5.2 (Class I, Zone 0 Considerations) of API RP 505.

Valves in the bilge suction pipe connected to cargo or cargo stripping pumps should be of the stop check type.

Spaces above deck which can normally be drained by means of a drainage system do not require a fixed pumping system.

All valves in machinery spaces controlling the bilge suction from the various compartments should be of the stop check type. When fitted at the open ends of pipes, the valves should be of the non-return type.

Bilge pumps should be of the self- or automatic-priming type, and capable of continuous operation in the absence of liquid flow. Bilge pumping capacity should be adequate to remove the maximum liquid input from non-failure operations (e.g., service water washdown, fire water from deluge or hose reels). For machinery spaces containing equipment essential to safety, independently powered pumps should be considered with one supplied from an emergency source of power. Any hull compartment containing equipment essential for the operation and safety of the FPS should be capable of being pumped out when the FPS is in the extreme inclined (damaged) condition (i.e., maximum incline or list angle).

If the bilge piping is tied into a topside treatment facility, back flow into the bilge system should be prevented.

10.2.2b Bilge System—Considerations for a Spar Hull: Typically, the hull of a spar facility is made up of ballast tanks and void spaces. It is desirable to minimize the installation of fixed piping in the hull and similarly minimize deck penetrations in the hull. To this end, a fixed bilge system is typically not installed for hull void spaces in a spar hull; however, means must be provided to eliminate any liquid accumulations in these void hull compartments. This has been accomplished by designing the spar hull to allow access to void spaces for the use of portable pumps for the purpose of bilge pumping. If this option is chosen, at least two portable bilge pumps should be provided on the spar FPS along with the equipment to allow their deployment in any hull void compartment not fitted with a fixed bilge system.

10.2.2c Bilge System—Applicable Regulations: The owner should determine specific applicable regulations to the type of vessel to be used for the FPS, and to the particular geographical location. See section 1.2

10.2.3 Ballast System

10.2.3a Ballast System—General Considerations: The ballast system serves a number of functions including:

a. Adjustment of trim, draft and center of gravity of the FPS to maintain optimum stability and operating capabilities.

b. Adjustments of the FPS trim, draft and center of gravity to accommodate environmental conditions.

c. Take on and discharge ballast to adjust for the loading and discharge of cargo oil.

d. Dewatering of hull compartment to facilitate inspection and maintenance.

e. Damage control and correction of center of gravity.

Adequate consideration should be given to the ballast system's piping arrangement during the design phase with regard to interconnection and proximity to cargo systems and tanks. For example, ballast piping with permanent connections to cargo piping, as well as ballast piping passing through cargo tanks, should be considered the same as cargo piping (reference Section 10.2.4). Such ballast piping that possibly could contain hydrocarbons should not pass through spaces where sources of ignition are normally present.

The user should refer to the RCS Rules, which provide much more detailed guidance on piping arrangements for FPS with crude oil storage.

The ballast systems on all types of vessels should be capable of pumping from and draining all ballast tanks when the vessel is either upright or listed 5 degrees.

All ballast tank isolating valves should be arranged so that they will remain closed at all times except during ballasting operations. If remotely operated valves are installed, a means of manual control should also be provided, and the design of the control system should consider the effects of loss of control power and ensure that, in such an event, uncontrolled transfer or loading of ballast water will not occur.

A readily accessible means of isolation of the sea-chest and intake system, or any discharge below the waterline level, should be provided.

10.2.3b Additional Ballast System Considerations for Column Stabilized Vessels: When designing the ballast system, emphasis should be given to redundancy and reliability of the ballast system, its control and monitoring instruments and its equipment during all modes of operation. A single-point failure on any piece of equipment, or flooding of any single watertight compartment, should not disable the damage control capability of the ballast system. If it is apparent that the damaged condition trim angle would impair the operability of the ballast system, additional means are to be provided for damage control.

Ballast pumps and controls should be designed for numerous differential hydrostatic head conditions without causing damage due to excessive velocity or cavitation. Depending on the Net Positive Suction Head (NPSH) requirement for the main ballast pumps, de- watering of the ballast compartments may require a separate stripping system for lowering the water level below that level attainable by the main ballast pumps. The stripping system may also serve as partial rate backup to the ballast system. Provisions should be made to de-water flooded machinery spaces with consideration given to the inclined damage angle and available NPSH to the remaining pumps. Integrating seawater supply and ballasting functions into a common system should be considered, but the reliability of the ballast system should not be impaired.

Control systems should be provided to prevent accidental opening of flood valves for all modes of operation. Blinding off of systems not in use should be considered. The ballast system design should prevent uncontrolled flow of fluids passing into one compartment from another whether from the sea, water ballast, or consumable storage. Ballast tank valves should be designed to remain closed except when ballasting.

Remote-controlled valves should fail closed, and should be provided with open and closed position indication at the ballast control station. Position indication power supply should be independent of control power supply unless a 24V DC system is used for both.

10.2.3c Additional Ballast System Considerations for Spar Hulls: The ballast system on a spar is not considered to be as critical a system as it is on a column stabilized hull. Accordingly, the additional requirements outlined above for column stabilized vessels need not be applied to spar-based FPSs.

The ballast system on a spar is typically made up of a series of deepwell or submersible pumps for deballasting, one installed in each ballast tank, and arranged to discharge directly overboard or to a common ring main and then overboard. Ballast water is pumped into the tanks via another pump that is arranged such that it can supply ballast water to all ballast tanks. Isolation valves are provided in the ballast supply line to each tank.

The paragraph above is a description of a typical system and is provided for informational purposes only. System arrangements other than those described would also be acceptable provided these comply with all applicable regulations and RCS Rules.

10.2.3d Ballast Systems—Applicable Regulations: Regulations that are applicable to the facility should be determined by the owner. See Section 1.2.

10.2.4 Cargo (Crude Oil) Systems

Cargo piping systems should be independent of all other systems, and should be routed so that they do not pass through tanks containing fuel oil, or through spaces where sources of ignition are normally present unless the alternative measures regarding Class I, Division 1 or Class I, Zone 1 areas cited in Section 10.2.2a (Bilge System) are satisfied. Cargo piping may be routed through unclassified areas where sources of ignition are normally present only if the piping system in that space is a totally welded, closed system, without valves, flanges, or other appurtenances that pose potential leak paths. The positioning and arrangement of cargo discharge/loading pipes within tanks should be evaluated and designed to minimize the possible buildup of static electricity charges. Normally this is accomplished by positioning the discharge as low as possible within the tank. Adequate provisions should be incorporated in the cargo system's design to allow for expansion of the cargo piping system.

In selecting pumps to be used in the cargo system, care should be taken to ensure that the pumps are designed to minimize the risk of sparking. The space in which the pumps are located should not contain motors, lighting, or other equipment which would be a source of ignition. In general, these spaces are arranged to exclude all electrical equipment, with the exception of certified intrinsically safe systems and explosion-proof lighting. Electric motor drives for the cargo pumps should be in a separate space with their shafts passing through a gas-tight bulkhead to the pump room via gas-tight shaft glands.

As an alternative, (per API RP 500 Section 12 (Recommendations for Determining Degree and Extent of Classified Locations at Drilling Rigs and Production Facilities on Floating Production Units) or API RP 505 Section 12 (same title)), electrical components, including explosion-proof or flameproof motor drivers for cargo pumps, suitable for operation in Class 1, Division 1 or Class I, Zone 1 areas respectively, may be installed in the cargo pump room provided the alternative conditions cited in Section 10.2.2a (Bilge System) are satisfied.

The arrangement of the cargo tanks and cargo system should be such that all cargo tanks are separated by oil-tight cofferdams from galleys, living quarters, below-deck general cargo spaces, boiler rooms and machinery spaces where sources of ignition are normally present. These cofferdams should be adequately vented and wide enough to allow ready access. Cargo pump rooms, ballast tanks, fuel oil tanks or void spaces may be considered as cofferdams.

Regulations that are applicable to the facility should be determined by the owner (see Section 1.2).

10.2.5 Tank Sounding System

All integral hull tanks should be provided with sounding tubes or other suitable manual means of determining the presence and amount of liquid in the tanks. The size of sounding pipes should not be less than 1.5 inch in internal diameter. They should be led as straight as possible from the lowest part of the tank to an accessible location. If these terminate below the topmost watertight deck, they should be fitted with a quick-acting self-closing valve for oil tanks. Sounding pipes from other tanks can terminate with a valve or screwed cap. A striking plate should be mounted in the tank to prevent damage to the plating by repeated striking of the sounding rod.

Regulations that are applicable to the facility should be determined by the owner (see Section 1.2).

10.2.6 Tank Venting and Overflows

All tanks, cofferdams, void spaces, tunnels, and compartments not fitted with other ventilation arrangements should be provided with vent pipes. The arrangements of the tank structure and vent pipe should be such as to permit the free passage of air and gasses from all parts of the tanks to the vent pipes. The vent pipes should be arranged to provide adequate drainage. If overflows are used in conjunction with the tank vents, consideration should be given to their design to prohibit fluids from flowing from one watertight subdivision to another in the event of damage. The selection of tank vents and overflow locations should consider the location of the final calculated immersion line in the assumed damaged floating position. In general, vent pipes should terminate on the open deck by way of return bends. All vent outlets should be fitted with a permanently attached means of closure. This means of closure may be required to be automatic, such as vent check valve, dependent on the position of the vent relative to the final waterline after damage. The applicable international, national or regional regulations and/or applicable RCS Rules should be consulted relative to vent closure requirements.

Pump capacity and pressure head should be considered when calculating the sizes of vent pipes. In general, for all tanks that can be filled by pump pressure, the cross sectional area of the tank vents should be at least 125 percent of the effective area of the filling line. If overflows are used in conjunction with the tank vents, then this criteria should be applied to the sizing of the overflow and a reduced vent size may be considered. Recommended minimum sizes for vent pipes are as follows:

- 2.0 inches (50mm) I.D. for water-ballast tanks and fresh water tanks.
- 2.5 inches (63mm) I.D. for oil tanks.

Note that the above criteria is general and the use of high capacity and/or high head pumps may require vent pipes sized larger than those recommended above.

The vent outlets from fuel oil tanks, cargo tanks where the flashpoint of the cargo oil is above 140°F (60°C), and cofferdams should be fitted with corrosion-resistant flame screens having a clear area through the mesh not less than that required for the vent pipe. These outlets should be located in a position to minimize the possibility of ignition of gases escaping from the pipe.

Venting cargo tanks where the cargo oil has a flashpoint below 1400°F (600°C) should be accomplished by a closed venting system designed to ensure that the tanks cannot be subjected to excessive pressure or vacuum. On FPSs where an inert gas system is installed, means should be provided to ensure adequate tank venting when a tank is isolated from the inert gas system.

Regulations that are applicable to the facility should be determined by the owner (see Section 1.2).

10.2.7 Inert Gas Systems

The function of an IGS is to maintain a non-explosive atmosphere in the vapor spaces of cargo tanks. This is normally accomplished by blanketing the tanks with treated flue gas or gas produced by inert gas generators. The inert gas displaces the oxygen in the tanks and maintains the atmosphere below the explosive/flammable limits. Typically, regulations require that the oxygen content not exceed 5 percent by volume. Additionally, regulations require that the system capacity be no less than 125 percent of the maximum discharge capacity of the FPS.

Adequate means of isolation should be provided in the inert gas piping to prevent the possibility of backflow of hydrocarbons to machinery spaces or other non-hazardous spaces. This is normally accomplished by fitting a water seal and a stop-check valve. The stop-check valve should be fitted upstream of the waterseal. Applicable national and international regulations should be consulted relative to specific requirements for arrangement of these devices.

Each tank connected to the IGS should also be provided with pressure/vacuum protective devices to prevent the tanks from being subjected to over or under pressure. These devices would also provide protection to the cargo tanks when isolated from the IGS. Alternative means of providing protection may be considered, such as providing an open vent path (e.g., via a 3-way valve, etc.) to a safe surface location when isolated from the IGS during cargo tank cleaning operations.

Extensive and detailed requirements for IGSs are contained in IMO's *International Convention for the Safety of Life at Sea* (SOLAS). It is recommended that SOLAS be considered for IGS installations on a FPS.

In addition to integral tanks, consideration should be given to the possible need to supply gas to storage/process vessels on the deck of the FPS. The appropriate regulatory body should be consulted concerning these requirements.

Consideration may be given to alternate systems which would provide the same level of safety as an IGS. One type of system which may be considered is produced-gas blanketing. This type of system is an enrichment system which would use produced hydrocarbon gasses to raise the concentration in the vapor spaces of cargo tanks above the explosive/flammable limits. Before such a system is selected, appropriate regulatory bodies should be consulted to determine its acceptability and the possible need to provide a backup system to ensure an adequate supply of gas is available at all times. Cross-connection hazards of inert gas systems and produced gas blanketing systems shall be considered if both systems are installed in a primary/secondary mode.

Regulations that are applicable to the facility should be determined by the owner (See Section 1.2).

10.2.8 Crude Oil Washdown (COW) Systems

The owner should consult with the appropriate authorities to determine if a COW system is required.

Many designs incorporate a COW system, even if it is not required, for the purpose of sludge control in the tanks. If a COW system is to be fitted, the provisions of the IMO *Revised Specifications for Design, Operation and Control of*

Crude Oil Washdown (COW) Systems relative to safety should be considered in the COW system's design. An IGS is recommended if a COW system is utilized.

10.2.9 Cranes

The methods for establishing rated loads for cranes can be found in API Spec 2C. Cranes can also receive Cargo Gear Certification from a RCS. Local and flag nation government requirements should be investigated as applied and required. In addition, the effect of the FPS's motions on all crane operations should be considered. Other applicable regulations, if any, should be determined by the designer early in the design stage.

10.2.10 Production Vent/Flare Systems

Various vent system designs for the production plant should be considered early in the FPS's design stage. Since these structures have significant effects on weight, wind loading and center of gravity, it is important to establish realistic relief rates and the system's sizing criteria in the initial design phase. API RP 520 Parts I and II and API RP 521 provide guidelines for pressure relief systems. Dynamic loads from the motions of the FPS should be considered during the design of flares, vent stacks, and booms, and the effects of such structures on the stability and motion characteristics of the FPS.

10.2.11 Waste Gas Flaring

10.2.11a Special Considerations: Compared to waste gas flaring from a fixed offshore platform, or onshore facility, flaring from a FPS requires special consideration for the following reasons:

- The flare structures must be designed for dynamic loading.
- Flaring from a FPS incorporating crude oil storage (e.g., tanker-based FPS) may present an ignition source in close proximity to a large volume of crude oil and/or hydrocarbon vapor.
- Export tanker loading operations may result in venting of hydrocarbon vapors relatively close to the flare.
- Many FPSO installations are designed to weathervane around a turret or other mooring. The position of the vessel is dependent on a combination of wind and current whereas only the wind will effect dispersion of gas from a vent. Gas dispersion from a vent should be analyzed for all possible vessel alignments.

