The use of SCRs with SEMI for the Development of Deep Water Prospects

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Summary

Steel Catenary Risers (SCRs) with Semisubmersible have recently been used in a number of deep water developments in the Gulf of Mexico.
Acceptable design of SCRs for production and export of oil and gas is enabled by ensuring that the risers can meet the required fatigue and strength targets. Vessel motions affect both the fatigue and strength performance of the risers.

The paper describes the approach and project structure used in recent projects to optimize the vessel motions to enable feasibility of different type of steel catenary risers as well as highlights the key technologies that had to be developed as part of these developments.

Introduction

In any offshore development our task is to deliver the fluids from the seabed to the floating structure safely and at low cost. Integral parts of such systems are the pipelines along the sea bed and the risers. Steel Catenary Risers (SCRs) are an efficient and economic way of carrying the fluids from a subsea development by extending the subsea flowlines to the floating host facility. The feasibility of the SCRs is strongly linked to the dynamic performance of the host facility.

Traditionally, SCRs have been used in the GOM as export riser systems and attached to either TLPs or Spars. Increasing trends for subsea developments from a variety of field sizes and water depths > 3500 ft, have made SCRs one of the favoured riser systems for production and test risers. In the past there has been a perception that vessels other than TLP or Spars are too lively to accommodate SCRs. The benefit of the SCR is that it is a simpler system as compared to top tension or hybrid risers. Furthermore, it is less costly since it only requires a connection system at the floating platform and somewhat more stringent fabrication in terms of welding compared to a static flowline to ensure adequate fatigue.

The oil industry has improved the basic semisubmersible hull form progressively to meet demands for increasing payload capacity, while retaining acceptable dynamic motions and improving station-keeping capability. Initially, drilling requirements drove semisubmersible design. Production semisubmersibles were adapted from basic drilling designs. Hybrid or flexible riser systems were tailored to suit the motion characteristics of these units for moderate water depths.

Today, the leading edge driver for semisubmersible design has become the application of steel catenary risers as a preferred flowpath solution for high-rate production in ultra-deep water. Semisubmersible designs have successfully adapted to meet this new challenge, while also delivering even greater deck load capacity to support large production plants.

Floating Facility Requirements

Hull Performance

During the Semi design, care is taken to select motion performance, because load-carrying efficiency will tend to decrease for improved motions (at a given total steel weight) for the unit. This tradeoff is at the heart of the design process for a semisubmersible that will support SCRs. There is more to motion optimization for SCRs than just minimizing wave-induced heave, which was the primary driver for good drilling performance.

Although the complexity of the design problem has increased for semisubmersibles with SCRs, recent experience has shown that a robust range of design solutions exist to meet motion requirements and also satisfy a range of different payload needs. This can be achieved without sacrificing primary semisubmersible constructability assets, such as: 1) Simple hull panel configuration, 2) modest plate thickness, 3) dry transportability of completed unit, (together with modest wet tow draft with complete topsides).

A basic discussion of design drivers for hull wave period ("first order") motions and payload capability is provided below in Table A in order to better illustrate the tradeoffs.

Table A – Semisubmersible Platform Design Drivers for Motion and Payload
▪ Larger units move less, but payload should determine size, not motion.
▪ Reduction in heave motion requires extra freeboard for wave clearance. This increase in freeboard must be considered with regard to stability (due to a higher payload COG).
▪ Increasing draft is the primary driver for improvement of vertical mode motions (heave, roll, pitch). However, increasing draft leads to decreased payload capability (due to lower center of buoyancy).
▪ Number of columns is not a strong driver of vertical motion but can have an influence on lateral wave response, especially with regard to wave period sensitivity
▪ Column spreading should be matched to required stability for deck load and also deck area requirements.
▪ Pontoon and column asymmetry is an available option to save steel while supporting a deck layout for hazard separation (heavy production modules aft – light quarters forward).
▪ Column lateral dimension is a primary driver for lateral motion performance (surge, sway, yaw), but water plane requirements for stability typically govern the column cross-section.
▪ Ring pontoons have been a recent trend to improve motions for production units. Pontoon shaping and angled columns can help with motions. Towing resistance is not a strong driver for long-term production service.

The above discussion has been focused on possible levers to improve the linear "wave frequency" response of semisubmersibles in a seaway, consistent with payload and deck area requirements. A later section discusses the interaction required to match motion performance to riser dynamic limitations.

A basic principle of floating system design requires that natural periods are controlled so that no direct wave energy should be evident at any natural period. For example, heave period of a semisubmersible will typically approach or exceed 20 seconds, and other modes of motion for the unit will have even longer natural periods.

