An Introduction to Current Floating Structures Hull Design Practice

D. Zhang
Deepwater Engineering Research Center

ABSTRACT

The design of deepwater floating structures has reached a new stage in recent years with the substantial increase in water depth and various types of new structure concepts. The previous research-dominated design approach has gradually shifted into the designed-oriented engineering approach, although the researches of various new issues still play an important role in design due to the lack of industry previous experience on some of the complexity of the structures. The shift of the industry approaches in the design of the floating structures reflects some of the new development of the industry: 1) the maturation of the industry in recent years; 2) the increasing need of quickly developing the discovered oil/gas fields; 3) the substantial increased number of deepwater floating projects; and 4) the worldwide participation of deepwater field exploration and production.

Floating structure concept plays a very important role in deepwater projects; and the design of the floating structure is one of the most important tasks in the project. The importance of the floating structure in offshore projects can be demonstrated in the following several areas: the substantial dynamic structure responses due to wave loading and current loading; the limited motion requirements of risers in deepwater water; and the increasing difficulty of installation for different components of the system.

Three major technical aspects have to be considered, i.e. the strength of the structure, the fatigue resistance capacity of the system, and local and global stability of the structure. Strength design has to consider both the characteristics of structure geometry and wave environmental. Depending on the type of the structures, the governing forces can be maximum acceleration loading, maximum pry/squeeze loading, or maximum mooring induced loading. To resist the ever-changing dynamic environment, fatigue design plays a very important role in the design of floating structures. This is the most complicated design requirement, and cause often major difference between floating production structures and other types of structures.

This paper will review the current design practice of floating structures, evaluate the main tasks during the design and associated major technical requirements, and address the major technical challenges encountered during the design. As a close-out of the paper, the author will discuss some potential future developments in the design of floating structures.

KEY WORDS: floating structure; floating system; structural design; design practice; deepwater.

INTRODUCTION

China has more than 40 years near shore development history of oil and gas fields. Several successful models have been established and used in the oil and gas field developments. These models include two major categories distinguished by how the oil and gas are processed. The first category is the fields developed with both the exploration and production carried out with the facilities in the offshore water; the second category is the fields with production carried out using the facilities on land, while the exploration is performed in offshore water.

Entering twenty first century, oil field development in offshore China is rapidly expanding into deepwater. The conventional fixed platform models cannot satisfy the requirement of new field developments. Floating system, such as tension leg platform (TLP), floating production semi-submersible, or Spar will be needed to introduce into the oil field development.

FPSO has been used for oil field development in offshore China since 1980’s. Lufeng 22-1 oil field development is a typical example using standalone FPSO with subsea system. Since early 1990’s, considerable interest has been expressed for concepts where the wellheads are elevated above sea level by means of a separate structure. In this way, dry access to the wellheads is provided and well-proven technology can be utilized to bring the well-streams to the surface.

The industry of oil and gas exploration and production worldwide has gone through tremendous developments for the last one and half decade. During this period, the water depth has increased to several thousands of meters from several hundreds of meters for production platforms. The active fields have also spread to worldwide from used-to-be a couple of concentrated areas, such as North Sea and GOM. This rapidly expansion of the industry not only require the advance of the hardware, but also put a high demanding on the technical capability of the engineering society.

Floating systems are now becoming the leading tools for expending the production of oil and gas in offshore oil and gas fields. Most future increase of production will come from floating production systems. These floating systems range from water depth of several hundreds of meters to several thousands of meters. Different types of floating systems have to fit into this wide spectrum of water depth. Currently, there are four type major types of floating production systems, i.e. tension leg platform, spar platform, semi-submersible platform, and FPSO.

TENSION LEG PLATFORM STRUCTURE

Tension leg platform has been used more than a decade. Especially in recent years, the use of tension leg platforms for developing moderate to deepwater oil fields has been one of the major choices for the offshore industry. More than two dozens of tension leg platforms have been installed in moderate to deepwater; and the concept has been used in all major oil fields around the world. Gulf of Mexico used the most, with total 19 in production or under design/construction. In Asia, although there is only one TLP installed so far, but there is increasing interesting in adopting this technology. The water depth for these platforms ranges from 150 meters to 1500 meters. Currently, there are three new TLPs under design and construction, and more are in talking.

Tension leg platform started from North Sea, but has been widely used in Gulf of Mexico. With the pickup of oil exploration around the world, TLP has now extended to Southeast Asia and West Africa. Interestingly enough, all the fields in Southeast Asia and West Africa are planned/used two tension leg platforms for each field development, with the assistance of FPSO or FPU.

Tension leg platform (TLP) is anchored to sea bottom through strong vertical tensioning system. Thus, the system has very minimum vertical motion, and is very favorable for top tension riser type of production system. As vertical mooring, tendons are pre-tensioned and kept in intension all the time during the platform life, even during the extreme design condition. Tendon are relative expensive, and tendon system is usually limited to water depth of less than 2000 meters. Hull structure, as a floating body of the system, needs to resistant both the wave dynamic environment and high tension loading. Thus, in TLP design, the global structure analysis and all major connections are governed by both the strength and fatigue. These analyses will be critical to the successful design of the structure.