Safety concerns resulting from flaring near stored crude or export tanker loading are amplified by the limited egress opportunities for the operators (relative to an onshore facility). Where the flare tower is also used to support the hull tanks' inert gas venting system, careful selection should be made of the venting point with respect to the possible flare ignition source.

10.2.11b Flare Configurations: Three types of flare configurations have been successfully used for FPS gas disposal:

1. Tower flares in which a vertical flare tower locates the flame sufficiently high to provide adequate separation from hydrocarbons for safe operation.
2. Extended boom flares in which a flare boom angled off from the FPS results in the flame being over water. In this system, physical separation of the flame from hydrocarbons is the primary means of providing safety.
3. Enclosed ground flares in which the flame is contained in a chamber, usually a vertical cylinder, and with controls and other equipment is designed to ensure safe operation within close proximity to hydrocarbons.

In certain instances, more than one type of flare may be utilized simultaneously.

10.2.11c Design Codes/Requirements: FPS flare design should be in accordance with the following:

1. Flares should be designed in accordance with API RP 521. Alternatives to API RP 521 requirements consistent with current technology and practice and/or proven methodology may also be considered.
2. For dynamic loading, flare structures should be designed in accordance with API RP 2T.
3. Enclosed ground flares should be designed to contain liquid carryover, and to survive burning of such, without catastrophically failing or leaking this liquid. Containment volume should, at minimum, be equal to that of the largest process facility vessel which could potentially discharge to the flare in an emergency blow-down case. Means should be provided to safely drain liquids from the ground flare.
4. Flare towers and extended boom flares should be protected against liquid carryover based on the following guidelines:
   - Conservative design of the process equipment and controls.
   - A liquid knock-out vessel upstream of the flare which may include an automatic system for dumping liquid to separate tankage before liquid carryover to the flare can occur. Additionally, the knock-out vessel should be sized to handle liquid hydrocarbon accumulation during upset and shutdown events to ensure no liquid hydrocarbon carryover to the flare will occur as a result of the event.
5. Enclosed ground flares should be provided with means to ensure the atmosphere within the chamber is not explosive prior to ignition.
6. Gas detectors should be located as close as possible to ignition sources for the purpose of detecting unacceptable

hydrocarbon gas levels. Dispersion analysis should be conducted to determine if hazardous conditions exist for the facilities if sweet gas is vented instead of flared. If it can be demonstrated that hazardous conditions do not exist, gas detectors do not have to be installed.

7. Enclosed ground flares should be provided with a separate gas vent for discharging unburned gas in lieu of flaring, during flare shutdown and emergency situations. The gas vent should be located sufficiently distant from the enclosed ground flare to prevent the possibility of the hot surfaces of the enclosed ground flare igniting the vented gas.

8. Dispersion studies should be conducted to ensure gases vented from export tankers during loading do not pose a safety hazard due to potential ignition by the FPS flare.

9. Radiant heat analysis should be carried out on flares to ensure that the flare radiation levels on structure and at locations where personnel may work or have access are within the limits defined in API RP 521. Users shall consider "emergency" versus "continuous" flare radiation conditions where "continuous" is defined as flaring of gas for some time period where the rest of the process train remains online. An example of this are excursions where gas compression machinery trips but well production continues for some period while the compressors are put back in service. This has particular impact on a FPS where the consequences of shutting in subsea wells may have severe operational impact (wax, paraffin, and hydrates).

10.2.12 Electrical Systems. Electrical system requirements for the marine component of a FPS installation are well established by RCS Rules and national/international standards. Likewise, the requirements for the industrial component are well established by industry standards such as API RP 14F and RCS Rules and national/international standards. Specific areas of concern that should be highlighted are as follows:

- *Hazardous areas and electrical equipment in hazardous areas:* Hazardous areas are those areas where there is a likelihood that flammable gases or vapors may be present. These areas should be delineated as outlined by RCS Rules and/or national/international standards for cargo oil storage areas and as outlined in API RP 500 or 505. Care must be taken to ensure that all electrical equipment installed in these areas are properly certified as being safe to operate in the applicable class or zone rated hazardous area.
- *Grounding:* It should be noted that established marine industry practice prohibits the installation of low voltage (less than 1,000 volts root mean square (rms) line to line) grounded distribution systems on units storing produced fluids in integral hull tanks. Reference should be made to RCS Rules or other appropriate international marine standards for specific guidance. Grounded distribution systems of any voltage level may be considered if the ground fault return path is provided within the cable system for all feeder, distribution, and utilization cables and the system is designed such that the ground return path is primarily through the cable rather than the hull structure. High-resistance ground systems are recommended and should be considered to minimize fault current. On medium voltage systems, low-resistance grounded systems are allowed by certain RCS Rules.
- *Emergency Distribution System:* Marine regulations require the provision of a separate and independent emergency source of power to supply safety critical power, upon loss of main power.
- *Integration:* The integration of marine and industrial systems is an area requiring careful coordination.

10.3 SAFETY SYSTEMS

10.3.1 Personnel Safety

10.3.1a General: Regulatory agencies have established certain requirements for personnel safety which will affect the design of the FPS's. In addition to the regulations identified in this section, the designer is recommended to consult the following API RPs, during initial project planning:

- API RP 14J
- API RP 75

10.3.1b Means of Escape: The space limitations imposed will require early planning for means of escape for personnel. Two alternative means of escape are recommended for the following types of spaces:

- An accommodation space over 300 square feet.
- Continuously manned spaces.
- Spaces manned on a regular working basis.

Escape means should be planned to allow personnel to move from the uppermost level of the FPS, to successively lower levels, to lifeboats, and, if possible, to the water level. Whenever possible two separate isolated escape routes from any working or accommodation area should be provided. Consideration should be given to providing some means of fire protection for personnel escaping along the primary escape route from the accommodation spaces to the survival craft. On tanker-shaped FPSs it may be prudent to install a temporary safe refuge at the end of the unit remote from the accommodation and escape tunnels along the FPS.

10.3.1c Emergency Evacuation: A comprehensive, site-specific contingency plan should be developed for the emergency evacuation of all personnel aboard the FPS. The objective of this plan should be to provide personnel with the direction and equipment necessary for a timely and safe evacuation from the FPS in an emergency.

10.3.1d Lifesaving Equipment: Lifesaving equipment include life boats, life rafts, ring buoys, life preservers, exposure suits, distress signals, etc. All floating production units should be provided with lifesaving equipment as required by flag (if applicable) and/or coastal state administration. In the absence of specific requirements from an administration, it is recommended to consider the lifesaving equipment requirements in the *IMO MODU Code 1989 with amendments*.

10.3.1e Alarms: A general alarm system is required. The design of this system should meet the following requirements:

1. Capable of being activated by manually operated alarm boxes and by an automatic fire detection system, if provided.
2. Continuously powered with an automatic changeover to standby power supply unit in case of loss of normal power supply.
3. Designed to handle simultaneous alarms with the acceptance of any alarm not inhibiting another alarm.
4. Audible in all parts of the FPS. In high ambient noise level working areas, visible means of alarms should be provided.

Refer to flag and/or coastal state administration requirements for guidance on applicable requirements for a general alarm system on a specific installation. In the absence of guidance from the administration, compliance with IMO Code on Alarms and Indicators is recommended.

10.3.2 Fire Protection

10.3.2a General: Fire protection measures on a FPS consist of structural fire protection measures, fire water system, fixed fire extinguishing systems, portable fire extinguishers, safety equipment, and fire/gas detection systems. What makes a FPS unique is that it is made of a marriage of two different technologies: the marine component, which is made up of the hull and marine systems, and the industrial component, which is the process facility. Fire protection systems and arrangements for the marine component are adequately addressed by RCS Rules, flag state Administration requirements (if applicable), and international requirements. Likewise, the fire protection systems and arrangements for the industrial component are adequately addressed by API RPs, RCS rules and national/international regulations. Interface of the marine and industrial components of a FPS creates a design and operational challenge and requires a rational analysis of the hazards to tailor the fire protection arrangements and systems to provide suitable protection of the overall facility. As an example, the fire protection requirements for a FPS which processes and stores produced hydrocarbons in integral hull tanks would be different from a FPS which processes hydrocarbons and exports the produced fluids via pipeline without any integral storage facilities. The difference would be based on the added hazard of stored hydrocarbons in integral hull tanks and the impact a fire or explosion in the storage area may have on the remainder of the facility. Based on an analysis of the hazards, additional structural fire protection and additional fire detection and fire fighting systems may be required.

10.3.2b Structural Fire Protection: A plan detailing the extent and methodology for protection of structural steel should be developed early in the design stage of any FPS project. Systems for structural fire protection could be either active, such as water spray, or passive, such as steel backed with insulation or intumescent coatings. In selecting a system, the following points need to be considered:

- Active systems can increase water system capacity requirements and require provisions for drainage for fire water runoff.
- Passive systems provide protection but may not represent a minimum weight solution.
- Requirements for access to structural members under passive coating system for inspection.
- Testing requirements for active systems.

As stated in 10.3.2a, the requirements for structural fire protection of the marine and process components of a FPS are well established. What needs to be examined is the impact of the process system on the marine component and likewise the impact of the marine component on the process system. Although the applicable codes, standards, and regulations need to be consulted for each FPS, typically if external bulkheads of the accommodations, working spaces, control rooms, and similar type spaces are within 100 ft of the process facilities the provision of a firewall (A60 or higher structural fire protection) on the side(s) of the accommodations facing the process facilities should be considered.

10.3.2c Fire Water System: All FPSs will require a fire water system that supplies hose stations throughout the unit. The system will require sufficient redundancy so that a fire in any space or open area would not render the system inoperative. Typically a minimum of two pumps with separate sources of power will be provided which supply a fire main that is fitted with isolation valves so that if a section fails, the failure could be isolated and the remainder of the system would remain operational.

Other fire protection systems that may be supplied from the fire main include, but are not limited to, foam systems that are typically installed to protect produced hydrocarbon storage areas and helicopter decks, a process deluge system, and active structural fire protection (waterspray) systems. When sizing the fire water system, all fire risk scenarios must be considered and the system should be sized to be capable of supplying all systems that would be required to operate simultaneously in any single fire risk scenario. For example, looking at a typical ship shaped FPSO where the process system is mounted on a deck over the cargo (hydrocarbon storage) block, the fire risk scenario of a fire on the cargo deck would require the following fire water systems:

1. Fire main with fire hose stations.
2. Cargo deck foam system to fight the fire.
3. Process deluge system to cool the process vessels and equipment.
4. Possibly an active structural fire protection system on the accommodations or other structure.

It can be seen from this example that the capacity of the fire water system on a FPS would be significantly greater than that for an equivalent sized marine facility without a process facility.

Reference should be made to RCS Rules, national/international standards and codes, API RP 14G, and applicable NFPA standards for guidance.

10.3.2d Fixed Fire Extinguishing Systems: Fixed fire extinguishing systems are usually installed in machinery spaces, electrical equipment rooms, and control stations as well as accommodations. These systems include gaseous systems, sprinkler systems, water mist systems, foam systems, and dry chemical systems. These systems can be manually actuated or automatically actuated by a fire detection system. Requirements for fixed fire extinguishing systems for protection of the marine component of a FPS are well established. RCS Rules and applicable national/international regulations, codes and standards should be consulted in this regard. Fixed fire extinguishing systems for the industrial component of a FPS (process facilities) should be provided to address hazards associated with the process equipment, process related machinery, hydrocarbon storage areas, electrical equipment rooms, and other areas or spaces constituting a fire hazard. Reference should be made to RCS Rules, national/international standards and codes, and API RP 14G for guidance.

10.3.2e Portable Fire Extinguishers: Portable fire extinguishers are intended as a first line of defense against fires of limited size and should be provided throughout the facility even though other fire extinguishing systems and equipment are provided. Portable fire extinguishers are self-contained and can be brought to bear on a fire quickly. Portable extinguishers are rated for the type of fire they are intended to fight and also the size (i.e., the amount of extinguishing agent). Refer to NFPA 10 for further information on the ratings of portable fire extinguishers. Portable fire extinguishers should be provided throughout the FPS in sufficient quantity and placed at locations so they can be best utilized to fight a fire at the equipment they are provided to protect. Refer to RCS Rules, and national/international standards, codes, and regulations for requirements for portable extinguishers for protection of marine facilities. Refer to API RP 14G, RCS Rules, and national/international standards, codes, and regulations for guidance relative to portable extinguishers for protection of process facilities and related areas.

10.3.2f Safety Equipment: Safety equipment in this context is considered to be such equipment as fire axes, firemen's outfits, breathing apparatus, lanterns, stretchers, fire blankets, etc. Safety equipment should be provided throughout the FPS as required.

10.3.2g Fire/Gas Detection Systems: A fire and gas detection system is critical as an early warning system against fire on a FPS. These systems not only sound an alarm, but in many cases also automatically initiate fire protection systems such as fire pump start- up, process deluge system, sprinkler systems, gaseous extinguishing systems, etc. and initiate ESD functions as necessary.

Fire detectors are categorized by what they detect. Some detect smoke while others detect flame or heat. It is suggested that systems be installed using multiple types of detectors and the type of detectors selected for a given area should be based on the type of fire expected in that area. For example, smoke detectors are very well suited for installation in the quarters.

It is recommended that open and enclosed fire hazardous areas be provided with a fire detection system. Refer to API RP 14G and API RP 14C for guidance. It is also recommended that the accommodations be fitted with a fire detection system as well as other areas that are considered part of the marine component of a FPS.

A combustible gas detection system should be provided in all enclosed and semi-enclosed areas that might accumulate combustible gases and in all intakes for air ventilation systems. Recommended detector set points for low and high gas alarms should be 20 percent Lower Explosive Limit (L.E.L) and 60 percent L.E.L. respectively. Reference should be made to appropriate standards and codes for further guidance. Line of sight gas detectors which detect wavelength of hydrocarbon vapors are suitable for open, unenclosed area gas detection and may be considered.

If the FPS is intended to handle fluids and or gases containing hazardous hydrogen sulfide (H_2S) levels, it is also recommended an H_2S gas detection system be provided. Recommended detector set points for low and high gas alarms should be 10 ppm and 50 ppm respectively. It is recommended that provision of a fresh air breathing system or alternative means to protect personnel from H_2S be made as appropriate. Installation of a "flame-out" detection system for flare systems handling H_2S should be implemented for personnel protection.

10.4 PRODUCT STORAGE FACILITIES

The destination of the gas, oil and water leaving the process facilities will have been determined during selection of the system configuration (see Section 1.4). Based on this determination, it may be necessary to provide product storage facilities on the FPS.

10.4.1 Gas

It is assumed that gas will be exported by pipeline. There are concepts for handling the storage and shipping of gas from FPSs without the use of pipelines. These concepts include cryogenic storage, offloading and shipping (liquefied natural gas carriers); conversion of gas to methanol or other liquids; shipping of gas at high pressure or injecting the gas into a formation. If the volume of gas is sufficiently small the remainder left after fuel use will be vented, flared, routed to vapor recovery compression, or injected into a suitable reservoir, if shown to be environmentally and operationally safe. Specific guidance for these concepts is not within the scope of this document. Gas storage arrangements should comply with existing national/international codes as appropriate.

