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INTEGRATED APPROACH TO RISER DESIGN AND INTEGRITY MONITORING

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ABSTRACT

The paper discusses the integrated approach to deepwater riser design and integrity monitoring. The integrity monitoring of riser systems is key to ensuring functionality and operability throughout the life of the field. Riser response monitoring is a key indicator that can provide the operator with critical performance data during day to day operation and in extreme events. This information further enhances the understanding of complex riser behavior in order to improve design practices. The importance of riser monitoring is further increased due to uncertainties in the design data and prediction of the riser response to complex loading environments. The paper discusses various approaches of riser monitoring that suit specific objectives and requirements.

Risers are monitored to provide information on riser response due to environmental and operational loads. Environmental loads include direct action of waves, currents and hydrostatic pressure. Operational loads include temperature and internal pressure. Risers are also subject to vessel motions driven by environment and operational requirements. Monitoring equipment provides data on riser response to day to day loading (fatigue monitoring) and infrequent events, such as loop currents, hurricanes or significant vessel offsets. Physical quantities that are typically measured are motions, strain and temperature. Description of riser monitoring techniques and equipment used is provided within this paper.

The second part of the paper discusses the link between monitoring and using the gathered data for riser assurance and improvement of the design techniques. Monitoring is presented as part of the bigger picture – a tool to minimize risk and deliver safe and effective solutions for deepwater offshore operations.

DEEPWATER EXPLORATION

Deepwater oil and gas exploration is beating existing records every year. In the 1950s, deepwater drilling was defined as about 100 feet of water, while now ultra-deep water is defined as 5,000 feet or more. Ten years ago, in 1996, the record deep production platform Mars was installed in close to 3,000 ft water depth in Mississippi Canyon Block 807 by Shell. The record set for drilling in is 10,011 feet. According to the James K. Dodson Company (Dodson) forecast, a total of 837 wells are forecast to be drilled in 2006 in GoM, which is a 13% increase over 2005. Of the total number of wells 165 or 20% will be drilled in 1,500 ft of water or greater. The total number of wells forecast for exploration in water depths greater than or equal to 1,500 ft indicates the most significant improvement over projected results in 2005, with an additional 35 wells expected to be drilled, which is a 46% increase. Last September, Chevron Corp and its partners Devon Energy and Statoil ASA, announced that they pumped oil from 5.3 miles below the Gulf of Mexico surface. The exploration of offshore leases in GoM accounts for approximately 30 percent of all U.S. oil and gas production.

RISER LOADING

Risers are one of the key technologies that enable deepwater oil and gas exploration. Risers, although at first sight seem to be a fairly simple structure – a conduit between two points, pose significant design challenges due to its complex loading. Riser loading comes from two sources – internal and external. Internal loading sources include:

- Pressure,
- Temperature,
- Weight of fluids,
- Abrasive and corrosive fluids,
- Mechanical loading from the drill-pipe in case of drilling risers.

External loading, which is caused by the environment that riser is located in can be categorized as:

- Current loading,
- Direct wave loading,
- Hydrostatic pressure,
- Water temperature,
- Vessel motions transferred to the riser,
- Riser – seabed interfaces.

Both internal and external loading on the risers are often not well defined. Internal loading is mainly dependant on parameters of the reservoir. Although the techniques of characterization of the reservoir undergone tremendous development over recent years and are one of the key drivers enabling extending the boundaries of deepwater oil and gas exploration, the knowledge of reservoir is never full until the oil is produced. Design basis put together at early stage of the oil field development are relying on incomplete data sets and contain many assumptions. In addition, riser internal loading may vary from the originally assumed due to operational changes in a course of field life. Future expansions, tiebacks and corrective action to component failures may require modification of riser function that was not accounted for during the original design phase.

External environmental loading is as much, if not more difficult to predict. Current deepwater developments are often located in remote sites, where long term environment monitoring programs have not been conducted and data is not always adequate. Design basis are

formulated relying on the limited statistical data, and as such may not fully represent the long term in-situ conditions. Two examples are hurricanes and loop currents present in the Gulf of Mexico. Recent hurricane seasons marked by such names as Lili, Ivan, Rita and Katrina resulted in many efforts to better characterize hurricanes and provide better guidelines for design of offshore facilities. [5], [6]. Loop current monitoring and forecasting is another big challenge for Gulf of Mexico. Initiatives such as Eddy Watch [9] provide very valuable data for oil and gas exploration, but due to volatile nature of the phenomenon, accurate prediction and definition of the design basis is very complex. Loop currents in range of 3 knots may sustain in one area for several weeks and then move to another location. The following year, the same location may not see high currents at all. Drilling and completion operations that are most sensitive to loop currents, typically take less than one year. Thus it is particularly hard to define appropriate statistical criteria that can be used during design of the risers.