The main components for a conventional TLP are: production facilities, drilling rig, floating hull, mooring tendon and foundation, and production risers, as well as export risers. Figure 1 shows a typical conventional TLP. There are different types of tension leg platforms. The main difference is the variation of hull forms. The four types of most common tension leg platforms are:

- conventional TLP
- MOSES TLP
- SeaStar TLP
- E-TLP

Hull forms have different kinds. Conventional tension leg platform has four columns and four pontoons. The early conventional TLPs all had round columns. Conventional TLP mainly relies on the four large columns to provide the buoyancy and stability of the platform. Pontoons and deck structure (or deck frames) to provide the resistance of pry/squeeze loads generated by wave actions. Due to the large size of the columns, round shape column helps to reduce the drag forces on the structure. Pontoons are mostly rectangular. The most represent characteristics for conventional TLP is the large columns, large pry/squeeze loads, and self-stable with topsides installed. Conventional TLP had the reputation of high cost. This is why conventional TLPs have always been used in large oil field development. A field with large potential reserves and long field life would probably be better served by a large TLP structure if the water depth is relatively deep, when the potentially low operating expenditure, high uptime and flexibility for future payload variation become significant qualifies for project economy. The cost of the project is usually very high due to the large size of the structure.

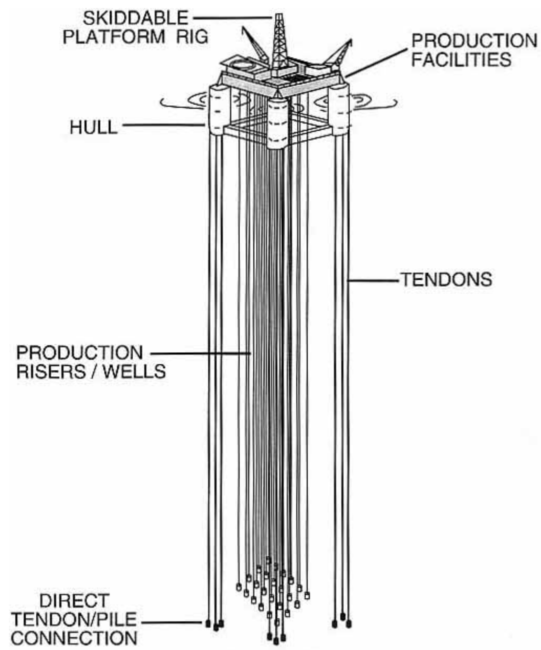

Figure 1. Tension Leg Platform Components

Recently, mini-size of conventional TLP starts to use square columns, such as West Seno TLP. Conventional TLP has the tendons attached to column directly. The radius of tendon restoring force is limited by the hull outer dimensions.

E-TLP is basically similar to conventional TLP except that the tendon supports are extended out to provide more hydrodynamic efficiency.

SeaStar TLP has a hull form of single column with three pontoons. Topsides structure is typically cantilevered out due to the limitation of the column footprint. SeaStar TLP is more suitable for small payload. If the payload gets heavy, the column size could increase substantially, thus induces more hydrodynamic responses. Typically 6 tendons are needed, with two tendons on each pontoon.

MOSES TLP has a large base and small columns. The base structure and mooring tendons forms a close-to-rigid system. Columns are sat on this base system. To some extend, this decouples the column dynamic response and tendon response. With the fact of small columns, closed column spacing, and decoupled column/base response, pry/squeeze load is usually not governing the TLP design. Tendon radius is not affected by the deck structure size, and can be optimized to achieve the best performance. So far, MOSES TLP has shown the best performance in both of design efficiency and economical result.

TLP structure can have six to sixteen tendons. Most of the TLPs have eight (six for single column TLP) tendons, with two tendons at each corner. Tendons are round pipe and have a diameter of ranging from 24” to 42”, depending on the need of the platform. Thickness is around 1”. Tendons consist of tendon pipes ranging from 75 meters to 90 meters, and connected to each other at the ends by tendon connectors. Tendon connectors are much more expensive compared to tendon pipe, thus one of the design goals is to reduce tendon connector numbers. The length of each tendon pipe segment is also affected by the lifting capacity of the tendon pipe and handling tools.

Tension leg platform can be redeployed for a new field after the depletion of the field. Currently, at least three tension leg platforms have been investigated for this option. For a similar field and comparable water depth, the major work for deploying a TLP will be the mooring system and foundation. It is very obvious that a new foundation system will be needed. For the mooring tendons, the system can be reused with some modification to the tendon length. If the field requirement and/or the water depth change substantially, redesign may be needed to check the payload capacity and set down of the structure. Typically, for the same size hull structure, the payload capacity will be less for deeper water due to the set down of the structure and the increased tendon and riser weight payload.

The produced oil and gas from tension leg platform is usually transported through SCR to the nearby FPSO or to the shore facilities depending on the availability of the pipeline network. Since the motion of TLP is usually reasonable small comparing to structure like FPSO, the SCR design for TLP structure is normally quite straightforward.