Since there is no wave energy present at natural periods, any long period response that does occur for all floaters is the result of non-linear mechanisms. This type of non-linear response is controlled chiefly through the presence of damping for vertical modes. For lateral modes, both damping and lateral restraint (from mooring lines and SCRs) are effective motion limiters.

Mooring System

The mooring system design for a deepwater production semisubmersible is driven by a maximum acceptable static offset (including dynamic lateral motion) for the SCRs. Variation in weather severity or current severity from different headings ("directionality") may be included in the analysis. Predicted lateral top end semisubmersible motions (wave frequency and non-linear) are also characterized for the particular design of the unit.

For a subsea development with large number of risers, it is essential to include the effect of the SCRs in the lateral force applied to the unit. This is best accomplished by modeling the SCRs as another set of catenary mooring lines to capture the changing lateral SCR force with position. Multiple SCRs with a range of headings provide a complex set of constraints. Asymmetric mooring system layouts can result due to field architecture requirements and due to design tendency to “group” SCR attachment points away from the accommodation end of the platform.

A later section describes the interactive design approach required to match mooring design with riser lateral motion constraints. Mooring system designers are cautioned against over-optimizing the offset characteristics of the moorings because it is common for the SCR riser design to change in several respects (e.g. number of SCRs, departure direction, size, contents) as field development plans evolve. Scope should be kept in the mooring design (both literally in terms of extra top end adjustment) and figuratively to allow for some SCR design changes.

Riser Requirements

Because the SCR is a dynamic pipe, it must be designed so that to withstand the motions from floating facility, dynamics from waves, and water currents (VIV) and ensure adequate fatigue performance over the design life. Although the entire string exhibits dynamic behavior, there are mainly two critical areas. The point where the riser touches the seabed (TDP), and the area below the connection to the floating facility.

The SCRs need to be designed to have adequate strength during severe events (do not exceed the allowable working stresses) and adequate fatigue life.

The important parameters affecting the design of the risers are:

- Steel strength and operating pressure and temperature
- Wave and vessel motions.
- Currents over the entire water column
- Internal fluid, which could have an additional effect on fatigue.
- Properties of the soil where the SCR touches the seabed
- Insulation requirements (driven by flow assurance), which in turn will affect the overall diameter, buoyancy and dynamic characteristics.
- Hang off angle and position of the riser relative to the COG of the vessel
- Stiffness of the connection arrangement at the vessel.

The riser loadings are combinations of the static vessel offset, pressure, soil characteristics as well as dynamic effects from heave during severe events like hurricanes. Sufficient strength is required to ensure that the SCR does not buckle at the TDP and that the stresses are within the allowable limits, depending on the operating scenario (0.67 of yield during normal operation, and 0.8 of yield during extremes). It is typically the heave response of the vessel in hurricanes that will produce the highest stresses in an SCR.

Previously most of the SCRs were attached on either TLPs or SPARs. These vessels have relatively low heave motions compared to SEMIs. However, as discussed in the previous section, SEMI motions can be optimized to produce adequate heave characteristics.

Despite the optimization of the SEMI for heave, in the presence of GOM hurricanes, the extreme motions can put SCRs into compression and make their response become quite non-linear. To ensure robustness of the design under such conditions, it is necessary to study the response of the system at higher levels of input than are normally considered. It may be appropriate, for instance, to simulate the SCR in a 1000 year event to demonstrate a reasonable margin of safety in the 100 year event. The SEMI mooring system can be optimized to also reduce the offsets, hence ensuring that the SCR stresses remain within allowable in extreme scenarios.

Although it is difficult to generalize what SCRs will work with different vessels, because of the different parameters affecting the performance, Figure 1 shows an availability plot of diameter versus submerged weight of SCRs connected to a SEMI in deep water ~6000 ft in the GOM. For a combination of diameters and submerged weights below the yellow region, for Semis 1 and 2 as in Figure 2, the SCRs can be designed with acceptable stresses. Above the yellow region the SCRs diameter weight combination will

result in an unacceptable design. When the design falls in the shaded area, the SCRs begin to see compression at the TDP and their response becomes non-linear.
In general similar graphs can be generated for different geographical areas and water depths to aid feasibility or not of SCRs at an early project selection stage. Obviously one should not rely entirely in such high level graphs, but during design detailed analysis of the system should be conducted.