RISER FAILURES

Two drilling riser partitions have been reported over the last few years, Transocean Enterprise in 1850 m [0] and Diamond Offshore Ocean Baroness in 1740 m [2]. Both of these risers were suspended in high currents over prolonged period of time directly before failure. However there was no monitoring systems on the risers and thus, no data is available if and how much VIV fatigue damage contributed to the failure. Other failures, which were not catastrophic, but are costly to the operator and potentially more hazardous, are related to wear issues. Two examples of such failures are seal failures on the choke and kill lines and failures due to wear of the conduit pipe from rotating drill pipe. Choke and kill lines failures are attributed to the VIV and excessive wear on the seals [7] during riser installation

Wear in the riser is caused by the side load imparted by the drill string on the main riser pipe and is dependent on: the lower flex joint offset angle above the BOP, the tension loads on the riser and the drill string, and any side load on the riser. Wear can occur in several places in the riser system, but is mostly observed in riser section above the lower flexible joint. Wear progress can also carry through the flex joint, and if unrecognized, into the BOP. Investigation of the wear related failure is described in [8].

Production and export risers to date have noted fewer failures than drilling risers. This is potentially due to more stringent design requirements as well as less rigorous handling and installations requirements. However, recently there have been several cases of failures of particular production and export riser components. In late 2004, Shell Exploration & Production shut down the Mars tension leg platform (TLP) to replace the flexible joints on both its oil and natural gas export lines. Fortunately, no more serious failures occurred on production or export risers. Consequences of such failure could be catastrophic to environment and potentially unsafe to offshore personnel.

INTEGRITY MANAGEMENT

The uncertainties in riser design and environmental and operational loading lead to changes in the operation approach to risers. In recent times, operators have designed, constructed and installed many deepwater production and export riser systems with the belief that the large factors of safety built into the designs are sufficient for long term operation. Due to the indications from the failures and near-misses mentioned previously, operators understand the need to properly inspect and maintain the deepwater riser systems installed from the various assets, throughout the life of the field.

Asset integrity systems and strategies are currently being developed by operators to extend the life of an increasing number of assets. Some companies, such as BP use all encompassing integrity management programs that include all of the risers and flowlines in certain geographical area. Example of such program is presented in [3].

Integrity managements systems use risk based techniques that provide the means by which consequences of a loss of integrity of a riser are assessed against modes of failure and the probability of such a failure mode occurring as shown in Figure 1. This allows for active management of assets, minimizing failure probabilities with known margins while at the same time optimizing integrity monitoring efforts. The graphical representation of the integrity management process is shown in Figure 2.

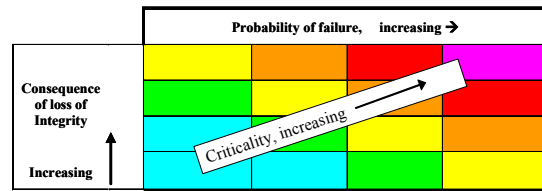


Figure 1 – Assessing Criticality of Failure Occurrence



Figure 2 – Integrity Management Process

There are three main conditions for effective integrity management:

1. Good database of as-built information
2. Well defined and executed integrity monitoring plan
3. Good, reliable information regarding in-situ conditions

The two first points are addressed in phase of project planning and are limited to “office work”. The third point may, and frequently does, require additional equipment to be installed on the risers to measure riser response to the environment.