SPAR PLATFORM STRUCTURE

Since its first installation of Oryx spar, spar platforms have gone through some major changes. The early conventional spars are replaced by truss spar in the recent developments. Heave plates are added in the truss spar to provide damping of the system. As a result of the improved system response, the truss spar has been able to reduce its overall length dramatically from conventional spar, thus resulting a significant saving of the project.

There are three types of spars in history: conventional spar, truss spar, and cell spar. Conventional spar has outer shell carried all the way to the keel tank from top, typically length about 220 meters. The top portion of the spar is called hard tank, ranging from 80 meters to 100 meters. The bottom portion of the spar is called keel tank, or soft tank. It holds the solid heavy ballast, and opens to see water. As a result, the keel tank does not take hydrostatic pressure once in place, but only solid ballast weight. Between hard tank and keel tank, shell skins provide connections and protect riser from environmental loads. Riser is supported separately by buoyancy can from hull structure. This decoupled vertical action of riser and hull reduces the riser motion, but adds a large riser stroke at top of structure.

Truss spar has the similar hard tank, and keel tank, but replacing the middle shell skin with truss structure and heave plates. The heave plate provides additional damping to the system, thus reduces the overall length of the spar. Truss portion is a typical tubular structure, but with substantial dynamic loading and hydrostatic loading acting on it. Mooring lines are typically attached at the bottom of hard tank, very close to the overall center of gravity of the floating system. This reduces the global motion of the spar system, thus reducing the mooring line loads. Two types of riser supports have been used: the buoyancy can type and direct lock type.

Cell spar originated from the concept of simplifying fabrication. Seven cylinders are tied together to provide the buoyancy for the system.

Spar platform needs special installation procedure. Typically spar hull is towed to in-place for upending, and topside is then installed using heavy lifting or float-over. After upending of the hull, a work platform is installed. With the help of this work platform, mooring lines will be installed, and solid ballast will be pumped into keel tank. This solid ballast brings the center of gravity very lower and creates the condition for topsides installation.

SEMI-SUBMERSIBLE PRODUCTION PLATFORM

Semi-submersible production platform has picked up its market in recent years, mainly to fit in the gap of TLP when water depth gets deeper. For water depth above 1500 meters, semi-submersible platform and spar platform are used widely.

The configuration of the current semi-submersible platforms is very much resembled to the conventional TLP structures, instead of ship-shape structure. The structure is symmetric, has four columns and four pontoons. Fairleads are typically located at the similar locations of porch structures. The dynamic responses of typical semi-submersible structures are relatively large, thus the structure only applies to wet-tree platforms. In recent years, tremendous efforts have been spent on making the structure dry-tree friendly, mainly by increasing hull draft to reduce the dynamic motion.

Like TLP structures, the critical design activities of semi-submersible structures include the global structure design and analysis and major connection joints of structure components.

This paper will focus on the common structural design practice of these production platforms in the oil and gas projects. It will review and summarize the methodology and major design activities. The major technical challenges during the design will be discussed, together with the existing industry solutions. Discussions will be made for potential future development of floating system design.

TECHNICAL CHALLENGES AND DEVELOPMENTS

There are a number of technical challenges in the design of floating structures. These challenges are mostly related to the global response of platform structure, including wave action, slow motion, and fatigue. Some of these are related to global motion response, others are related to the complexities of the structure. Other challenges also include the lack of experiment data and lack of industry experience.

Tension Leg Platform

The design of tension leg platform is the state of art technology. With the increased use of TLP structures and the accumulated experience over the projects, the design of tension leg platform has reached a new stage. Although there are continued variations of the configurations, the technology for design of TLP structure is relatively mature, and the methodology has been verified through many projects.

TLP sizing is a design optimization process. It takes both the knowledge of floating structure and design experience. In this design process, for each configuration considered the key objective is to minimize the hull and mooring sizes for given payload, while meeting the following inter-related operational constraints:

- minimum and maximum allowable effective tendon tension
- minimum air gap maintenance
- horizontal offset

For the selected configuration and given environmental condition, the following design parameters are also automatically determined:

- minimum column height
- optimal tendon size and pretension employed
- mean offset, setdown and dynamic response

TLP hull structure not only provides the buoyancy for the entire system, but also provides the ballast for operation. It provides links between the production risers and topsides facilities. Hull structure takes wave loads acting on the system and is under fatigue influence all the time.

Fatigue design plays a very important role in TLP structure application. All major connection areas are governed by fatigue. Typically, these fatigue sensitive areas will use insert special materials and have special welding requirements and profiles. These connection areas include topsides to hull connections, pontoon to column connection, tendon to hull connection, and SCR/riser to hull connection.

Tendon mooring system is another major component. Tendons are hollow pipes with diameter ranging from 24” to 42” and wall thickness around 1”. The minimum diameter 24” is determined by the accessibility for welding treatment. The upper diameter is decided by the design requirement. Entire tendon length contains several tendon segments and linked together offshore through tendon connectors. Each segment is typically in the length of 75 meters to 90 meters, determined by tendon lifting operation. Each tendon segment is welded together by several tendon pipes, which usually come with a length around 20 meters from mill. The ends of each segment are welded to tendon connectors, and prepared for offshore installation.