10.4.2 Oil

Pipeline export of oil may require that the FPS have a provision for limited storage. This provision may be provided in the process system as additional residence time, or an additional surge vessel. If pipeline export is not used, then it is expected that a considerable volume of storage would be required to be compatible with a shuttle export tanker or barge export method.

This storage capacity may be provided by the export tanker or barge itself, in this case unless a backup redundant shuttle/storage vessel is provided, the production system must shut down when the export vessel is unable to accept the produced crude.

The storage capacity may be included in the FPS as atmospheric tanks or water displaced tanks, either as part of the main drilling/production vessel, or in a dedicated floating vessel, or in a dedicated subsea tank.

10.4.2a Atmospheric Tanks: This is familiar tanker storage arrangement, which may be used on ship shaped and other types of FPSs.

The oil stored in atmospheric tanks have a free surface. Oil discharged from the tank would be replaced by inert gas to maintain a safe condition (see paragraph 10.2.7). Gas or vapor evolved from the oil, or displaced during tank filling, would be routed to a safe vent location or captured in a closed vapor recovery system.

This type of tank must be designed for the extreme hydrostatic heads which can occur with the tank empty or full, at the appropriate extremes of the FPS's draft.

Tanks of this type would conventionally be fitted with Crude Oil Washing (COW) systems (see paragraph 10.2.8). COW is valuable in maintaining a low level of solid/wax build-up in the storage tanks.

10.4.2b Water Displaced Tanks: Oil may also be stored in tanks which are maintained full of liquid by displacing removed oil with seawater. This type of system has been used extensively in concrete gravity-base fixed platforms. This concept reduces the extremes of hydrostatic head associated with empty and full tanks, which are particularly significant with deeply submerged tank locations. It also reduces the extremes of the FPS's draft variation associated with full and empty tank conditions, and is of greater significance to hulls having small water plane areas such as column stabilized or spar buoy configurations.

With this type of system, care must be taken to prevent release of oil to the environment, particularly as an emulsion layer may build up at the oil/water interface. The water displaced during filling is typically routed to the sea via a buffer separation tank. Additionally, the displaced water may be routed through an oil detection and/or clean-up system prior to discharge to ensure a sufficiently high quality discharged water. The water quality required will be subject to host state requirements. Venting arrangements will be required to ensure that tank pressure levels remain within the design values, and that any gas evolved from the oil is safely vented. Provision may be required to account for possible wax and/or solid build-up within the tanks. Removal of any such build-up may not ordinarily be possible with this system, and the piping arrangements may need special consideration to prevent operational problems due to contamination/blockage, etc.

10.4.3 Produced Water/Well Cleanup Fluids

Produced water storage may be required when the water is to be exported from the FPS for final treatment elsewhere, or where tanks are to be used for additional residence time in the produced water treatment system.

Similarly, for initial flowback from producing wells, hull tanks may be considered for use in enhanced gravity settling and chemical treatment. This may be preferable to introduction of the cleanup fluids into the main processing train.

Consideration should be given to the chemical composition of the produced water with its propensity to promote scaling and/or corrosion, the temperature of the water, and its subsequent impact on the tank structure, and the possibility of sand carry over from the wells, with resulting accumulation in the tanks.

10.4.4 Product Storage Integrity and Segregation Requirements

Adequate integrity and segregation of storage must be provided to reduce risks regarding release of the product to the environment, creation of fire/explosion hazards, personnel hazards, or contamination of tank contents. All applicable regulatory requirements must be met.

Particular aspects of tank segregation, venting and piping arrangements are further discussed in paragraphs 10.2.4 and 10.2.6.

10.4.5 Oil Pollution Prevention and Control

The prevention and control of oil pollution should be considered in all aspects of FPS design, fabrication, installation, and throughout its life cycle. A Shipboard Oil Pollution Emergency Plan (SOPEP) should be developed and maintained by the owner. A SOPEP will provide guidance to personnel onboard as to what actions are to be taken immediately following an oil pollution incident. It will also provide a point of contact on the FPS for coordination of shipboard activities with national and local authorities in combating the pollution. The SOPEP will contain information on the oil pollution response equipment that is maintained onboard the FPS, as well as equipment that is maintained in the area, including information on the period of time required to bring it to bear on the pollution incident.

10.5 REFERENCES

Effects of Motion of Process Facilities for Floating Production Systems, by C. L Rice, OTC Conference 1985, OTC Paper No. 5034

Process in Motion: Experience With Oil/Gas Separation on the Hutton TLP, by E. IL G. Bell, et al, OTC Conference 1988, OTC Paper No. 5838.

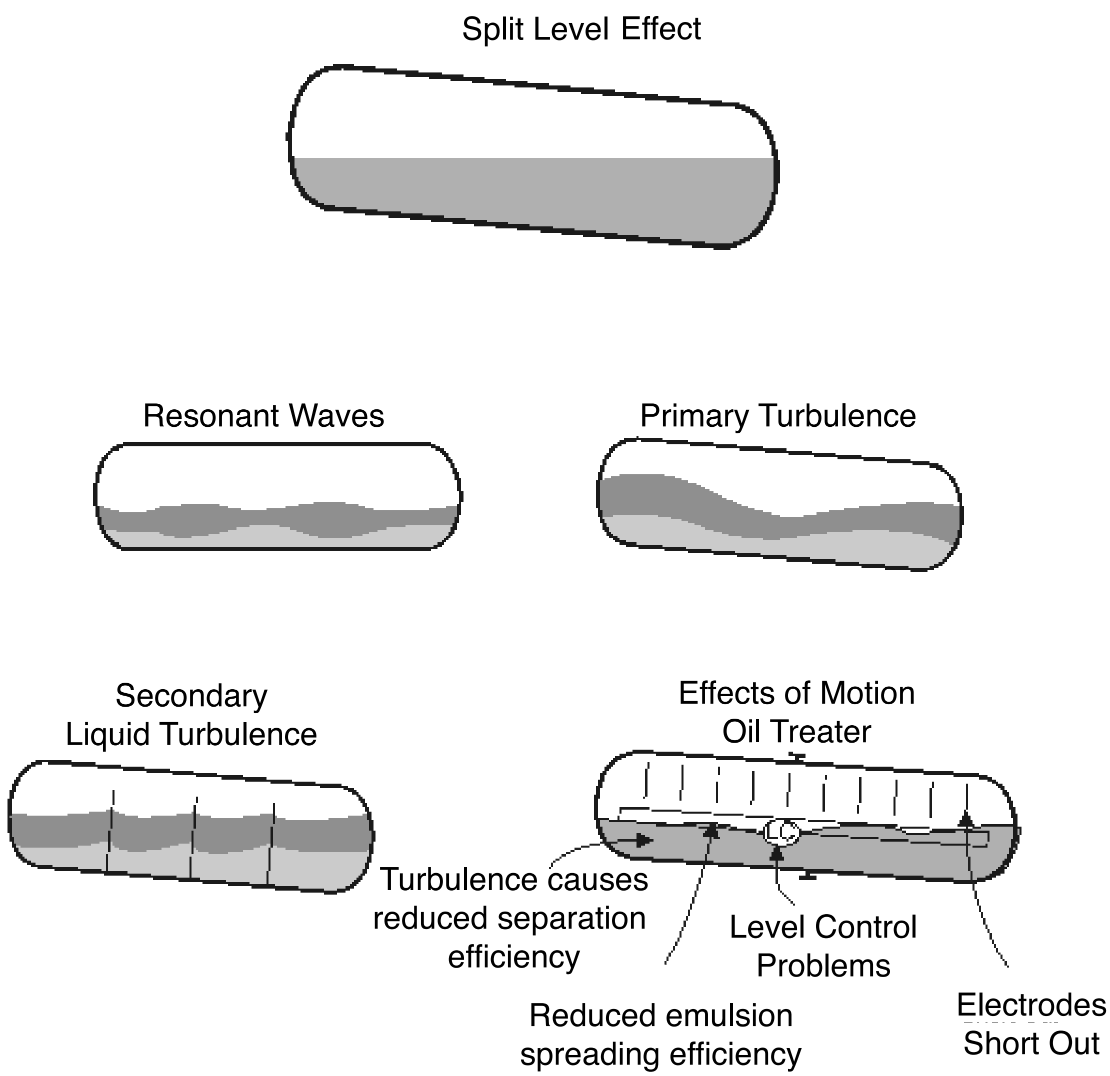


Figure 10.1—Effects of Motion on Process Equipment

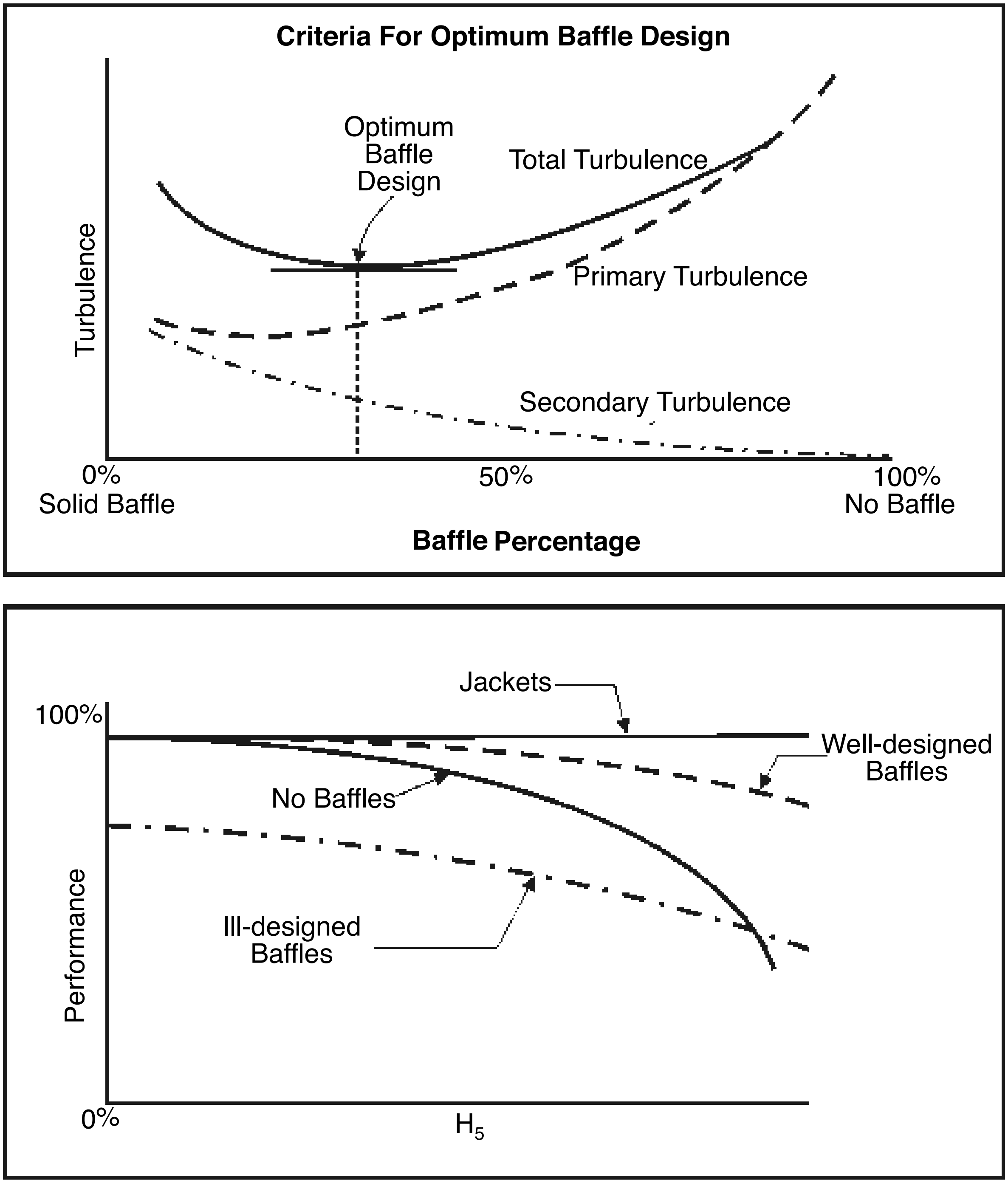


Figure 10.2—Baffle Design and Performance

11 EXPORT SYSTEMS

11.1 BASIC CONSIDERATIONS

11.1.1 Introduction

After processing oil and gas, a FPS must be capable of safely and efficiently storing and offloading the produced hydrocarbons for export into a fixed or mobile transportation medium such as a pipeline or tanker. The FPS export system is the conduit used to transfer the hydrocarbons from the FPS into the transportation medium.

11.1.2 System Selection

The type, size, scope, and limitations of an export system designed to export produced hydrocarbons from a FPS will generally depend upon the following basic considerations or parameters:

- FPS size, type and production and discharge rate.
- Type of export transportation medium.
- Water depth and site specific environmental conditions.
- Hydrocarbon characteristics and operating pressure.
- Scope and arrangement of other field facilities.
- Space available and maneuvering room at field site.
- Applicable codes and standards.
- Operating philosophy (including the use of thrusters and DP systems).

All of the above must be considered in the selection of a FPS export system. Operating philosophy will dictate allowable downtime of the export system, which will have significant impact on which type of export system is selected.

11.2 TYPES OF EXPORT SYSTEMS

11.2.1 General

FPS export systems will generally fit into one or a combination of the following categories:

- Riser and pipeline export system
- Tanker transfer
- Shoreside transfer

These three categories form the basis of most FPS export systems and are the primary subjects of this section of the RP.

11.2.2 Riser and Pipeline Export

Riser and pipeline export system involves the transfer of produced oil, gas, water or other products from the FPS through conduits (risers) to subsea connections of pipeline (flowline), wellhead, template, or pipeline end manifold (PLEM) for transmission to shore or injection into a suitable geological formation. Unless the fluids are first transmitted to nearby booster pumping stations or compression and treatment platforms, the FPS will likely require high-pressure gas compression, gas and water treatment and high-pressure pumping facilities to condition the produced fluids for export.

For a turret moored weathervaning FPS, a high pressure swivel (sealed, rotatable joint, or coupling) or drag chain hose system will also be required. If the swivel or wrap-around hose is already planned for the incoming production stream, it can be equipped with multiple paths to also accommodate the outgoing export risers.

11.2.3 Tanker Transfer

Tanker transfer is another commonly used FPS export system. Hydrocarbons may be transferred from the FPS, directly into trading tankers of opportunity or into dedicated shuttle tankers and barges for export or shuttling to onshore or offshore terminal(s). FPS-to-tanker transfer can be accomplished using any one or combination of the following transfer schemes:

- Alongside (side-by-side) transfer (Figure 11.1).
- Tandem transfer (Figure 11.2).
- Separate offloading mooring system transfer (Figure 11.3).