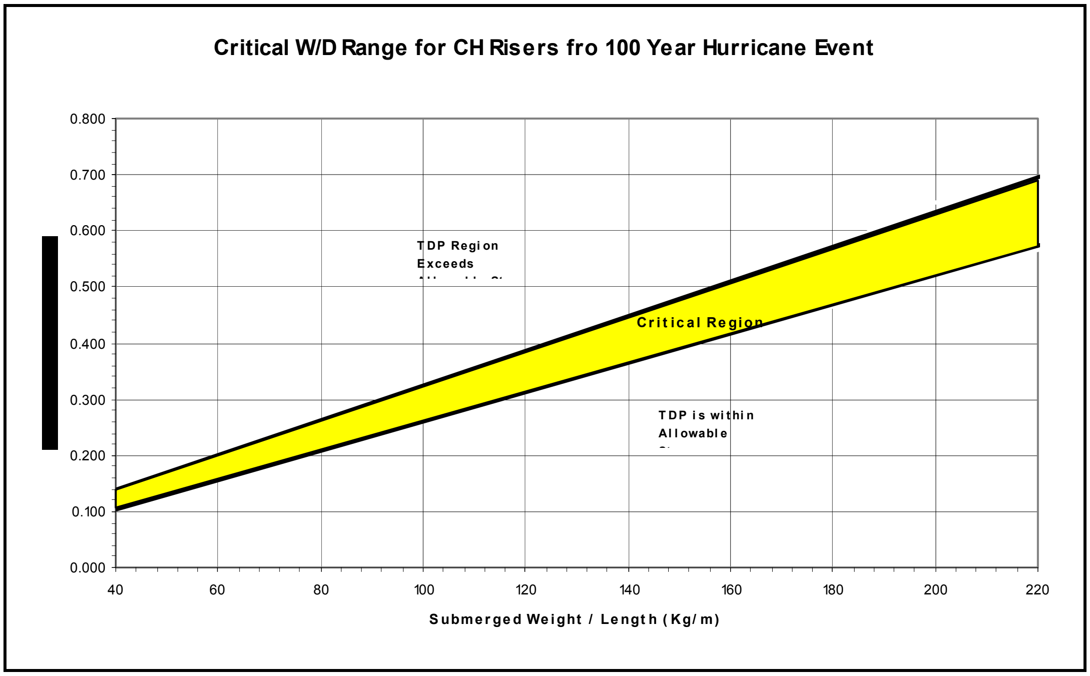


Figure 1: SCR Strength feasibility graph for 6000 ft WD for a given SEMI motions

There are two main SCR fatigue contributors, wave actions and VIV from the incident currents. The surge and sway motions of the Semi are dominant factors affecting the SCR wave induced fatigue. The vessel needs to be optimized for such motions. Figure 2 indicates the typical wave spectrum and surge motions in an optimized Semi.

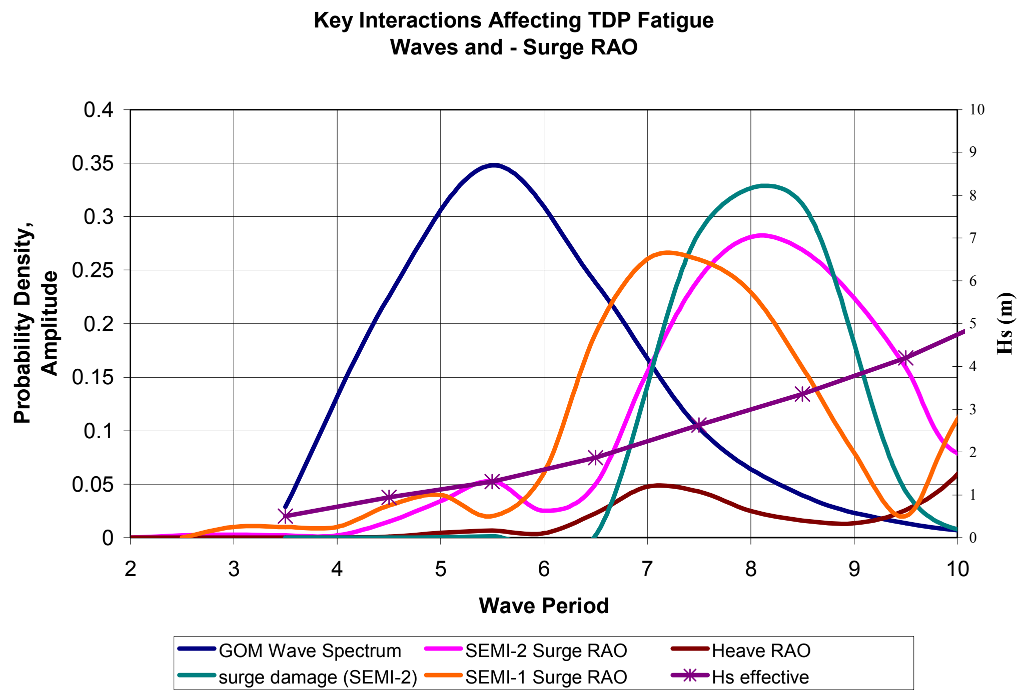


Figure 2: Wave and Vessel Spectra of a Semi 40000 tn payload in GOM

By moving the peak in the surge away from the peak wave frequency, better fatigue performance of the SCRs can be achieved. It is also indicated that other motions like heave peak further to the right. As the plot shows, for the heave optimized semi, heave contributes little to the response in fatigue.