Due to the high fatigue requirements of the system, TLP structure fabrication has some unique features and needs special attention. The material for the primary load path areas usually has high strength, high ductility, and high sharp-value requirements. Good weldability and certain chemical contents limitation are also important.

Spar Platform

Spar platform is widely used in relatively deeper water depth. It has several advantages:

1) It can perform direct well operation through the riser. Risers can be supported by buoyancy can or direct tied to hull structure;
2) Though riser vertical motion is larger than on TLP structure, but it is much smaller than on semi-submersible. The center of gravity is lower, so the motion is reduced, especially the pitch of the structure.
3) Unlike TLP, spar platform is relatively insensitive to topsides weight. The increased weight of the topsides will cause the increase of hull size for buoyancy, but not too much to the mooring system.
4) Easy for redeployment.
5) Spar platform has advantages to TLP as water depth gets deeper.

The design of spar platform needs to consider both the wave loading and slow motion of the system. Global bending is the dominated design case for the spar hull. Maximum global bending will be generated during upending and/or during in-place condition when the hull reaches its maximum pitch angle under the combined effects of wave, slow motion, and mooring loads.

The slow motion of the system creates additional fatigue damage at all major connection areas. At the lower connection of keel tank to truss, the damage generated by slow motion can account for 60% to 80% of the total damage, depending on the structure configuration and field environment. Even for the upper connection of hull to topsides, the fatigue damage caused by slow motion can’t be ignored.

This slow motion of the floating system creates challenges to the structure design in both strength and fatigue aspects. The accurate method of solving this problem in time domain will be very time consuming, and not practical to the always fast tracked engineering schedule. Design waves approach has been adopted for design of spar structure. The consideration of slow motion in this design approach has always been a technical challenge to the designers.

The determination of some of the design loads has always been the topics of engineering. These loads include upending load and wet-towing loads on heave plates.

Semi-Submersible Production Platform

The newly designed semi-submersible production platforms have very similar configuration of conventional TLPs. Semi-submersible platform normally needs some kind of storage system, so the design of the hull marine system is most likely more complicated than the TLP structure. Also, due to the stability requirement of the system, semi-submersible structure normally has more compartments.

The integration of the hull structure with topsides for semi-submersible normally has advantages over TLPs structure. Since there is no stability issues like most TLPs have, semi-submersible structures are normally integrated quayside or near shore. This eliminates the need of offshore heavy lifting.

DESIGN PRACTICE

The hull design of platform structure is one of the most critical tasks in floating system. Although each type of structure has its unique requirements, the major activities in the hull structure design include the following:

1) Creation of a hull structure design premise document
2) Structural layout and scantling design
3) Global structural strength analysis
4) Global structural fatigue analysis
5) Global structural stability check and design
6) Top of hull structure and topsides connection strength and fatigue design and analysis
7) Major connections strength and fatigue design and analysis

8) Mooring porch strength and fatigue design and analysis
9) Riser/SCR support strength and fatigue design and analysis
10) Ring/web frame strength design and analysis
11) Flat/bulkhead strength design and analysis
12) Outfitting/appurtenances design and analysis

Design wave approach has been widely used in floating structure design. Design waves are selected based on the structural configuration, environmental conditions, preliminary global performance results, and previous design experience.

Global performance Analysis establishes the overall motions and responses of the floating structure and provides global performance design check for the various platform components. The response analysis and design checks are fundamentally based on working stress design, but are supplemented by reliability-based criteria. The key function of the global performance Analysis is to establish that the platform meets all the motions and overall performance requirements and to provide loads to the hull and mooring design groups.

Typical software used for plating structural analysis are ANSYS and SESAM. These software are well tested for offshore projects, and used by most design companies.

Design Premise Document

Creation of a design premise document (DPD) is the first, but most important step. The primary purpose of the DPD is to establish the technical basis for design, engineering and construction of the floating structure. The DPD shall represent the current basis of design, and defines the scope, basic parameters, and extent of the structure for the project. The DPD document also outlines the technical approach and methodology used by the engineers to solve each technical issue. As a management tool, the initial issue of the document is designed to provide the basis for proceeding with design engineering and the commencement of the execution of the project. In addition, the document provides management with the basis for stewardship of the project until the design and construction is complete. The DPD will be an active document amended throughput the project to reflect the current scope and design basis.

Hull Structural Scantling Design

Structural layout and scantling design determine the primary structural scantling sizes of plating, girders, and stiffeners. It is the start of global structural analysis and preliminary weight estimate. The hull structure is a stiffened plate structure with internal longitudinal stiffeners, girders, web frames, bulkheads, and flats. Its major components usually include column(s), node structures, pontoon or truss structure, and supports for topsides and moorings. The major appurtenance for the hull includes SCR porches and support structures, caissons, walkways and ladders, etc.