Alongside transfer is the method of transferring fluids from a FPS vessel to an offloading tanker which is moored side-by-side. Tandem-moored transfer is the method of transferring fluids from a FPS vessel to an offloading tanker which is connected astern of the FPS vessel. Both the alongside transfer and the tandem transfer can use a flexible offloading hose arrangement, an above-water hose boom, or a hard pipe swivel joint boom to transfer fluids to the offtaking tanker. The method of hose storage will depend on the environment at given location. For fluid transfer using the separate offloading mooring system transfer, the offloading tanker will be moored separated and remotely from the FPS and connected to the FPS via one or more risers, and subsea flowline for the transfer of fluids.

11.2.4 Shoreside Transfer

Shoreside transfer may be a practical method of exporting hydrocarbons if the FPS and its mooring system are designed for disconnection and the reservoir can tolerate or benefit from periodic shut-ins. The FPS must be capable of transporting the oil to shore under its own propulsion or could be towed/pushed by another vessel. For a Category 2 or 3 short-term FPS (refer to Section 2.3) having adequate storage capacity, oil can be stored on board and discharged periodically to shore facilities. A disconnectable FPS, used for shoreside transfer, should be equipped to discharge the cargo at a suitable shoreside oil terminal.

11.3 EXPORT SYSTEM DESIGN CONSIDERATIONS

11.3.1 General

In most FPS applications, water and gas would likely be produced as a product of the hydrocarbon production process.

Produced gas can be utilized or disposed of in a number of different ways, including the following:

- Reservoir reinjection for secondary recovery production.
- Injection to another reservoir for future recovery.
- Transmission to shore.
- Liquefication and transfer to a LPG/LNG tanker.
- Use as fuel on either the FPS or other platforms.
- Flaring or venting if allowed by local regulations.
- Conversion to other products on the FPS..I
- Combination of any of the above.

Produced water may be discharged overboard of the FPS after proper treatment and is subject to local regulations governing the discharge of oily wastewater; however, produced water can also be exported from the FPS for reinjection into the field reservoir for secondary recovery purposes. If the water production rate is minimal, it can be stored on board the FPS, and later transported by FPS or tankers for disposal on shore.

11.3.2 Gas Export

Gas offloading piping should be installed in the open, or in well- ventilated areas, and should be routed away from openings which have access into living and working areas of the FPS. Classification of areas for electrical installations along the route of the gas offloading piping should be in accordance with API RP 500.

Should compressors, or pump shut-off pressure or its relief valve settings, exceed the pressure rating of any part of the offloading system, means of separate relief should be fitted. Refer to API RP 521 and other appropriate codes and standards for the design of pressure relief systems.

Riser and pipeline export system is usually designed for hydrocarbon and water transfer at operating pressures greater than the low-pressure transfer method by hoses. The design criteria for export risers and pipelines should follow those for the production risers discussed in Section 9.

The design, construction and testing of the FPS high pressure offloading piping and the outlet of the water and gas processing facilities, should be in accordance with RCS rules and API RP 14E. Piping material specifications up to and including the export flange should conform with the recommendations provided in ASME/ANSI B31.3.

Pipe stress due to thermal expansion, FPS motions and deflections, internal/external loadings, and piping flexibility should be controlled through proper design and placement of pipe bends, anchors, sliding supports and restraints. Requirements for pipe stress analysis should be in accordance with the following codes:

- ASME/ANSI B31.3 for onboard FPS piping.
- ASME/ANSI B31.8 for downstream steel pipeline transmission.
- API 17B, 17J and API RP 2RD for flexible pipe export risers.

11.3.3 Liquefied Gas Export

Produced gas may be exported from a FPS in a liquid state such as Liquefied Petroleum Gas (LPG) or Liquefied Natural Gas (LNG). Export of LPG/LNG is a complex and hazardous operation for which appropriate design and operating precautions must be taken. LNG and LPG transfer operations are not covered in this RP.

11.3.4 Crude Oil Export

A common method of exporting crude oil from a FPS is by transferring under low pressures, using the tanker or shoreside transfer methods described in Section 11.2. The design, construction, testing and installation of low-pressure crude oil export systems, including hoses, loading arms, and piping manifolds should comply with relevant RCS Rules, Oil Companies International Marine Forum (OCIMF) recommendations, ASME codes or other applicable codes and standards. Operational and safety considerations for transfer of oil between vessels should be as outlined in OCIMFs *Ship-to-Ship Transfer Guide*.

11.3.5 Metering System

For custody transfer and fiscal purposes, the hydrocarbon export system should include a metering system to monitor the quality and quantity of transferred hydrocarbons. To achieve the highest level of measurement certainty, an in situ prover is required. To facilitate timely computation of transferred volumes, flow computers should be included. For transmission of the generated custody transfer data to accounting systems, a supervisory computer with a data transmission interface should be provided.

For quality measurement an automatic sampling system should be included. It should be installed in accordance with the API *Manual of Petroleum Measurement Standards*. In addition, it may be desirable to include on line sediment and water (S&W) and density measuring equipment. This equipment is commonly provided as a quality loop and is usually installed downstream of the metering equipment, together with equipment to ensure a representative flow stream through the loop.

The meters and prover are normally installed on the open deck of the FPS and all exported hydrocarbons should flow through the meters with no chance of bypassing or recirculating any part of the flow stream. Meters, provers and flow computers, should conform with the requirements of the API *Manual of Petroleum Measurement Standards*. The choice or use of a metering system does not usually affect the selection of a particular type of export system for the FPS; however, it is important to consider the effect of the metering system in the hydraulic analysis of the export system.

11.4 RISER AND PIPELINE EXPORT

11.4.1 General

Riser and pipeline export system is the most used method for export of gas and water from a FPS. The export riser configurations should be similar to the production risers defined in Section 9. Various configurations are in use to provide flexibility in order to accommodate FPS motions and wave and current loading. The export riser may consist of rigid pipe, flexible pipe or hose-type pipe. The bottom of the riser may be attached directly to a subsea wellhead, template, manifold, or to a pipe line- end-manifold (PLEM). Design of the export risers should follow API RP 2RD and API RP 17J.

11.4.2 Limitations

The risers used in the export system should be designed to accommodate the FPS motions calculated in accordance with Section 8. For proper design of risers and subsea pipeline systems, the sea bottom soil characteristics, bottom profile and current profile should be known. A complete site specific survey should be conducted along the route of the pipeline and a dynamic riser analysis should be performed to determine the riser configuration and the location of the PLEM. Special requirements for pigging, heat tracing or hot oil circulation should also be established. Related design guidelines in API RP 17A, API RP 17B, Specification 17J, and API RP 1111 should be followed.

For a turret moored free weathervaning FPS (>360 degrees), a high-pressure swivel between the FPS and the export riser will be required. The export swivel should be similar to the production swivel, as presented in Section 9.

11.5 ALONGSIDE TRANSFER

11.5.1 General

Alongside, (or side-by-side), transfer of hydrocarbons is often used for offloading from a ship shaped FPS in benign areas with mild weather conditions. This method involves berthing or mooring an export tanker or a barge alongside the FPS. Hydrocarbon products are then transferred through marine type hoses or loading arms to the cargo tank manifolds. These are usually installed amidships on either side of the export tanker or the barge. Pneumatic or foam-filled fenders should be used to avoid damage to each vessel's hull which may result from contact between the two vessels. The offloading hoses should preferably be tended by a cargo hose derrick or a gantry arrangement. Loading arms installed on the deck of the FPS are self-powered systems with optional positioning and alarm functions. Tending of loading arms and offloading hoses should preferably be automated and use integrated systems to signal an unsafe condition where fluid transfer must be shut down and disconnection initiated quickly.

The export vessel is secured to the ship shaped FPS by mooring lines usually passed over from FPS to the export tanker. The side of FPS selected for oil transfer usually depends upon:

- Location of process equipment, including flare, on the deck of the FPS.
- Desired headings of each vessel, (i.e., bow-to-bow or bow-to-stern).
- Prevailing environmental directionality.

In either case, an emergency release system should be employed to contain the product in the event that loading operations are interrupted.

11.5.2 Limitations

Alongside transfer is probably the most weather-limited method of exporting crude oil because of its high sensitivity to wave and wind effects, especially when two tankers, berthed side-by-side, have radically different hull dimensions and shapes; however, in some cases two tankers may be accommodated simultaneously on both sides of the FPS, in either a bow-to-bow or bow-to-stern configurations.

Excessive wave height is a major cause of downtime for alongside transfer. A wave height of 2 to 3 meters has been recommended as the maximum design condition for allowing safe mooring of two tankers side-by-side; however, this wave height limitation may vary, depending upon the following conditions:

- Type of FPS.
- Differences between FPS and export tanker sizes and hull shapes.
- Relative wind, wave and current direction, speed and characteristics.
- Weathervaning capability of the FPS.
- Adequacy of fenders and mooring equipment.
- Transfer equipment design.
- Maneuverability of the offtaking tanker.

The design of the FPS mooring system should consider the offloading configuration as an operating condition. The environmental limits for alongside transfer operations should be verified by analysis or model basin testing.

Designers and operators should use increased caution if using an export tanker which has larger dimensions, draft ranges, and/or hull displacement than the FPS to which it will be moored. Geometry may make the side-by-side mooring difficult and result in a condition which may not have been considered in the design of the offloading equipment. Consequently, the design basis for the FPS mooring and export systems may be dominated by the offloading condition.

Alongside transfer from a spread-moored or compliant-type FPS is rarely used and is not recommended; however, if properly planned, both the FPS and its mooring system should be designed to absorb the maximum mooring and impact loads caused by the export vessel, and at the same time, allow the vessel to safely clear all mooring legs.

11.5.3 Fendering System

Fenders used for alongside offloading of a FPS should preferably be of a rubber, floating type filled with air or foam. In any case the fender should be designed to absorb the impact of the largest planned export vessel berthing alongside the FPS. Fenders should also be positioned to spread the impact force as evenly as possible along the sides of the FPS. The number and size of fenders used depends upon the maximum size of the export vessel expected to call on the FPS, and on its anticipated maximum approach velocity and angle when coming alongside. Smaller secondary fenders may be provided on the bow and stern for additional protection against impact from the export vessel while approaching or leaving the FPS.

Fenders may be tended by cables attached to dedicated, retractable davits mounted on the main deck of the FPS, or by cables rigged, through fairleads and rollers, to the FPSs mooring winches.

Fender handling equipment should be designed for the largest size and heaviest type fender to be used. An impact factor for dynamic loading should be at least 2.0 and should be in accordance with API SPEC 2C. Local buckling in the fender area should be checked and appropriate design considerations should be applied.

11.5.4 Offloading System

Transfer of oil between vessels moored alongside using one or more standard marine hoses should comply with the recommendations of OCIMFs *Hose Standards*.

Hoses can be tended by one or more cranes or A-frame structures, or by a gantry mounted on the main deck of the FPS. Hose-lifting devices should be capable of lifting the wet weight of the longest and largest string of hose required onto the largest export vessel expected alongside. These should also have a swing radius or cantilever which will allow them to span the cargo oil manifolds of the largest export vessel, and at the same time, reach a designated hose storage and maintenance area on the main deck of the FPS.

A bolster, curved plate, or similar should be used to prevent fraying of the hoses at the FPS side, and a self-actuated, breakaway coupling may be installed on each transfer hose string at the export tanker end to prevent hose failure from excessive tension or impact. If used, the coupling should be designed to minimize the spillage of oil upon disconnection to an absolute minimum.

Alongside transfers between vessels may also be accomplished using one or more marine loading arms mounted on the main deck of the FPS. The loading arm assembly is typically constructed using constant motion swivel joints and rigid piping components such that a powered movable pressure containing piping system can convey fluid. The design range of motion of the loading arm should be consistent with the mooring and fendering limitations and should accommodate the expected draft ranges and heave, roll and pitch motion between the tanker and the FPS. Automated connect and disconnect flanging using hydraulic couplers and a radio controlled handset allows additional maneuvering flexibility and safety. Automated tending is accomplished with position monitoring of the loading arm opening angles and may be electronically integrated with a dynamic positioning (DP) system. An alarm sequence using the position information and preset motion limitations should be programmed and linked to an emergency release system (ERS) on the end of the loading arm connected to the tanker manifold. Emergency disconnection from the tanker manifold is an OCIMF recommendation. This and other recommendations appear in OCIMF *Design and Construction Specification for Marine Loading Arms*.

Rapid drain piggable loading arms may be used in an emergency release system to reduce the risk of delayed response of conventional systems and reduce hydrocarbon spillage or slop volume. This philosophy incorporates similar control strategies discussed above for initiation of disconnection. The gas volume and type used to displace a pig and the hydrocarbon through the loading arm must be considered in the use of this method.

All low-pressure crude oil offloading or manifold piping installed on the FPS should comply with RCS standards for cargo oil piping. Should the shutoff pressure of any FPS offloading pump exceed the pressure rating of any hose, fitting, or loading arm, a relief valve should be installed on each offloading manifold or piping to prevent overpressuring of the downstream loading system. Each offloading manifold should be equipped with a catch basin or drip pan, and manifolds should be spaced and positioned according to the recommendations of OCIMF *Standards for Oil Tanker Manifolds and Associated Equipment*.

11.6 TANDEM TRANSFER

11.6.1 General

Tandem transfer is a commonly used low-pressure crude oil export system, which involves offloading of hydrocarbon from a FPS to a tanker which is moored in-line with the FPS. Vessels can be arranged bow-to-bow or bow-to-FPS-stern, and the transfer of hydrocarbons can be made through an above-water hose boom, a floating or submerged hose, or a hard pipe and swivel joint boom to tanker system. Compared to the alongside transfer method, the tandem transfer method can be used in harsher environments. The system offers better possibilities for quick disconnection and further separation between the vessels. Tandem transfer can be adapted for use with both a weathervaning or a spread moored FPS.

The offtake tanker can be moored to the FPS by one or more hawsers. A dynamically positioned (DP), thruster assisted, or supply boat/tug assisted tanker may improve the operational safety of the transfer operation. DP capabilities may also increase the operational limits.

11.6.2 Limitations

The tandem transfer method is weather-limited, but can transfer crude oil in environments with higher wave intensities than the alongside transfer method. Experience has shown that, if DP is employed to reduce hawser jerking (snapping), tandem transfer can be designed for waves typically 5 meters (about 16 ft.) significant height. The actual limiting wave height for mooring and loading operations depends upon the following:

- Distance between FPS and export vessel.
- Size of export vessel and FPS.
- Crosswind and current conditions.
- Type of FPS mooring system.
- Maneuvering space at the site.
- Export tanker station-keeping capabilities.
- Station keeping support vessel bollard pull.
- Degree of automation in the hawser and offloading connection.
- Location of manifold hose connection.
- Experience and skill of the marine personnel.
- Ability of operations staff to safely access connection/disconnection areas.
- FPS station keeping capabilities (fishtailing and surge control).

The export vessel can be larger in size than the FPS, and its limiting size depends on the strength of the FPS mooring system and the tandem hawser system. Tankers with side thrusters and/or dynamic positioning systems will impart lower loads to the FPS mooring system and can operate in higher wind and wave limits than vessels without these systems.

Tandem transfer hose systems are limited by the number of hose strings which can be used, the availability of hose sizes (usually 6 to 24 inches), and by the availability of FPS pumping capacity which can limit the size and length of hoses used. The size of floating hose strings may also be limited by the hose-lifting capacity of the export tanker.