INTEGRITY MONITORING OVERVIEW

It is critical for the real success of the integrity management process that integrity monitoring is closely linked to management requirements. Riser monitoring systems can vary tremendously in scope. The scope of this paper will be limited to monitoring systems for riser structural response. The complexity of the monitoring system is the derivative of the monitoring objectives. There are several criteria monitoring systems can be characterized by:

1. The monitoring philosophy – Local vs. Global Monitoring
2. The measured parameter – Strain vs. Motion
3. The way of extracting the data – Stand-alone vs. Real-time

Local vs Global Monitoring

Risers are simple structures with complex response. As highlighted in the earlier sections of this paper, risers pose a design challenge not so much due to the complexity of the structure, but due to the complexity of the loading. There are two types of loading acting on almost any structure – extreme loading and long term fatigue loading. In case of risers both these types are not that well defined. However, in terms of response, it is probably fair to state that riser response to extreme loading is better understood than its long term fatigue response. Due to the complexity of the riser response, defining failure modes and location of the critical failure points can be challenging. This point can be illustrated on example of VIV response of the drilling riser and of the riser – seabed interaction of the SCR.

The fatigue life distribution along the riser for various operating conditions and different analytical assumptions as calculated using SHEAR7 is shown in Figure 3. Different results are obtained for different operating conditions (mud, top tension) and analytical assumptions. One can easily notice is the high change in the results due to change in analytical parameters. Depending on the assumptions, the fatigue life may present a problem only at few clearly identified hot spots, or along the majority of the length.

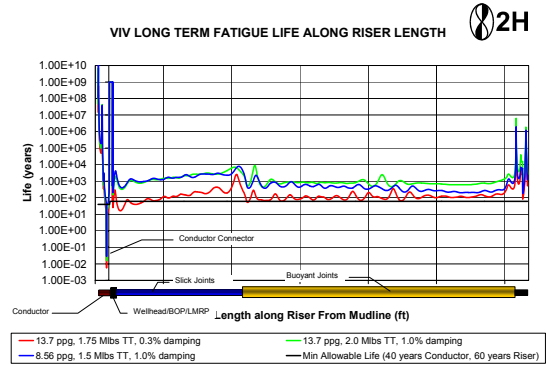


Figure 3 – Drilling Riser Fatigue Life Distribution

Critical locations of the SCRs are limited to hang-off area and touch down zone (TDZ). While the hang-off area is clearly defined and does not change during riser life, TDZ may extend over a significant length. Vessel offsets due to hurricanes and current and operational repositioning of the vessel (ie drilling operations on spars) or exactly to decrease the localization of the critical area, can cause the TDZ to cover several hundreds of feet.

The above examples indicate problems that may be encountered when defining the requirement for monitoring systems. How to specify and locate the instrumentation to ensure capturing of the critical points? So far, the only successful way of resolving this issue is to measure riser global response and based on it, to extrapolate the results over entire riser. This methodology has been successfully applied on number of projects conducted by 2H. [10] and [4].

However there are situation, where monitoring of the local hot-spots has merit. Such example could be monitoring of bottom drilling riser joints located directly above the lower flexible joint. Transducers are connected through the riser control systems and MUX cables to the vessel. This allows for local measurements of riser strain or motion, which, although not able to provide the full picture of riser response, supply useful data and allows support of operational decisions, especially during riser installation and retrieval.

Strain vs. Motion

In theory, strain and motion are the parameters that can be interchangeable. In practice the measurement of strain or motion present their own sets of challenges. The following are the

pros and cons of the strain vs. motion monitoring:

Motion

- Pros:
 - Simple structure interface – motion sensors are typically enclosed in relatively small size metallic pressure containers, which can be simply strapped to the riser;
 - Low cost – typically several times or less than equivalent strain monitoring device;
 - Proven track record in deepwater – motion sensors have been successfully used for a number of years.
- Cons:
 - Data processing is required in order to calculate stresses.

Strain:

- Pros:
 - Direct reading of strain – no additional processing required;
 - Straightforward processing to get fatigue.
- Cons:
 - Complicated interface with pipe – depending on the type of measurement may require stripping of the protective coatings;
 - High cost;
 - Little track record in deepwater and low subsea reliability of certain instruments.

Based on the above listed set of pros and cons of motion and strain monitoring the following recommendations can be given. Due to its low cost and simple riser interface, motion sensors are particularly suited for assessing riser global response, when number of sensors is required along the length of the structure. Strain sensors are viewed as supplemental to motion sensors and only limited number of sensors is recommended to locally verify the measurements and calculations obtained from motion sensors. Strain sensors can be also used successfully in limited real-time monitoring systems when the objective is to measure and present real-time riser response at several identified critical locations in order to supply operational information. The example of the 2H stand alone riser motion monitoring system (INTEGRIPod-M) is shown in Figure 4.