A designer of flat plate structure needs to consider not only a balance of strength, buckling, and fatigue of overall structure, but also its constructability and cost. There is a trade off among plate thickness, stiffener spacing and girder spacing. The fabrication of the steel structure and the constructability should also be considered in the design. Figure 2 illustrates a typical stiffened flat plate structure. It consists of: plate, longitudinal stiffener, transverse frame or girder, longitudinal girder or bulkhead, and local stiffening such as brackets.

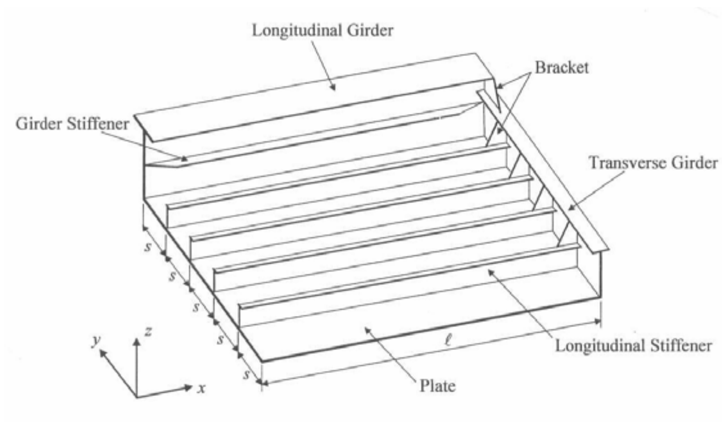

Figure 2. Typical Stiffened Flat Plate Structure

For a floating structure, although the fatigue is always one of the major dominant factors, most of the areas are governed by hydrostatic pressure induced by platform draft and set down. Compared to the conventional structure with in-place draft of 20-30 meters, the in-place draft of spar and some new TLPs has a range of 40-80 meters, driven by better hydrodynamic responses. With water depth reaches 1500 meters level for tension leg platform, the set down has also increased dramatically. All these changes have constituted new challenges to structural design.

The scantling design is typically governed by two (2) loading types that may act independently, or in union. These loading types are the local loads and the global loads. To resist the local hydrostatic loading which acts normal to the plating, the structure plating fields are stiffened in a two (2) level orthogonal framing system. The first level of framing is the angle stiffeners that are typically spaced around 450 mm to 1050 mm centers. These stiffeners function as supporting member of the plating field. The second level of framing is the transverse girders, which are typically orthogonal to the stiffeners, and function as supporting member to the stiffeners and plates. The global loads are typically acting in plane with the plating fields and need to be considered during the scantling design.

The pressure heads include the effects of operating draft, subsidence, tide, set down, and the dynamic pressure due to the effect of wave crest where applicable. Where it is appropriate, the effect of wave hydrodynamics should also be included.

Typical flat plate scantling design includes sizing of plate, stiffener, and transverse web frames. For most of areas, the maximum hydrostatic design head governs the design. Unity check is typically done in terms of the section modulus, shear capacity, and axial capacity.

Global Structural Strength and Stability Analysis and Design

The global primary strength design procedure is a deterministic design wave approach. A specific wave height and period are defined by preliminary global performance based on spectral response of the platform moving as a rigid body. For each environmental condition selected for structural design, separate design waves are provided which maximize platform acceleration, pry/squeeze forces, and column bending forces.

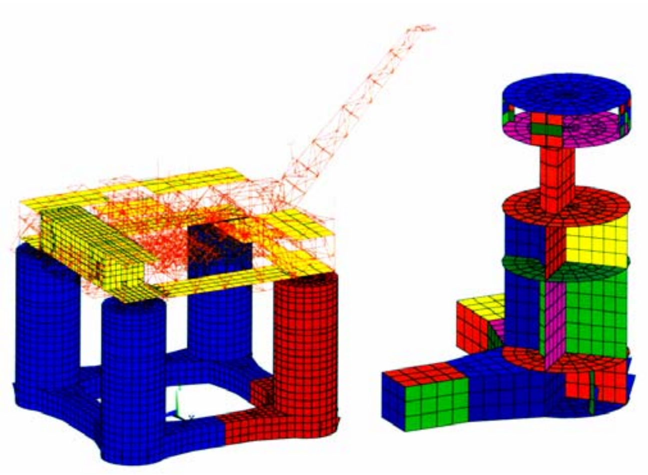

Figure 3. Representative Global Structural Model

Associated with each design wave, a consistent set of loads including hydrodynamic pressure distribution on the wetted portion of the hull, platform accelerations about the center of gravity, and inundation forces are generated. Stresses are then computed by structural programs for all elements in the model. Stresses from the global model can be computed for any position of the wave as it passes through the structure using postprocessor software. In this way, the controlling load cases can be identified for specific groups of elements, and passed to subsequent analyses using more refined finite element models.

There are three main purposes for the global structural strength analysis. Firstly, it is to identify control load cases with different wave height, wave heading, wave phase angle, and wave period for key areas in the hull structure for subsequent detailed structural review. Secondly, it is to provide stress information for hull structure shell plate thickness verification and stability checking. Thirdly, the global structural analysis results are to be used to provide cut boundary loads for local models in which global action has a significant effect on the design.