Reverse thrust may be required while mooring a shuttle tanker to a FPS to provide stability in cases where environmental conditions make the two vessel system unstable or unsafe. Reverse thrust may be provided by the shuttle tanker itself or by a tug. Accommodations for emergency disconnection of the tanker should be provided.

11.6.3 Tandem Offloading Hose Design

Offloading hose length, dimension, and configuration will depend upon the following parameters:

- Environmental conditions.
- FPS and offtake tanker motions.
- Distance between vessels based on mooring requirements.
- Maximum amount of hawser stretch.
- Location of offloading manifold on the FPS.
- Location of loading manifold on the export vessel.
- Maximum freeboard of both vessels.
- Slack allowance.

It is recommended that an over-the-rail type hose be used for a horizontal hose/manifold connection where the hose end has to bend over the side of the vessel, and a reinforced- type hose be used for a vertical connection where the hose end hangs from the manifold connection.

Tail type hoses (e.g. dumbbell type) should be used in locations where the hose string is susceptible to kinking or continuous bending, such as at the waterline. Hose ends on the tanker end of the hose strings should be equipped with a hang-off chain, quick closing/opening fitting, blind flange, pick-up line and marker buoy.

One or more smaller size tail hose sections can be attached at the export end of the floating hose string to reduce its lifting weight. This is to ensure that all export vessels expecting to call on the FPS, especially the smallest in size, can safely lift the export end of the hose string out of the water for connection to its loading manifold. If hose maintenance is carried out on the FPS, there should be provisions for lifting and hoisting the heaviest, disconnectable floating hose piece onboard the FPS.

A duplex, dry break hose coupling should be installed at or near the export tanker end as a weak link on each floating hose string to prevent breakage of the string due to accidental overload in order to minimize spillage of oil. Drip pans should be installed under each loading and offloading manifold.

When the offloaded crude oil has a pour point higher than ambient or sea water temperatures, or has a high wax content, there should be means for flushing entire hose strings and offloading piping with sea water, or other low pour point, wax-free fluids. The flushing should be accomplished after each offloading operation is completed. As an alternate to flushing, the offloading system can be fitted with heat tracing, or rigged for re-circulation of warm oil to prevent build-up of wax or solidification of oil.

Arrangements should made in any case to flush the hose to a shuttle vessel or back into the FPS tanks for routine maintenance.

11.6.4 Above-Water Tandem Offloading System Design

The above-water method of tandem transfer differs from the floating or submerged hose method in that the offloading hose or hard pipe with swivels rarely touches the water and is supported by a boom extended from the FPS. The tanker and/or the FPS should be equipped with dynamic positioning thrusters or other means for station-keeping to maintain a safe distance between vessels. The safe distance between the two vessels, and the resulting loading system length, depends upon the reach and height of the boom, the amount of hawser stretch (if not DP) and on the tankers capability for maintaining accurate positioning on the boom.

A weak link and emergency disconnection means should be provided to prevent damage from accidental overload of the system.

11.6.5 Hawser Design

The hawser or mooring rope used for berthing an export vessel (except for alongside transfer) should be of a nylon, polypropylene or polyester material, and should normally be of a braided, eight-strand construction. A ship shaped FPS should be equipped with a quick-release hawser assembly connection, in case quick disconnection is needed. Hawsers should be sized and specified in general conformance with API RP 2SK and RCS Rules. Use of hawser tension load monitors and recording device is recommended, hawser angle with respect to the fairlead may also be monitored. Hawsers should be subjected to periodic inspection and testing at regular intervals.

11.7 SEPARATE OFFLOADING MOORING SYSTEM TRANSFER

11.7.1 General

Hydrocarbons can be offloaded under low pressure from the FPS to an export tanker through a separate, offloading mooring system connected to the FPS via risers and subsea pipelines. A separate offloading mooring system is used where separation between the FPS and the export tanker is important for safety reasons or in areas where space is too limited to allow safe tandem transfer.

The subsea connection between the FPS and separate offloading mooring system may be made with marine offloading hose, flexible pipe, and/or hard piping. A continuous, flexible pipe may be used between the FPS offloading manifold and the swivel on the separate offloading mooring system.

The offloading mooring system may be located in any direction away from the FPS. Minimum safe separation between the FPS and the offloading mooring will be determined by the environmental conditions, water depth, offloading tanker capabilities, operators operational safety philosophy and possible local regulation.

11.7.2 Mooring System Considerations

The size of the largest export vessel expected, the environmental conditions, and the bottom soil condition at the offloading centers will determine the type and size of mooring system used. The mooring system should be a quick connect/disconnect-type and should be designed to comply with Section 8 herein, API RP 2SK, and applicable RCS rules. A mooring analysis should be performed in accordance with the API RP 2SK recommendations to properly size the mooring system.

11.7.3 Riser System and Offloading Hose Considerations

The size of the largest export vessel expected, the environmental conditions, and the bottom soil condition at the offloading centers will determine the type of riser system and/or offloading hose used. The riser system and/or offloading hose should be of a quick connect/disconnect-type and sized for the offloading capacity required and should not exceed the maximum allowable capacity.

The riser should comply in principle with Section 9 herein, API RP 2RD, and applicable RCS rules. A riser analysis should be performed in accordance with API RP 2RD recommendations.

The design of the offloading hose system should comply with the OCIMF *Hose Standards*. The handling and storage of the offloading hose when not in use, is dependant on which offloading system is used, environmental condition, water depth, and operators philosophy. The handling and storage procedure for the offloading hose should be established to minimize wear and tear and minimize possibility for oil spillage. Where possible, the hose should be flushed after use.

11.7.4 Separate Offloading Mooring System Descriptions

Numerous systems for separate offloading mooring systems exist which have different specific features. The weather and operating limitations for these systems will vary, being dependent on the operating requirements and export tanker station keeping capabilities, such as dynamic positioning and thruster capabilities. Some of the wide variety of single point mooring systems are presented below.

a. *Conventional Buoy Mooring (CBM):* For relatively mild environments, shallow water and prevailing wind, a CBM may be used for mooring and loading the export vessel which will maintain one fixed heading. The system is a multi-point, spread- moored type which consists of a series of small mooring buoys arranged radially around the export vessel. The vessel is connected to the buoys by mooring lines which are passed from the vessel and are usually attached to a quick-disconnect hook on each buoy. Each buoy is anchored to the sea bottom. The export vessel should be aligned with the submerged offloading hose or riser, to prevent excessive stress on the riser or its PLEM under any motion or excursion of the vessel.

b. *Catenary Anchor Leg Mooring (CALM) Buoy:* The CALM buoy mooring legs are anchored to the seabed by anchors or piles, and the export vessel is connected to the surface CALM buoy by a hawser and floating hose string. A turntable and swivel allows the FPS to weathervane around the CALM buoy. An alternative design is where the CALM buoy itself is weathervaning around an internal turret in the buoy instead of the turntable and yoke arrangement.

c. *Single Anchor Leg Mooring (SALM) System:* Instead of multiple mooring lines a similar surface buoy with turret turntable, swivel, mooring hawser and offloading hose can be anchored with one mooring line chain. This system is referred to as single anchor leg mooring (SALM) system. Another SALM system places the turret turntable and swivel on the seabed on top of a suction anchor or pile anchor. The mooring line hawser and submerged loading hose is brought to the surface and connected to the export vessel. Required elasticity in the mooring system is provided by the mooring line itself and a midwater mooring line buoyancy element. In idle disconnected condition the system is laid on the seabed and only a pickup line is on the surface.

d. *Loading Platforms (FLP/ALP):* A spar buoy type mooring system with a surface weathervaning rotating platform deck with the offloading hose hanging down to the sea surface for pick up is a floating offloading system referred to as floating loading platform (FLP). A similar cylindrical column with a surface platform deck, but attached to the seabed with a universal joint arrangement on an anchor base is referred to as articulated loading platform (ALP).

e. *Submerged Turret Loading (STL) System:* The submerged turret loading system consists of a suitably shaped buoy with an internal turret. The buoy with the riser attached to the turret will float at a determined depth below the surface. A pick up line from the buoy will go the surface such that the buoy can be pulled into the dedicated export tanker with a matching receptacle cone and locked off. When the buoy is locked in place, the export tanker can then load in all specified design environment conditions. This system allows the STL to weathervane.

The above example systems and others can be used with both conventional tankers and DP operated shuttle tankers. DP operated shuttle tankers will increase the range of allowable operating conditions.

It should be noted that several other configurations exist which are in use in different areas of the world that are not covered by these examples. The examples presented above and illustrated in Figures 11.1, 11.2 and 11.3 are included for reference only.