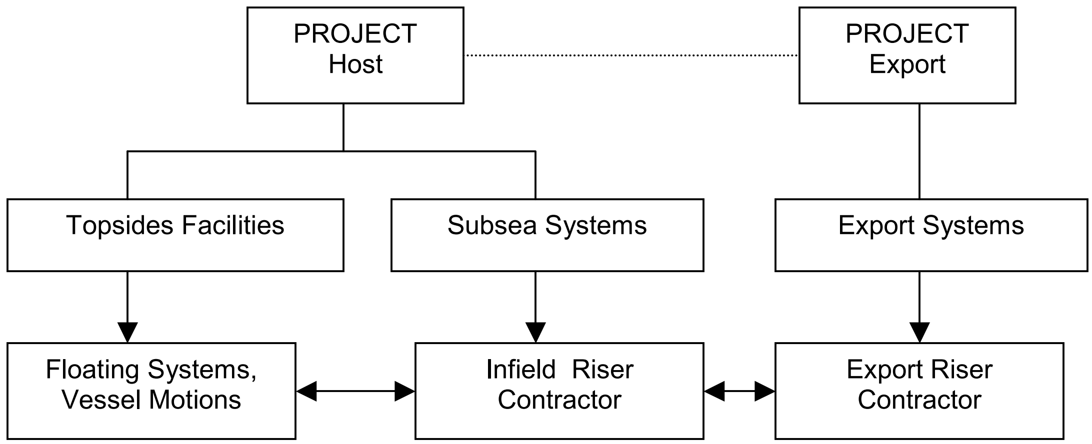
Hanging the SCRs to the inside of the pontoon and closer to the COG minimizes the moment leaver and improves the dynamic characteristics.
Also the higher the hang off angle the better the fatigue performance are, although the tension requirements increase significantly.

If the risers are un-straked, the current interacts with the pipe inducing VIV, which can dominate fatigue. If the risers are straked, VIV can still contribute significantly to fatigue but the wave fatigue will dominate. This subject will not be addressed further in this paper, but it is worth noting that an appropriate allowance must be made in the design for the fatigue damage that will be consumed by VIV.

Soil stiffness at the TDP affects the fatigue life of the SCRs. In a project, it is important that specific site soil information is available before the design progresses too far.
Field lay out and clashing philosophy between SCRs are the main parameters governing the required SCR spacing at the vessel. One advantage of SEMIs over other vessels is the room available to space the SCRs to avoid clashing.

Design Approach

In two recent deep water projects, the project teams were organized as indicated in Figure 3



Teams Worked closely from concept select phase of the project.
Used common design basis and analysis methodologies. One meeting for both riser teams and vessel contractor. Teams lead by a company team leader. Teams were proactive on the communication. Did not wait for the "standard interface" meetings. Informal communication between the teams made the process a success.

Figure 3: Project Organisation

The design loop used between the riser teams and the vessel designer is summarised in Figure 4. Because of the strong interdependency between the riser performance and vessel motions, it is essential that both riser and vessel contractors work very closely. From concept select phase the aim of the project was to produce a floater with motions to ensure the feasibility of the SCRs, both in terms of strength and fatigue

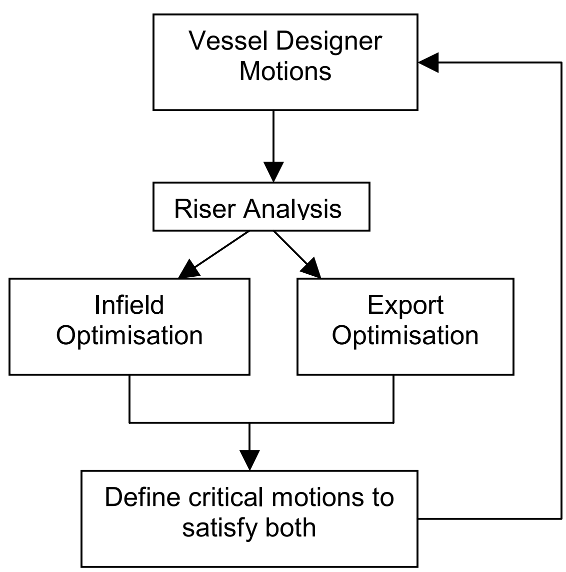


Figure 4: SEMI-Riser Design Loop

The Vessel designer had the responsibility for producing the vessel motions while the two riser contractors were responsible for the design of the infield and export SCRs respectively.
Independent verification of the vessel motions and design was coordinated by the vessel design contractor, while the riser design verification was coordinated by the company. One verification contractor was used for both the infield and export risers.