Design waves, including inundation effects, are typically run for 8 wave approach directions for all global load cases. Results of the global analysis provide snapshots (instances of a particular event when stresses for a given critical location are maximized). Results are processed and stress information is obtained for all governing instances. These snapshots, or governing load cases, will also be used as input to subsequent detailed structural review that is capable of accurately determining states of stress on a local scale.

Final stress information, including non-averaged equivalent stress and component stresses, for the major components of the hull structure is obtained by post processing the analysis results for all the control load cases with particular wave heading and phase angle identified. The combined stress plots will be stress combinations of static and dynamic effects.

Buckling design can be performed by following either the DnV code or API code. Buckling check is performed for the hull plate following the procedure outlined in design code for plate buckling. It is important that all the plates are satisfactory with the buckling criterion. The usage factors for plate elements need to be less than the allowable usage factors. Panel buckling check also needs to be performed for the critical areas subjected to compression. It is necessary that both plate-induced and stiffener-induced panel buckling usage factors are within the allowable limit.

Global Structural Fatigue Analysis and Design

The primary objective of the global spectral analysis is to determine the screening fatigue lives using a global finite element analysis (FEA) model to identify potentially fatigue- sensitive regions within the hull structure. The other objective is to obtain the Weibull shape parameters (ξ) for each of the control element groups for further use in local fatigue analyses.

A full spectral analysis shall be performed for the screening of the structural fatigue life at different locations of the platform hull. This analysis process uses hydrodynamic diffraction theory and the global structural finite element model. The analysis is to be performed to provide the screening fatigue lives for different critical locations on the hull structure and to provide the Weibull parameters for these different structural locations for further detailed fatigue analysis.

Using the spectral method, a long-term stress distribution shall be used to compute the cumulative fatigue damage ratio. Fatigue stresses shall be computed for the discrete fatigue-related sea states. The cumulative fatigue damage ratio, D, is computed according to Miner's rule,

$$D = \sum \frac{n_i}{N_i}$$

Where:

n_i = the number of cycles within stress range interval i, and N_i = the number of cycles to failure at stress range i, as determined by an appropriate S-N curve.

The fatigue damage ratio is not allowed to exceed unity. The associated fatigue life factors depend on the criticality of the component to the structure and accessibility and in-service repair-ability of the areas, and are summarized as follows:

		Is component accessible & repairable for in-service inspection? Yes	No
Is component critical to global strength or stability?	No	3	5
	Yes	5	10

The required fatigue life is equal to the hull service life multiplied by the fatigue life factor.

Spectral fatigue lives are calculated using the wave scatter diagram for the deepwater field in which the platform will operate. Stress RAO's are calculated for all chosen elements and for all the frequencies that have any significant wave energy. Fatigue lives are calculated for elements throughout the hull, including deck support structure. Connection regions such as top column posts are fatigue critical. The obtained fatigue lives are approximate because of the coarse mesh as well as the conservative S-N curve usually used for global structural fatigue model. Detailed local analyses should be used along with the corresponding Weibull parameter and the number of stress cycles to calculate accurate fatigue lives. Weibull stress distribution parameters should be obtained and tabulated in element groups for detail fatigue analysis. Any future detailed fatigue investigations and/or local FEA of fatigue sensitive regions should use maximum stress results obtained for the corresponding wave condition in conjunction with Weibull shape parameters given in the table to estimate fatigue lives. This particular regular design wave, coupled with a constant number of wave cycles, is used in the back calculation of Weibull (squiggly) data. The spectral fatigue analyses typically use 8 wave directions, each direction having around 25 to 30 RAO wave frequencies selected to cover the full range of hull structure stress response in order to accurately calculate fatigue damage.

The FE model for the global spectral analysis typically is generated using ANSYS or SESAM to provide an accurate representation of the platform structure both in terms of geometry and structural response as possible. In summary, the global spectral fatigue analysis is typically performed for in-place operating conditions for a total of 25 to 30 wave periods. The range will depend on the type of structures. The screened areas are typically concentrated on connections, column(s), upper column, etc. The calculated lowest fatigue life for the analysis needs to meet/exceed the design requirement, which typically requires 200 –300 years for underwater locations and 100 -150 years for above-water locations.

Top of Hull Structure and Topsides Structure Connection Strength and Fatigue Analysis and Design

The top of column connection transfers the static and dynamic loads from topsides into the hull. The deck is typically connected to the hull by means of posts, with diameter ranging from 1.5 meters to 2.5 meters, at the top of columns. Since this is detailed model for connection analysis, all components of top of column structure are typically modeled in details as shell elements exclusively.

Governing load cases for the top of column connection strength analysis are identified through global strength analysis. In global strength analysis, all the wave headings were scanned for the control elements to identify the wave phases causing a state of high stresses at the top of column connection regions. Based on the maximum von Mises stress, load cases are identified for further inspection using the top of column local model. Usually, a number of load cases with specific wave headings and phase angles will be analyzed for the top of column connection structure. Stress results, including von Mises stresses, component stresses, and shear stresses, for the major components of the top of column connection areas can be obtained by post processing the analysis results.