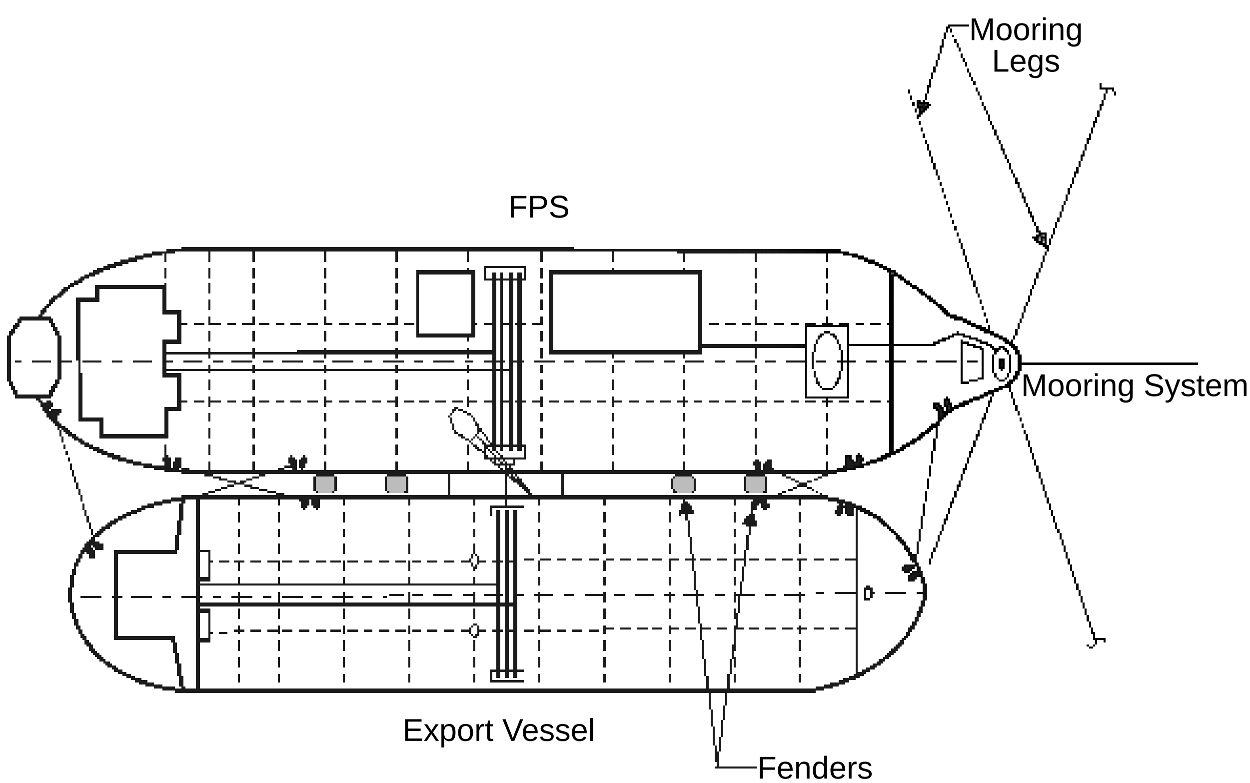


Figure 11.1—Alongside Transfer Export System

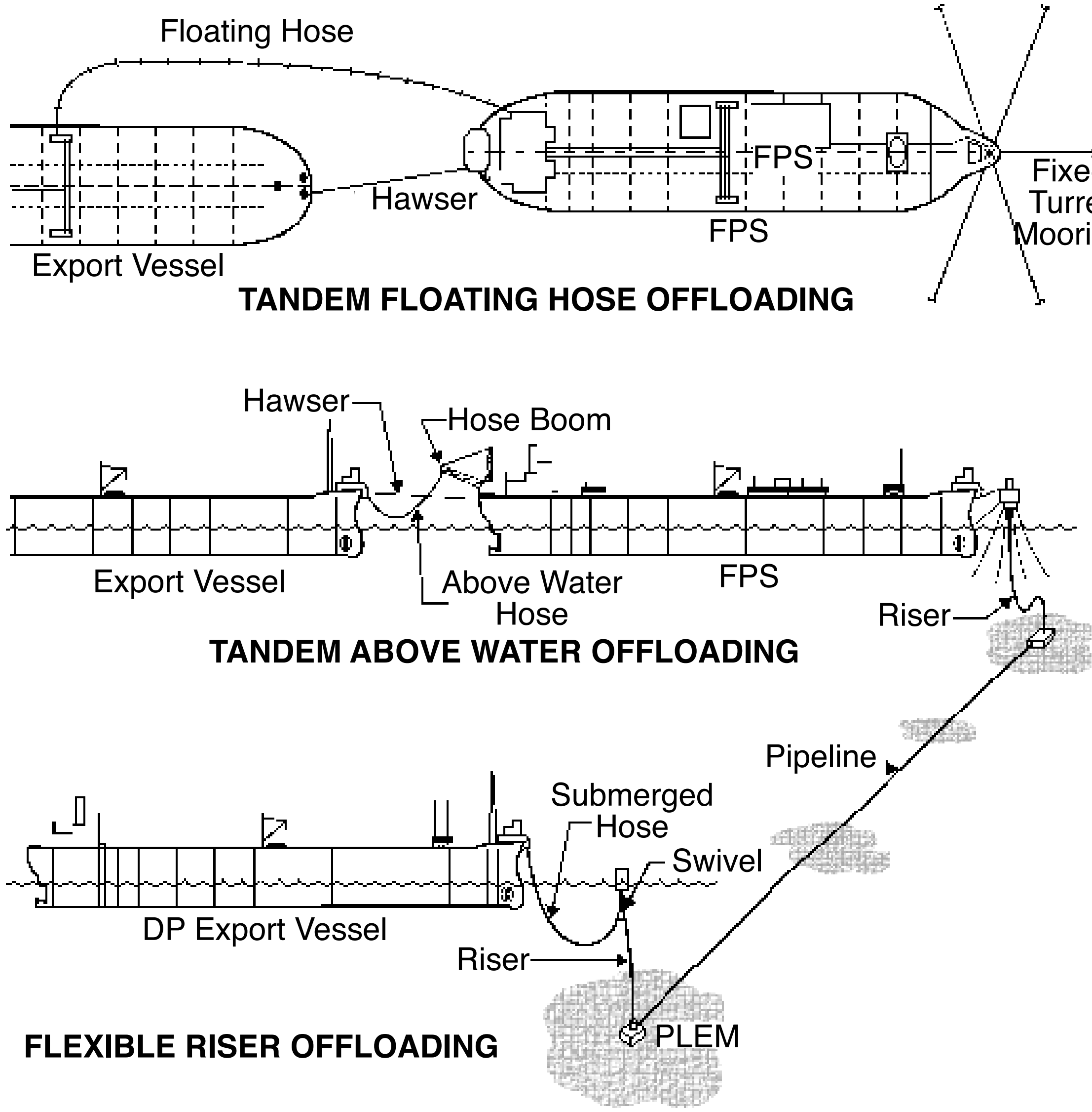


Figure 11.2—Tandem and Flexible Riser Export Systems

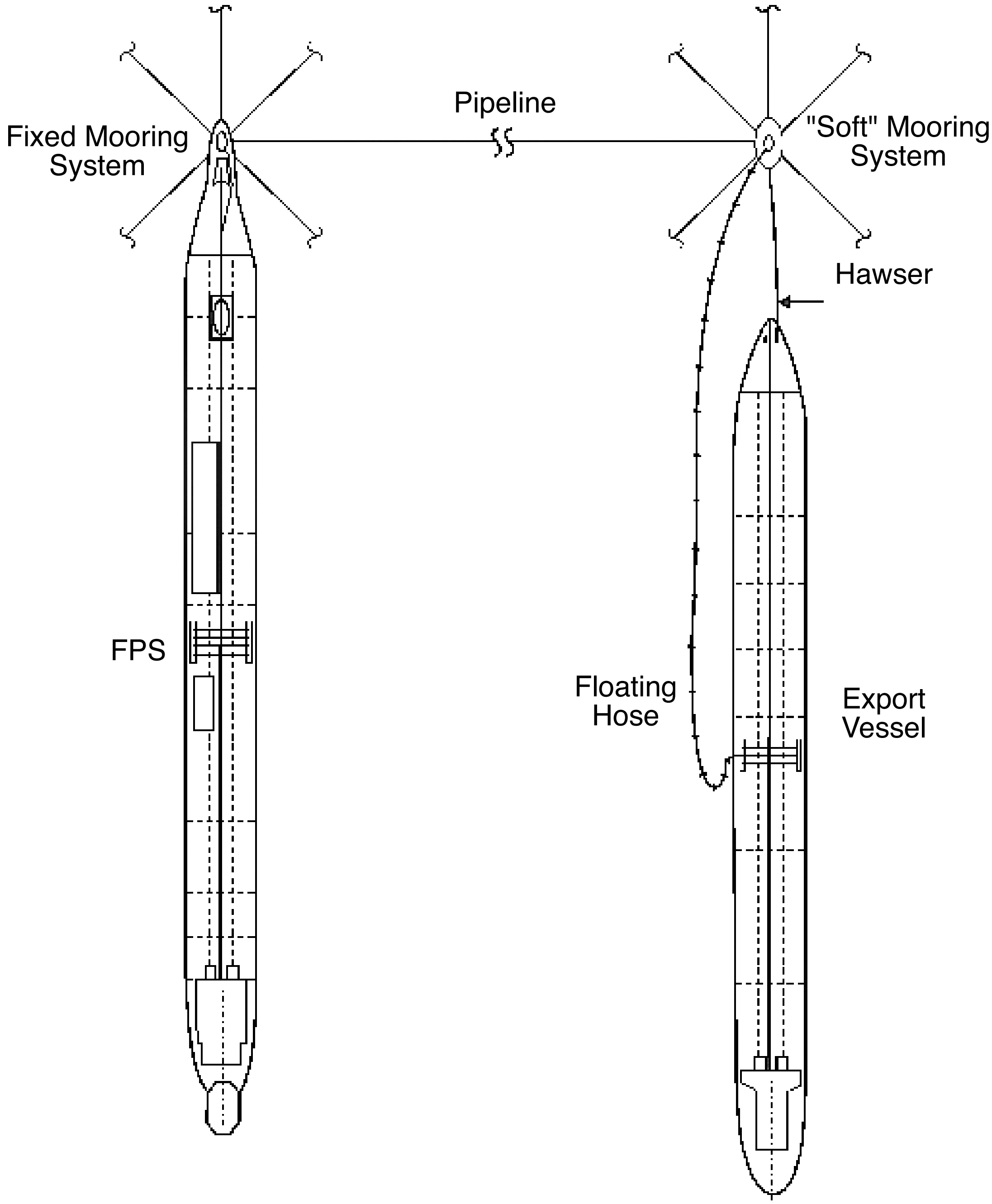


Figure 11.3—Separate Offloading/Mooring Export System

12 Fabrication, Installation and Inspection

12.1 INTRODUCTION

12.1.1 Scope and Objectives

This section addresses the fabrication, assembly, transportation, installation, and inspection of FPSs as defined in Section 1. Its objective is to provide recommendations on the conduct of these operations that are compatible with the other sections of this RP. The subsections on vessel fabrication are intended to apply to the construction of purpose-built floating production systems as well as new structural components of existing vessels being converted to floating production service. Reference is made to Section 7 for guidance on the conversion and reuse of existing floating vessels.

12.1.2 General Considerations

Fabrication, assembly, transportation, installation, and in-service inspection procedures should be defined during the planning phase of the project, to:

- Meet mission objectives.
- Ensure compatibility with design methods and assumptions.
- Identify design and loading conditions relevant to fabrication, installation and inspection phase, of the project.
- Comply with Owner, applicable classification, and regulatory requirements.

These procedures should be developed into detailed specifications during the design phase of the project. Close coordination between the engineer, fabricator, installer, RCS, (if one is involved), regulatory bodies, and the operator is essential in developing these specifications and ensuring their compatibility with the design basis specification. This coordination can be facilitated by the implementation of formal project quality requirements at the beginning of the project.

When developing these specifications, consideration should be given to ensure that:

- All work is carefully executed in accordance with quality, manufacturing, and testing procedures to assure that the work product meets design specifications and drawings. Faults and deficiencies should be corrected before the work product is painted, coated, or otherwise made inaccessible for inspection.
- Structural and mechanical integrity, and floating stability of the system are maintained during all phases of the project.
- Personnel safety is maintained during all phases of the project through established safety practices and the provision of personal safety equipment, temporary access and access protections, lighting, ventilation, fire fighting capability, etc., as required during all phases of the work.

12.2 STRUCTURAL FABRICATION—STEEL

12.2.1 General

This subsection addresses the fabrication of steel hull and deck structures utilizing structural materials and welding practices addressed in Section 13, RCS rules, or specifications designated by the owner.

12.2.2 Fabrication Specifications

Fabrication specifications should be developed for each structural system or subsystem and must be compatible with the structural design, welding and inspection standards used to design a system or a subsystem. These specifications should be developed in sufficient detail to ensure that assumptions contained in the relevant design, welding or inspection standard, or utilized in the design analyses (pertaining, for example, to structural tolerances, alignments, welding defects and detailing for adequate fatigue performance) are identified and satisfied during fabrication.

Where different standards and specifications are used for different structural subsystems, particular consideration should be given to defining fabrication requirements at the boundaries or connections joining such subsystems.

12.2.3 Tubular Structures

Fabrication of welded tubular structures, and associated fabrication tolerances, should be in accordance with Sections 8 (Material), 10 (Welding), and 11 (Fabrication) of API RP 2A.

12.2.4 Stiffened Flat Plates and Cylindrical Shells

Fabrication of welded stiffened plates and shells, and associated fabrication tolerances, should be in accordance with API BUL 2U and 2V, or other equivalent standard.

12.2.5 Plate Girders

Fabrication of welded plate girders, and associated fabrication tolerances, should be in accordance with Section 11 (Fabrication) of API RP 2A.

12.2.6 Ship Shape Structures

Fabrication of ship shape structures should be in accordance with RCS Rules or specifications selected by the Owner.

12.2.7 Fabrication Details

RCS Rules, Section 13 (Fabrication, Installation, and Inspection) of API RP 2T, and references identified in the Commentary can be referred to for guidance on the fabrication of structural details. Penetrations through load bearing structural members should be appropriately compensated and carefully detailed after consultation with the owner. Penetrations through structural members critical to structural integrity should be minimized, and areas where penetrations are prohibited should be clearly shown on fabrication drawings.

Splices in structural pipe, beams, and joint cans of tubular structures should be in accordance with Section 11 (Fabrication) of API RP 2A.

Temporary attachments to structural members should be treated in accordance with Section 11 (Fabrication) of API RP 2A; however, the owner shall designate critical locations (analogous to joint cans and stub ends on jackets) where flame cutting and mechanical smoothing should apply.

12.2.8 Other Fabrication Tolerances

Refer to Section 11 (Fabrication) of API RP 2A, for guidance on fabrication tolerances for deck beams, cap beams, grating, fencing and handrails, landings and stairs.

Special fabrication tolerances may be specified for special aspects of the design, e.g., mating a large deck to a spar hull.

12.3 Mooring System Fabrication

The user should utilize the existing industry codes and standards, where practical, in the manufacture and assembly of station keeping system components. The manufacturer should develop and use a comprehensive manufacturing and assembly process incorporating a total quality assurance and control system.

In general, fabrication should be in accordance with the applicable sections of API RP 2A, API RP 2T, API Bul 2U, and API Bul 2V and the specifications for the Design, Fabrication, and Erection of Structural Steel for Buildings, AISC. Welding and weld procedure qualifications should be in accordance with Section 13.

All components in any mooring liine (e.g., wire rope, chain, tri-plates) should be manufactured in accordance with API Standards or RCS Rules.

12.4 FPS Component Assembly

12.4.1 General

Assembly of the FPS components depends on the type of vessel involved, the system's design and the proposed fabrication and installation techniques. Refer to the recommendations of Section 13 (Fabrication, Installation, and Inspection) of API RP 2T pertaining to vessel assembly, erection sequences, dimensional and weight control, heavy lifts and, where applicable, hull and deck mating operations.

Where API documents are not applicable, the Owner can consult the RCS for guidance in the assembly of FPS components.

12.4.2 Assembly Plans

All aspects of FPS component assembly operations should be carried out in accordance with a pre-established plan. This plan should detail the procedures for assembly of all FPS components, and should consider any limitations inherent in the equipment, or in systems used in assembly operations, and in personnel safety.

12.5 TRANSPORTATION

12.5.1 General

Details for the transportation of the FPS components, from the fabrication assembly site to the installation site, should be planned concurrently with the structural design in order to clearly define loading conditions occurring during the transportation phase of the project. An assessment should be made of the cumulative fatigue damage to structural members which may be expected to occur during transportation. Where such damage is predicted to be significant, it should be included in the calculation of life cycle fatigue damage.

This planning should include the identification of requirements and documents which will be required by port and flag state regulatory authorities when the components depart the fabrication location(s). Classification Societies, marine warranty surveyors, and the coastal state regulatory authorities which have jurisdiction over the installation site, may require certification/documentation appropriate to the transportation operations, equipment and routes involved.

Transportation planning should also address route selection, the severity of weather and sea conditions which may be encountered en route, the need for weather forecasting or weather routing services during the actual transportation operations, and the need for contingency plans en route.

12.5.2 Vessels

Vessels may be transported under their own propulsion, aboard a self-propelled heavy lift vessel, towed while afloat (wet tow), or towed on a cargo barge.

Newly constructed self-propelled vessels should undertake sea trials comparable to those required of newly constructed ships, prior to departing for the installation site. Existing self-propelled vessels converted to floating production service may have their propulsion, electrical and/or bilge and ballasting systems significantly modified during conversion. Such vessels should undertake sufficient sea trials to verify their operability during transportation to site.

Operations for the transportation of vessels by wet towing should be in accordance with Section 13.5 (Transportation) of API RP 2T.

Operations for the transportation of vessels aboard heavy lift vessels or deck cargo barges should be in accordance with the relevant recommendations of Sections 12.2 (Transportation) and 12.3 (Removal of Jacket from Transportation Barge) of API RP 2A.

Consideration should be given to the provision of temporary mooring or other station keeping equipment for use en route and once the platform has arrived at the installation site.

For spar type of hull, various types of transportation are possible. The entire spar hull or spar hull segments may be transported dry from a first stage fabrication yard to a final assembly location for final joining of multiple hull segments into one complete hull, outfitting, etc. From the final assembly location to the final installation site, the spar hull can be towed either wet or dry. For a wet tow, the operation should be made in accordance with the normal ocean tow practice for regular offshore platform structures. For a dry tow, the spar hull can be launched from the tow vessel or floated off from the tow vessel after the tow vessel is submerged. All these operations should be carried out in accordance with a pre-established detail plan. The plan should include all the procedures, equipment required, and contingencies and be made as specified in paragraph 12.6.1.

As part of the transportation planning, detail engineering analysis should be carried out to verify the suitability of the proposed transport methods. In certain cases, a model test program may be required to validate the analytical results or to confirm the procedures. In particular, analyses are to be performed to determine the loads that the spar will be exposed to during the various proposed transport operations.

12.5.3 Other Components

Operations for the loadout, transportation and offloading of other FPS components which will be installed or assembled at the installation site should be in accordance with the relevant recommendations of Sections 12.2 (Transportation) and 12.3 (Removal of Jacket from Transportation Barge) of API RP 2A. Such components may include topsides modules, risers, flowlines, or components of the vessel's mooring system, such as anchors, anchor piles, or mooring lines. Transportation and handling operations require careful planning and evaluation to ensure that the components, their coatings, anodes and other appurtenances are not damaged.

12.6 INSTALLATION OPERATIONS

12.6.1 General

Installation of a FPS typically includes the following activities:

- Site survey.
- Development of an installation plan.
- Installation of subsea well template PLEM and/or other subsea components on site.
- Installation of mooring system.
    - Spread mooring or
    - CALM system deployment and attachment to FPS or,
    - Turret System deployment and connection to FPS
- Installation of riser systems.
- Installation and Hook-Up of Well Production, Utility, Process, and Export Systems.
- Commissioning and start-up of FPS.

12.6.2 Site Survey

Prior to the initiation of installation operations, a survey of the proposed installation site should be carried out. This should include a sea bottom survey to ensure that no recent changes to the installation area (such as debris and cuttings, sea bed movements) have occurred that could prevent installation of the sea floor components.

12.6.3 Installation Plan

A plan outlining the methods and procedures should be prepared for each activity associated with the installation of the FPS. This may be in the form of a written description, specifications, drawings, and/or engineering reports. Restrictions or limitations to any of the installation operations due to environmental conditions, vessel hydrostatic stability, vessel motions, structural strength, lifting capabilities, etc., should be stated. The plan should define weather conditions, equipment status and logistic support under which installation operations should be:

- Initiated
- Suspended
- Terminated
- Reversed for each major phase of the procedure

Since the complete installation consists of various activities which may be carried out in phases, the party responsible for executing an installation phase should be responsible for preparing the installation plan for that phase.

For marine operations which are part of the installation procedure, the owner should carry out engineering analyses verifying the suitability of the FPS design for various phases of the installation operation. In certain cases, a model test of installation procedures may be required to confirm analytical results. In particular, analyses are to be performed to determine type and magnitude of the loads and load combinations to which the structure will be exposed during the various marine operations. Due attention should be given to inertial and local loads which are likely to occur only during these operations.