Figure 4 – 2H INTEGRIPod-M Motion Sensors

Stand-alone vs. Real-time

Stand-alone systems were developed over number of years with goal of installation friendliness, robustness and easy of handling. Typically such system is an array of motion sensors enclosed in a metallic canister with batteries and memory. Motion sensors are periodically retrieved for battery replacement and data download. This can be done either with riser installation/deployment cycle for drilling and completion risers or with ROV for other riser types. Data is then collected and processed on-shore.

The cost of such system depends mainly on number of loggers that are required to capture riser response, but typically between 10 and 20 are required to capture deepwater riser response in high currents. Additional cost is associated with installation and retrieval and data processing. The deliverables from such system are the reports with data analysis and fatigue damage accumulation on continual basis along entire riser length. This information is used to verify the riser design and it's structural integrity as well as to help with appropriate scheduling of maintenance and inspection intervals and criteria.

Real-time systems are higher expenditure, as there is cost associated with connecting the equipment to the communication and power supply. These systems are tailored to the specific needs and they can vary significantly in scope. The example of a full spec real-time system is shown in Figure 5. The SCR monitoring system shown includes monitoring of the hang-off and TDZ portion of the riser. The system is integrated with existing field infrastructure using production control umbilical for power supply and communication.

monitoring may provide early warnings, which can prevent such failures.

Access to direct measurement may help improve operations in two ways – directly and indirectly. The direct way is applicable for drilling and completion risers when the monitoring system is providing real-time information on riser response directly to rig personnel. Such information can be used in following situations:

- During critical events such as retrieval of riser in high current and/or during high seas [12].
- When using riser drift to facilitate riser installation. Knowing real time riser response enables optimization of such activities.
- To mitigate VIV (i.e. by decreasing mud weight or pulling more tension), real-time feedback of riser response enables to confirm VIV alleviation.

Secondly, data collected during riser monitoring is used for better understanding of riser response to environmental and operational loading. This enables for modification of design techniques to more accurately reflect real life phenomena and to reduce design conservativeness, where applicable. For example, some data gathered on drilling riser monitoring campaigns suggests that the current VIV design practices can be overly conservative by an order of magnitude as shown in Figure 8, [4]. Integrity monitoring of risers identifies such discrepancies and provides basis for the modification of the design methodology and operational procedures.

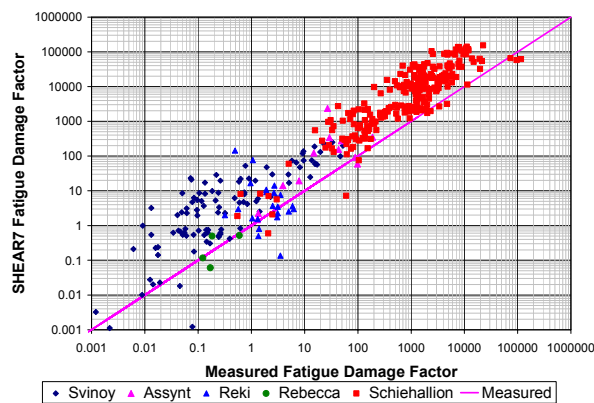


Figure 8 – Fatigue Damage Factor Comparison

Last but not least, drilling riser monitoring is a powerful tool for better definition of

maintenance and inspection strategies. The maintenance and inspection strategies differ between operators, contractors, equipment manufacturers and regions of the world and typically do not take into account type and magnitude of loading. Integrity monitoring can provide rationale for inspection intervals, by providing the data on actual riser behavior during service. The data can be used both to extend the inspection intervals if the riser is not used under high loading and to ensure that the inspection and necessary maintenance is conducted.

Proper specification of integrity monitoring systems provides the information that allows for closing the loop between the riser design, manufacturing and use and riser integrity management.

SUMMARY

The integrity monitoring systems for deepwater risers have been described. Integrity monitoring technology has been developed to become useful tool for assisting with design and management of deepwater risers. Real-time monitoring, integrated with riser controls and equipped with data processing software, provides information to support decision making during operations. Stand-alone monitoring is used to ensure drilling riser long term integrity and to gather data for improving understanding of riser response. The value of the integrity monitoring programs is provided by enhancing design methodologies, optimization of deepwater activities and enabling effective integrity management of deepwater risers.

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