For fatigue analysis purpose, only the wave action is required to obtain the cyclic stresses experienced by the structure. These cyclic stresses are used to estimate the fatigue lives of critical components in the top of column connection region. Stress ranges obtained from the detailed model analysis are directly used for fatigue calculation to obtain fatigue lives.

Governing load cases for the local top of column connection fatigue analysis are identified through global analysis. These cases are then analyzed for this detailed local analysis to get the maximum principal stress ranges. In the global spectral analysis, the Weibull parameters and stress cycle counts are calibrated to the corresponding design condition. Hence, this local fatigue analysis should be performed for this wave load condition in order to use the Weibull parameters calculated in the global spectral analysis. The final principal stress ranges are used along with the Weibull parameters and stress cycle counts from global spectral analysis to check the final fatigue lives for different locations in the top of column connection.

Major Connections Strength and Fatigue Analysis and Design

Major connections in floating structures are typically governed by both strength and fatigue. The analysis of these connections will need very detailed model to address both the strength and fatigue issues. Depending on the types of the structure, the connections are different. Major connections are listed below associated with the type of structure, except for top of column connection which was addressed already.

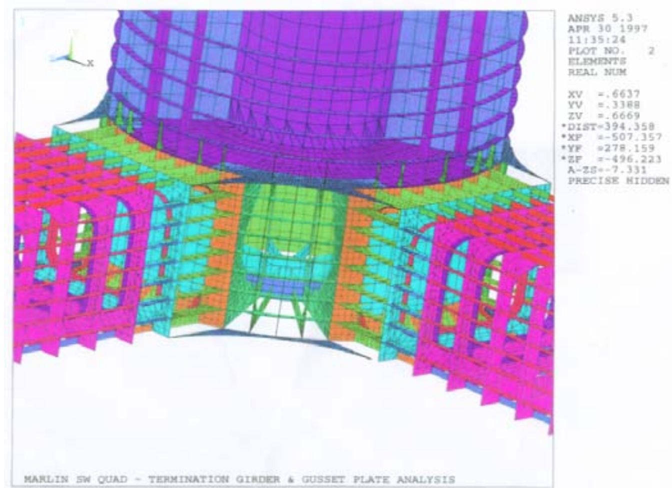

Figure 4. Representative Connection Structural Model

For conventional TLP structures, other major connections include pontoon to node connection and column to node connection. For satisfying the stability requirement, conventional TLP structure has large column spacing. Pry/squeeze loads are typically the dominating load for conventional TLP platform due to the configuration.

Extended-TLP platform is similar to conventional TLP structure, except that the tendon support is extended to reduce the hydrodynamic response and increase the structure efficiency. In addition to the connections in conventional TLP, E-TLP has added an additional connection: the added extend-leg connection to column.

Sea-Star TLP is single column structure. Instead of the normal pry/squeeze governing for most TLPs, Sea-Star TLP is governed mostly by acceleration-generated inertia load. The connections between pontoons and column are heavily dominated by dynamic load. Depending on the topsides weight and column height, this effect could be amplified significantly.

The configuration of MOSES TLP is quite different from conventional TLP. The use of big base has significantly changed the response of the structure. The dominated design load cases are a balance of pry/squeeze load and acceleration-induced load, but in a lower magnitude due to the reduced column spacing. The main connections include TSS structure to node, column to node, and base structure to node.

The main connections for truss spar platforms are the hard tank to truss structure and keel tank to truss structure. These connections experience large dynamic loading, including wave and slow motion. The transition from tubular structure to plating structure adds more complexity to the connection.

For the conventional spar, the connections of hard tank and keel tank to transition are similar, but in a much smooth pattern due to the plating connections.

Semi-submersible production platforms have very similar connections as conventional TLP: column to node and pontoon to node.

The purpose of the connection analysis is to analyze the critical load cases identified by the global structural analysis and to access the fatigue life at the regions. It provides information to check the strength, the stability, and the fatigue for the connection regions. The mesh density in the global model is not suitable to perform an accurate analysis for the connection brackets. The model specified for connection analysis is identical to that used for the global structural analysis, except that the mesh density at the connection region is much more refined to capture the stress more accurately.

These connections and associated gussets are in the critical regions and experience high in-place loads and high cyclic environmental loads, hence are highly fatigue-sensitive. The analysis provides information necessary to design these connections and gussets for both strength and fatigue endurance.

The model used for the fatigue analysis has to be very fine meshed in the interesting regions. The mesh in these regions is typically in the order of the thickness of the gusset plate so that principal stresses, obtained from this analysis, can be used in fatigue analysis with an SCF of 1.0.

In the global spectral fatigue analysis, the Weibull parameters and stress cycle counts are typically calibrated to one-year operating condition or one hundred year extreme condition. Thus, the local fatigue analysis needs to be performed for the same wave load condition in order to use the Weibull parameters calculated in the global spectral analysis. Furthermore, load cases with specific wave headings and phase angles, which cause maximum principal stress ranges in the gusset connection area, are identified through global strength analysis results. These cases are then analyzed for the detailed local analysis to get the maximum principal stress ranges. The final principal stress ranges are used along with the Weibull parameters and stress cycle counts to check the final fatigue lives for different locations in the gusset connection area.