Engineering analyses are to be performed to ensure that the FPS structure and any temporary attachments or appurtenances (e.g., tie-downs, skid beams) necessary for successful performance of the installation operations are of sufficient strength to withstand the type and magnitude of the loads and load combinations as noted earlier. Whenever a floating vessel is involved in any marine operations, the owner should check the ballasting arrangement for desired draft, heel and trim conditions. The owner should also check the adequacy of the hydrostatic stability of the vessel in every load condition envisioned during the operations.

Comprehensive contingency plans covering all phases of the installation should be included in the installation plans and procedures. The owner should develop the contingency plans in such a way that each phase of the installation operations could be reversed if a malfunction occurs.

12.6.4 Installation of Mooring System

The mooring system should be installed as outlined in the installation plan specific to that operation. The plan should specify each mooring line length and the coordinates of seabed anchors or piles.

A CALM system would require the installation of the mooring legs of the buoy first and subsequent connection of the buoy to the FPS by hawser or yoke.

A turret mooring system may be internal or external to the vessel, and may be either fixed or disconnectable. For a fixed turret system, the installation scenario would be similar to that of a spread mooring system such as used on a CALM. A disconnectable turret mooring system will require two phases of installation: first, installing the turret and its mooring legs; and then, connecting them to the vessel in accordance with the installation plan.

12.6.5 Installation of Riser Systems

Procedures for running risers should be developed considering the following factors:

- Water depth.
- Type of riser system (e.g., integrated or non-integrated surface, or subsurface completion, etc.).
- Type of connections and latching devices.
- Whether buoyancy is included (either internal or external air cans or foam).
- Whether guidelines are to be used or not.

12.6.6 Well Production, Utility, Process, and Export Systems

Well production, utility, process and export systems should be installed and hooked-up in accordance with the applicable requirements of API RP 14C, API RP 14E, API RP 14F and API RP 14G. The process flow diagrams, process and instrumentation diagrams (P&ID's), piping drawings, schematics, arrangements drawings, and associated specifications should be strictly followed during the installation and hookup of these systems.

12.6.7 Commissioning and Start-up of FPS

Start-up and commissioning of the FPS should be carried out following the procedure outlined in the specific plan for this operation. The owner should develop procedures to address all aspects of commissioning, start-up, and associated safety and execution procedures.

12.7 INSPECTION AND TESTING

Inspection and testing during fabrication and installation should be performed in accordance with API RP 2A or RCS Rules as applicable.

13 Materials, Welding, and Corrosion Protection

13.1 INTRODUCTION

13.1.1 Purpose and Scope

This section defines certain materials appropriate for the design and construction of FPSs.

13.2 STEEL

13.2.1 General

In general, the materials to be used for the construction of FPSs should follow the requirements and guidelines of the following:

- API RPs, (RP 2T, RP 2A, etc.).
- API Specifications (2H, 2W, 2Y, etc.).
- ASTM Specifications (A131, etc.).
- European Normatives (EN 10025, EN 10225, etc.).
- NORSOK.
- RCS Rules.

When referring to API RP 2A or API RP 2T, it should be noted that groups III and IV steels are generally not recommended due to fatigue considerations. Their use should be considered carefully. Impact test temperature requirements should be based on the Lowest Anticipated Service Temperature (LAST) and should be similar to those specified. Materials for the construction of chains should be in accordance with API Spec 2F and RCS requirements for materials for chain construction. Material fracture toughness requirements and weldability provisions in the design codes should be compared and stipulated for floating production equipment. For high stress connections, use of a higher strength and toughness should be considered. For connections that load the steel perpendicular, use of through thickness steels to avoid lamellar tearing would be appropriate.

13.2.2 Welding

The welding of steel for FPSs should follow good industry practices such as those outlined in API RP 2A, API RP 2T, and AWS Structural Welding Code D1.1 Guidance can be found in RCS Rules and guidelines for the construction of steel ships.

The welding specifications for a FPS should be developed to meet the requirements of the rules, specifications or guidelines designated by the owner.

13.3 CORROSION PROTECTION

13.3.1 Corrosion Protection for Steel

13.3.1a General: Structural steel in ballast and drillwater tanks is subject to higher corrosion rates and should be adequately protected from corrosion during the design life by an appropriate combination of coatings and sacrificial anodes. The exterior hull surface below the waterline should be protected by any one of (or a combination of) coatings, sacrificial anodes, and/or impressed current.

The steel materials should be protected from the effects of corrosion by using corrosion protection systems designed in accordance with:

- NACE Standard RP0176-94
- RCS Rules

For FPS in cold water locations, RCS rules should be used to account for water temperature and resistivity. The various corrosion protection systems available include special coatings, cathodic protection, material corrosion allowance, and corrosion monitoring.

Over protection of steel with cathodic systems may cause hydrogen embrittlement and should be avoided.

13.3.1b Antifouling: In geographical areas where marine fouling is significant, and organisms are active, the use of antifouling coatings may be considered to reduce marine growth, subject to local regulatory requirements.

13.3.1c Electrical Bonding and Isolation: To prevent damage from cathodic protection or stray currents, mechanical interfaces with equipment external to the FPS should be electrically bonded. Examples of such interfaces include:

- Fluid and electrical swivels and turret mooring systems
- Chain hawsers and stoppers
- Electrical cables

For station keeping systems which use wire ropes as part of the mooring system, it is recommended that the end sockets be electrically isolated to prevent the galvanized wire from acting as an anode for the adjacent components.

13.4 CEMENT GROUT

The requirements of cement grout as a material should be in accordance with the recommendations set forth in Section 8.4 (Cement Grout and Concrete) of API RP 2A.

13.5 ELASTOMERIC MATERIALS

Elastomeric materials may be used in the articulating elements of flexible joints. Selection of a material is highly dependent on the user's specifications and the design of the flexible joint. For these materials the user should follow the recommendations stipulated in Section 14.9 (Elastomeric Materials) of API RP 2T.

14 Risk Management

14.1 GENERAL

Accidents and extreme environmental events may result in injury, fatality, and environmental and property damage consequences. Risk management can be used to assess and maintain risks within acceptable levels. Risk assessment techniques can be used to evaluate frequencies and potential consequences of accidents during the life cycle of a floating production system [Ref. 1, 3]. The purpose of this section is to describe the basic elements of a risk assessment and to identify the FPS subsystems that may require special attention. This section does not provide detailed guidance on risk assessment methods, only a general overview.

Further guidance on risk assessments can be found in API RP 75 and the API RP 14 series. References that provide background material and guidance in the risk assessments applications are listed in the Commentary.

14.2 TERMS AND DEFINITIONS

accident: A circumstance that gives rise to injury or fatality, or environmental or property damage, or production losses or loss of facility.

consequence: The effects of an accidental event such as injuries, fatalities, and environmental and property damage.

event tree: A graphical representation of the relation between a primary cause (initiating) event and the final undesired events. Event trees are generally time dependent and rely on a sequence of events.

fault tree: A graphical method of describing the combination of events leading to a defined system failure.

hazard: An event with the potential to cause injuries and fatalities, environmental damage or property damage.

initiating event: Hardware failure, control system failure, human error, extreme weather or geophysical event, which could lead to hazards being realized.

probability: The likelihood of occurrence of a specific event.

reliability: The probability of an item or system to adequately perform a required function under stated conditions of use and maintenance for a stated period of time.

risk: The product of the probability of occurrence of a hazardous event and its consequence(s).

14.3 APPLICATIONS TO FPS

Design of FPSs, especially in deepwater, may include novel components, materials, or configurations. Deepwater floating systems may exhibit complex interactions among structural, mechanical, and process systems; all of which are affected by environmental conditions and human interventions. Risk assessment is a useful tool for understanding the overall behavior of a FPS including the interactions among its subsystems.

Risk assessment methods are also used to evaluate and sort the risks and implement mitigation measures, where applicable. Risk management process is a continuous improvement tool which can be effectively integrated into all phases of a facility's life cycle: concept selection, preliminary and detailed design, fabrication and installation, operations, and abandonment. Generally, the benefits from risk assessments and mitigation measures are higher in early phases of a life cycle where design changes can be easily implemented at low cost.

Figure 14.1 presents an overall schematic of the risk management process. The following sections provide a short summary of the associated activities in this process.

14.3.1 System Review

First step in a FPS risk assessment process is a review of its characteristics such as layout, system designs, operational plans, safety systems, and emergency escape and evacuation plans. Such a review may also include field information (e.g., distance to shore for evacuation), crude characteristics (e.g., gas-oil- ratio), and the list of planned activities. Upon completion of the review, the platform can be split into several clearly defined subsystems and/or activities for the purpose of the risk assessment. Table 14-1 lists typical examples of FPS subsystems that may be considered in a risk assessment and also related issues for each subsystem.

14.3.2 Hazard Identification

The objective of Hazard Identification (HAZID) is to identify the potential hazards, i.e., the events that could have direct risk impact or escalate through a chain of events and lead to accidents. A HAZID uses systematic procedures such as:

Checklist Checking against known concerns in similar systems.

What-If Brainstorming session involving scenario/accident postulation, using experience of participants.

HAZOP Hazard and operability evaluation which has historically been applied to process facilities and marine/hull systems.

FMEA Identification of single point failures and their mode and effect.

API RP 14J provides guidance and examples of a simplified checklist and a detailed checklist for analysis of facilities. FPSs can have various configurations and operational plans that could change the list of significant hazards. Thus, specific checklists and questions should be developed for each FPS to identify potential design errors and hazards. Table 14-2 lists several typical examples of hazards and initiating events that can lead to accidents in FPSs and also related issues that should be considered in a risk assessment.

14.3.3 Risk Estimation

In this step, frequency of occurrence of hazardous events, the likelihood of escalation into further accidents, and the magnitude of potential consequences are evaluated. The methods used could be qualitative or quantitative depending on the system definition and the objectives of the risk assessment.

The initiating event frequencies and conditional probabilities of the chains of events leading to accident scenarios are established using historical databases and fault tree, event tree, or reliability analysis techniques. Historical databases are available for several equipment types, many having significant years of offshore applications providing reliable frequencies.

Historical databases are frequently used when assessing the probability of blowouts, oil and gas leaks in process equipment, failure of pumps and generators, and leakage from risers and pipelines [Ref. 4–8]. The data available from these sources are most often generic and may not account for the specific equipment features or operating environment being considered. Therefore, judgment is necessary in applying historical data and the historical frequencies may have to be adjusted.

Fault tree analysis is typically used to assess the frequency of failure of a sub-system or the probability of occurrence of an event [Ref. 3, 9–11]. Event trees are often used to determine the likelihood of an event escalation and the associated consequences. Reliability analysis techniques are typically used to determine the probability of failure of a component or system such as a mooring line, mooring system, FPS hull structure, and risers subjected to a single event type such as dropped objects, vessel impact, or extreme environmental conditions (Refs. 11–13).

Consequence analysis involves analyzing the range of possible outcomes of an accident or initiating event. Consequences are typically evaluated in terms of injuries, fatalities, and environmental and property damage. Consequence analysis can be carried out in either a qualitative or quantitative manner.

Qualitative consequence analysis typically involves a verbal development of an accident scenario and then evaluation of its consequence intensities. This approach is commonly practiced using a risk matrix approach as described in Section 14.3.4.

Quantitative consequence analysis results in the quantification of the consequences of an accidental event. The consequence calculations are generally deterministic and predict the physical circumstances relating specifically to a given accident scenario identified from risk analysis (e.g., explosion over-pressure, radiation levels, or impact energy from a ship collision) and the injuries, fatalities, and environmental and property damage resulting from this accident.

Different methodologies and models are often used to quantify the consequences [Ref. 3, 15, 17]. Examples of analysis models include: dispersion of a toxic or flammable gas cloud, smoke movement, fireball, boiling liquid expanding vapor explosion (BLEVE), flash fire, jet fire, pool fire, and vapor cloud explosion, and energy absorption in a ship impact.

14.3.4 Risk Evaluation

Risk can be measured as a product of the frequency of occurrence of a hazardous event and its consequence(s). Qualitative and quantitative risk evaluations can be performed using a risk matrix showing the frequency of occurrence versus level of consequence. The selection of levels (categories) of frequency and consequence depends on the operator, and these must be defined at the start of the risk analysis. An example representation of a risk matrix is shown in Figure 14.2. Different matrices may be used at different stages of the analysis.

The definitions of different frequency categories could be related to range of probabilities. The consequences could be defined by degree of impairment of safety functions affecting personnel injuries or fatalities, barrels of oil spilled, or number of days of production loss.

Based on the position in the matrix, a risk classification such as low, moderate, and high may be used to decide the risk potential from an individual hazard. For example:

- *Low risk (L):* insignificant or minimal risk that need not be further considered and can be tolerated because of low potential for escalation and impact on personnel and environment.
- *Moderate risk (M):* risk level requiring implementation of reasonable and practicable risk reducing measures, or more detailed analyses to better define frequency and consequences.
- *High risk (H):* risk must be mitigated by means of risk reducing measures or through change(s) in design.

In the early phases of concept development, risk assessment is normally performed through qualitative categorization of frequencies and consequences. In later phases, the systems are better defined and, depending on the availability of data, a quantitative risk assessment may be used.

14.3.5 Risk Acceptance

Risk acceptance involves deciding whether a risk is tolerable and/or whether risk reduction measures are needed. Tolerable risk levels should provide a balance between absolute safety requirements and cost/benefits of proposed risk reduction measures. Acceptability of risk is generally determined by comparing risk of a FPS against the acceptable risks established for similar or other offshore systems with acceptable operating experience or with those established by other industries. There are typically many other factors that can affect acceptance criteria such as regulatory regime, novelty of a design, or the operator's ability to accept higher financial risks.

14.3.6 Risk Reduction.

If a tolerable risk level is not achieved in the risk assessment process, the next step is to identify risk reducing measures and evaluate their potential to reduce the risks to a tolerable level. Risk assessment is an iterative process, i.e., it needs to be repeated considering the changes in the system until a tolerable risk level is achieved.

When reducing risks, consideration should be given to (Refs. 2, 3, 14, 16, 17, 18):

- Achieving inherent safety by design improvements, e.g., eliminating the hazard or its frequency.
- Providing safety measures to control the propagation of an event into a major accident.
- Providing improved facilities for escape, evacuation, and recovery.
- Installing risk mitigation equipment to reduce the severity of consequences.
- Improving safety through risk prevention procedures and safety training.
- Response to incidents, particularly early warning/near misses.

The effectiveness of risk reducing measures will depend upon the design maturity and operations of an installation. The cost of implementing any changes resulting from a risk assessment increases progressively as the development progresses from concept selection to design, installation, and operations. For example, risk reducing measures in each phase may include:

- *Concept screening:* changes in layout of facilities or configuration of the FPS. These will have a large impact on overall safety and cost.
- *Preliminary design:* design changes for each subsystem to ensure that the safety goals are met.
- *Detailed design:* implement recommendations from HAZOP of process facilities and risk assessment of installation procedures.
- *Construction (fabrication, transportation, installation, hookup, commissioning and start-up):* develop and implement appropriate safety procedures to avoid accidents caused by human errors.
- *Operations:* ensure availability of detailed safety manuals and absolute commitment to safety on the platform. Perform escape and evacuation drills.