The target fatigue life for the gusset connection area is typically 10 times of the platform life. When doing this, designers need to keep in mind that this fatigue life also should consider damages caused during transport. The final fatigue life should be enough to cover the fatigue damage in-place and caused by transport, which shall be a one-time event.

Mooring Porch Structure

Mooring porches have two major types: tendon porch for TLP structure, and fairlead and chain jack porches for spar or semi-submersible structure. Both types of porches need to design for strength and fatigue.

Tendon porches and associated backup structure shall be designed to be stronger than the tendons they are supporting. The corresponding global design loads specified should be used to check the design, including operating, extreme, and survive cases. In addition, the following design load shall be checked for robustness of the tendon porch structure: tendon yielding case, taken as the tendon design minimum yield stress timed by tendon minimum cross-sectional area.

The allowable stresses should follow the design requirements specified. For the robust check, the allowable von Mises stresses should be: in the porch 95% of yield, or 47.5 ksi for 50-ksi-steel, in the backup structure shall be 90% of yield, or 45 ksi for 50-ksi-steel.

Mooring porch should check the strength for mooring line breaking; and fatigue for the operating field environment.

SCR Porch

SCR porches and receptacles normally are sized for the largest SCR loads expected. Both the vertical and horizontal offsets also need to be considered when the load cases are finalized. The range of possible SCR angles shall be based upon the maximum angle achieved during the 100-year design event. Stresses in the porches and receptacles shall be kept below allowable stresses for the extreme storm conditions for strength and fatigue as well.

Local Structural Analysis

Local structures are mostly dominated by local hydrostatic pressure or local concentrated loads. Such structures include: web frames, ring frames, internal bulkheads, internal flats, etc.

These models normally are not affected by global loads, so the analysis of these models only need to consider the hydrostatic loads or concentrate loads. Typically, for local structure analysis model, all elements are modeled as shell elements to correctly reflect the actual structure and to obtain the accurate stresses.

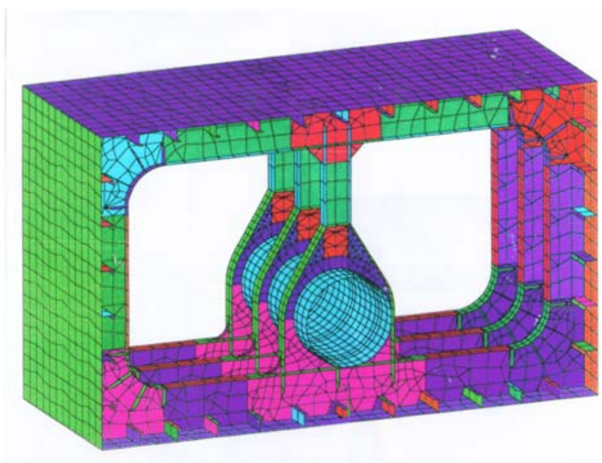

Figure 5. Local Analysis Structural Model

Outfitting and Appurtenances Design and Analysis

Analysis of hull appurtenances shall be performed in accordance with ABS/USCG, API or AISC rules as appropriate. Those appurtenances located in up to a 100-yr wave zone shall be designed to withstand wave loads as calculated by the Morison equation and utilizing the appropriate fluid velocities and drag coefficients. Appurtenances, which may have an impact on the primary hull structure, shall have

FEA analysis performed.

Some miscellaneous hull appurtenances are:

- SCR fixed and slide clamps and supports with back up structure
- SCR and Umbilical installation aids
- Watertight bolted manways and access platforms/ column elevator supports
- Construction and installation aids such as mooring/ towing padeyes and fittings, tendon installation winch platform and guide supports
- Caissons and piping attached to the exterior of the hull including Umbilical pull tubes and back-up structure.

FUTURE DEVELOPMENT

The most challenge that offshore development project is facing nowadays, is how to produce an efficient system in an almost always-fast track schedule project. Most of projects do not have schedule for engineering recycle, while at the mean time an efficient system is always demanded in order to keep project cost down. The increase of deepwater activities has raised new requirements on the design of floating structures: fast, accurate, and efficient.

Designers have always been looking for best ways to efficiently design the structures. The integrated system of hydrodynamic-structural-drafting has its promising future. This approach will combine the structural design, global load generation, engineering drawing, and fabrication drawing into an integrated closed system and greatly simplify the design process, reduce interface, and improve efficiency.

CONCLUSIONS

The current design practice of floating structure has been reviewed and discussed. There are number of technical challenges in floating structure design. They are the keys of having a successful structure.

Design wave approach has been widely used by the industry, and correct determination of the design wave is very important for the design of a floating structure. Depending on the type of the structure, determination of design wave will be different.

Global structural analysis plays a very important role in floating structural design. It will provide the information for global strength, global fatigue life, and global stability. Equally important, it also provides the information of critical regions in the structure, and provides cut-boundary loads for further local analysis.

The current approach of design floating structure is relatively mature. Design engineers are looking for better ways to improve the design efficiency, reduce interface, and improve accuracy.

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