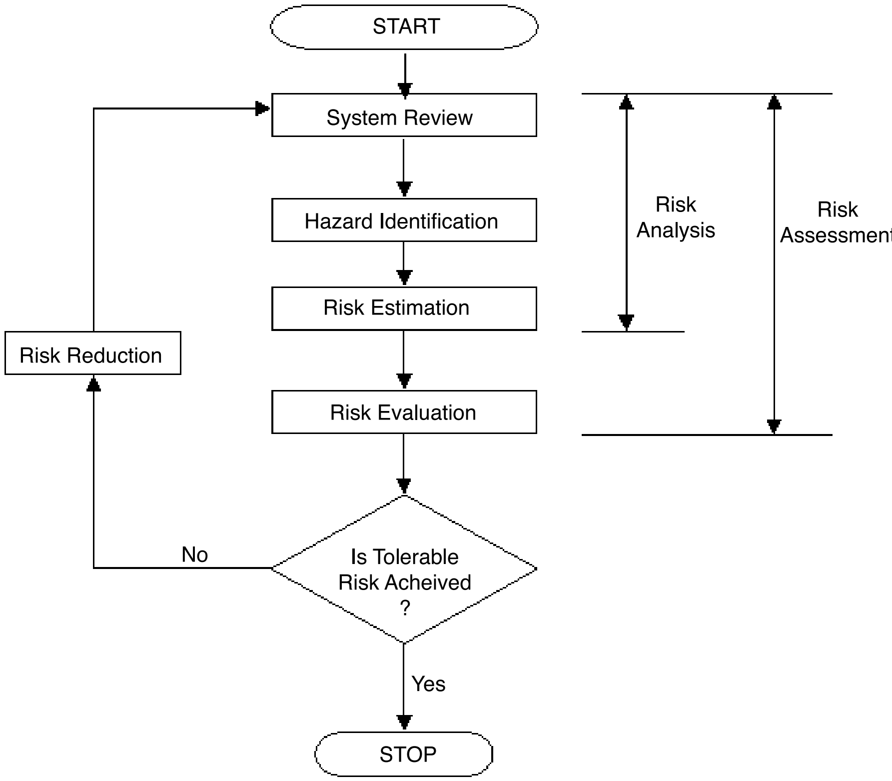


Figure 14.1—Risk Management Process

Frequency

High	M	H	H	H
Medium	L	M	H	H
Low	L	L	M	H
Remote	L	L	L	M
	Minor	Severe	Critical	Catastrophic

Consequences

High Risk	(H)
Medium Risk	(M)
Low Risk	(L)

Figure 14.2—Example Risk Matrix

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Table 14.1—Examples of FPS Subsystems in a Risk Assessment

Subsystem	Example(s) of FPS Related Issues
Drilling	Well control, equipment handling
Catenary Risers	Pigging, VIV, riser/seabed interaction
Top-Tension Risers	Strength and fatigue, intervention, vortex induced vibrations, falling objects, maintaining top tension
Wellheads, X-mas trees	Strength and fatigue, pressure leakage
Marine systems	Ballast control, collision avoidance
Storage/Offloading	Inert gas system
Station keeping	Dynamic positioning, mooring and foundation reliability
Process facilities	Blast, fire, escape time
Safety/Emergency Systems	Flare, escape and evacuation

Table 14.2—Examples of Potential Initiating Events for FPSs

Hazard	Example of FPS Related Issues
Blowout	Distance from shore influencing well control and personnel evacuation
Process Fire & Explosion	Escalation and impact on hydrocarbon inventory and personnel on-board‘
Riser/Flowline Failure	Potentially large inventory in risers as one falls to seabed
Vessel Explosion & Fire	Explosions in a confined space
Ship Collisions	Loss of stability
Station-Keeping Failure	Riser damage and potential drifting of vessel
Structural Failures	Water ingress into the hull

COMMENTARY - GENERAL

Several industry standards are referenced throughout this document. For the convenience of the user, these standards are listed here.

API

RP 2A	See RP 2A-WSD
RP 2A-WSD	*Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms–Working Stress Design*
Spec 2C	*Specification for Offshore Cranes*
RP 2F	*Specification for Mooring Chain*
RP 2I	*Recommended Practice for In-Service Inspection of Mooring Hardware for Floating Drilling Units*
RP 2L	*Recommended Practice for Planning. Designing, and Constructing Heliports for Fixed Offshore Platforms*
RP 2N	*Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions*
RP 2R	*Recommended Practice for Design, Rating, and Testing of Marine Drilling Riser Couplings*
RP 2RD	*Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)*
RP 2SK	*Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*
RP 2SM	*Recommended Practice for Design and Analysis of Synthetic Moorings*
RP 2T	*Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*
Bul 2U	*Bulletin on Stability Design of Cylindrical Shells*
Bul 2V	*Bulletin on Design of Flat Plate Structures*
Spec 9A	*Specification for Wire Rope*
RP 9B	*Recommended Practice on Application, Care and Use of Wire Rope for Oil Field Services*
RP 14C	*Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms*
RP 14E	*Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems*
RP 14F	*Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1 and Division 2 Locations*
RP 14G	*Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms*
RP 14J	*Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities*
RP 16Q	*Recommended Practice for Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems*
RP 17A	*Recommended Practice for Design and Operation of Subsea Production Systems*
RP 17B	*Recommended Practice for Flexible Pipe*
Spec 17D	*Specification for Subsea Wellhead and Christmas Tree Equipment*
Spec 17E	*Specification for Subsea Production Control Umbilicals*
RP 17G	*Recommended Practice for Design and Operation of Completion/Workover Riser Systems*
RP 17I	*Installation Guidelines for Subsea Umbilicals*
Spec 17J	*Specification for Unbonded Flexible Pipe*
RP 57	*Offshore Well Completion. Servicing, Workover and Abandonment Operations*
RP 75	*Recommended Practice for Development of a Safety and Environmental Management Program for Outer Continental Shelf (OCS) Operations and Facilities*
RP 500	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*
RP 505	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*
RP 520	*Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries, Part II, "Installation"*
RP 521	*Guide for Pressure-Relieving and Depressuring Systems*
RP 1111	*Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines*

API Manual of Petroleum Measurement Standards

ABS[1]

Rules for Building and Classing Steel Vessels

Rules for Building and Classing Mobile Offshore Drilling Units

Rules for Building and Classing Offshore Installations - Part I, Structures

Rules for Building and Classing Single Point Moorings

Guidelines for Building and Classing Facilities on Offshore Installations

Guide for Building and Classing Floating Production, Storage and Offloading Systems

Guide for Underwater Inspection in Lieu of Drydocking Survey

Guide for Building and Classing Floating Production Installations

Offshore Mooring Chain Guide

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Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings

ASTM[5]

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D1.1	*Structural Welding Code—Steel*

CFR[8]

33 *CFR*	Navigation and Navigable Waters
46 *CFR*	Shipping

DNV[9]

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COMMENTARY—COLUMN STABILIZED UNITS (Section 3)

3.4.2 A design wave approach is recommended for structural stress analysis of FPSs to calculate maximum stress. This design wave approach preserves the merits of the stochastic approach by using the maximum expected stochastic values of some characteristic response parameters in the selection of design wave parameters.

The sequence of major steps in this design wave approach is as follows:

1. Select and define the characteristic responses and corresponding wave headings for the specific platform design. This may be developed according to experience gained from a similar structure or experience derived from the stochastic design approach. Examples of characteristic responses which normally govern for the global analysis of twin hull column stabilized vessels are:
   - Split force between the pontoons.
   - Torsional moment about a transverse horizontal axis.
   - Longitudinal shear force between the pontoons.
   - Longitudinal acceleration of deck mass.
   - Transverse acceleration of deck mass.
   - Vertical acceleration of deck mass.
2. Develop the transfer function of the chosen design characteristic loads.
3. Derive the most probable characteristic loads using the stochastic short term response analysis.
4. Calculate the characteristic wave length (or period) for each of the design wave cases. Normally, the wave length should correspond to the peak-wave-length or slightly higher.
5. Calculate the characteristic wave amplitude, derive from the most probable largest response amplitude and the value of the transfer function corresponding to the selected wave length (or wave period).
6. Derive the detailed hydrodynamic loads for the selected design wave cases (pairs of characteristic wave amplitude and period). The method for generating detailed hydrodynamic loads are described in Section 6 (Environmental Forces) of API RP 2T.

Each load case corresponding to one wave length (or period) and one wave heading should be calculated at two time instances, called a real and an imaginary part. The real part may correspond to a wave crest amidship and the imaginary part to a wave zero- crossing at the same point.

COMMENTARY—STATION KEEPING AND ANCHORING SYSTEMS (Section 8)

The following describes some of the experience gained by industry in overcoming the deepwater mooring design challenges. It is the intent of this section to only discuss these issues for information purposes with the full recognition that these are frontier areas of emerging technology providing unique solutions on a case by case basis. The absence of long industry experience warrants that the design and installation of these systems be considered with an added degree of thoroughness to assure reliable performance.

Taut Leg Mooring Systems. The conventional catenary mooring systems work primarily by the catenary action of the mooring lines. Mooring systems provide a restoring force, which controls the large offsets from mean environmental loads and low frequency offsets, but do not restrict the wave frequency motions. The anchors for conventional catenary mooring systems are designed to take only horizontal loads, which in turn require that there is some length of mooring line lying on the seabed under all load conditions.

In contrast, for a taut-leg mooring system, the restoring force comes from stretching of the mooring lines. Taut mooring systems induce some vertical pull on the anchor, which reduces the line length and the mooring footprint considerably. The anchor must be designed to accept both horizontal and vertical loads.

Vertically Loaded Anchors. The anchor system for a taut-leg mooring needs to withstand significant vertical loading. Several innovative concepts have been proposed, which has resulted in the emergence of two common designs. The first group relies on design modification to conventional anchors for vertical load bearing capability, and the second group relies on suction piles.

Some of the conventional high holding power anchor designs have been modified to withstand vertical loading (Ref. RP 2SK, Appendix B.6); however, one needs to recognize that these are still drag embedment anchors, and the vertical load resistance is somewhat limited. The designer may note that Joint Industry Projects performed in the late 1990's have contributed significantly to the development of knowledge in this area, and they may like to refer to the conclusions of the following Joint Industry Projects:

- Vertical Loaded Anchor Joint Industry Report, Aker Maritime, Inc., 1993.
- DNV's DEEPANCHOR Joint Industry Project for developing design criteria of plate and fluke anchors.
- Norsk Hydro's Joint Industry Project on Alternate Mooring Concepts (addresses plate anchors).

Another proven design for withstanding vertical uplift loads are the driven or suction embedded pile anchors. The suction embedded anchors are also referred to as caisson foundations in some literature. The suction embedment is a very attractive solution for deepwater installation, where the anchor can be driven to the required depth by the use of an ROV and the installation vessel lowering the anchor. A good summary of suction pile anchors installed in various offshore FPS moorings is provided by Sparrevik (Ref. 1). That paper details a history of suction pile anchors.

Mooring Rope Types. Steel wire ropes are considerably lighter than mooring chain, but are still heavier than synthetic ropes such as polyester. In service performance of steel ropes are well known to the industry, whereas polyester ropes are only beginning to be used in the offshore industry and lack a comparable proven record. This is primarily due to the recent introduction of synthetic rope to the industry for deepwater mooring of floating production systems.

The industry has been investigating various synthetic mooring systems for deepwater mooring for nearly a decade. Over the last several years, polyester ropes have emerged as a very promising deepwater mooring choice. A good overview with some key references on the subject is provided by Winkler [Ref. 2]. Several deepwater polyester mooring systems are currently in use in offshore Brazil. The in-service experience to date is not long enough to draw definite conclusions on the long term performance of these ropes in the offshore environment.

For guidance on the design and use of synthetic ropes for mooring, the designer is referred to RP 2SM. Another good source of reference on the subject is the CMPT 1988 publication [Ref. 3].

Current Loads on Moorings and Risers. Current loads on mooring and riser systems can become an important part of the total hydrodynamic load acting on the FPS, especially for deep water and high current situations. These forces typically consist of static current force, low-frequency excitation force and low-frequency damping. The magnitude of these current forces on the moorings and risers can be comparable to that on the hull itself. In deeper waters, both the mooring line diameter and the line lengths increase. Hence, the area exposed to current loads is increased. In addition, the buoyancy units used with deep water risers attract additional current loads.

Drag force acting on the risers can be estimated using published drag coefficients (for cylinders) appropriate for the applicable Reynolds Number. Similarly, the drag on the mooring lines should be estimated using published experimental data. In both cases consideration should be given to the effects of flow-induced vibration on the "effective drag coefficient." Some studies have indicated that the drag coefficient can increase significantly due to flow-induced vibration effects [Ref. 4].

Current Effects on Thruster Performance. The performance of the thruster systems is also affected directly by current fields. The in-line ambient current field can result in thrust reduction. In addition, a cross-coupling drag is developed when the thrusters are operating at an angle to the ambient flow field (e.g., lateral thrusters). This effect can be explained by the change of momentum of the fluid mass brought about by the thrusters.

Effect of Drag Coefficient on FPS Response. The choice of drag coefficient for the hull, mooring lines and risers affect the following calculations:

- Static offset of the vessel due to current force.
- Viscous part of first-order wave force.
- Viscous part of second-order wave force (mean and low-frequency).
- Low-frequency damping.

Some of these calculation procedures are still under development. If possible the above contributions should be properly incorporated in the analytical model using a combination of advanced analytical techniques and model test results. Incorporating these forces will result in a more realistic estimate of the total response of the system.

References

Sparrevik, Per, *Suction Anchors—A versatile Foundation Concept Finding Its Place In the Offshore Market,* Proceedings of the OMAE 1998, Lisbon.

Winkler, M.M. and H.A. McKenna, *The Polyester Taut Leg Mooring Concept: A Feasible Means for Reducing Deepwater Mooring Cost and Stationkeeping Performance,* OTC Paper 7708, 1995.

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Triantafyllou, M. S., *"Cable Dynamics for Offshore Applications" in Developments in Offshore Engineering,* John B. Herbich (Ed.), Gulf Publishing Co., Houston, pp. 256-294, 1999.

COMMENTARY—MATERIALS, WELDING AND CORROSION PROTECTION (Section 13)

In way of critical connections, continuity of strength is normally maintained through joints with axial stiffening members and shear web plates being made continuous. Particular attention should be given to weld detailing and geometric form at the point of the intersections of the continuous plate with the intersecting structure. Welds in way of critical connections should have smooth profiles without undercut.

Connections which are critical are:

- Brace connections, in general (e.g., to columns, pontoons, decks and to other braces).
- Column/pontoon connections.
- Column/upper hull connections.
- Pontoon/pontoon connections (ring pontoon).

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