The approach used in the current projects by having three different design contractors is not easy to manage and requires big involvement from company personnel to coordinate the activities. Project contractual arrangements most of the time dictate the split between different disciplines. Experience within BP indicated that relying only on formal interfaces to ensure the communications between the different contractors, do not work and can result in expensive system modifications late in the design phase of the riser systems. An active project management with experience in the subject matter is necessary to guarantee the proper integration of the contractors' efforts.

To enable feasibility of SCRs with floaters in deep water, as a minimum, close communication between the different designers as indicated in Figures 3 and 4 is essential.
We also believe that the design of the mooring system should be with the vessel designer.

The challenges of the offshore environment and in particular in GOM required that new design procedures and methodologies be developed during the project. A number of tests were carried out to defining hydrodynamic coefficients for fatigue sea states (ref Proc OMAE, Oslo Norway, 2002, Paper No 28221), developing soil models, developing spreading methodologies and assessing impact of sour service on fatigue performance.

Soil Modeling

Soil stiffness has a significant effect on the fatigue response of steel catenary risers. A number of different soil stiffness models exist which give a range of soil stiffness values that may not always prove to be conservative. Recent data and models from the STRIDE and CARISIMA JIPs and internal BP test, together with site specific data, can be used to determine soil stiffness based on soil density and shear strength. The findings from the JIPs came from testing in the size range, displacement range and frequency range typical to SCRs fatigue motions. The results showed that even when risers entrench themselves, the soil responds to the dynamic small motions associated with fatigue seastates with a higher stiffness than the large displacement static stiffness. This higher stiffness leads to higher fatigue damage. Figure 5 shows the qualitative difference between the dynamic stiffness and the soil backbone curve slope.

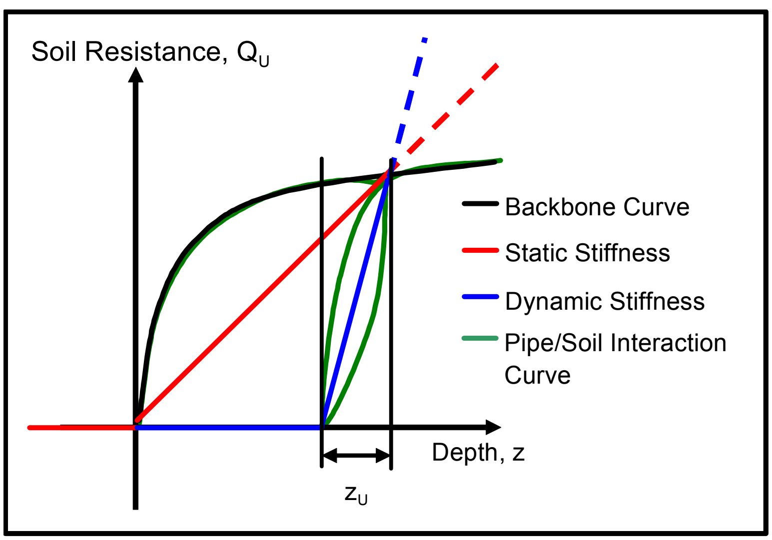


Figure 5: Soil Curves

Spreading

It is generally the case that wave loading fatigue damage on an SCR peaks at the TDP, where it touches the seabed causing a discontinuity. This is illustrated in Figure xx, where the dotted line shows a typical fatigue damage distribution along the riser length for a single seastate. It is logical to conclude that the fatigue damage at the TDP region can be significantly reduced if the TDP moves around over the long term, so that the fatigue damage is spread over a longer length of riser. Indeed, this long term TDP movement can be naturally occurring, or can be enforced through operational measures. A reliable source of this TDP movement comes from the vessel mean offsets, which vary with the intensity of environmental loading including wind, current and waves. The larger these offsets, the larger the effect of damage spreading.

Traditionally, long term fatigue seastates are condensed into three directions defined with respect to the initial riser plane, namely, in-plane far, in-plane near and cross. Wave loading fatigue analysis is performed for these three wave directions. As far as damage spreading is concerned, this approach does not closely represent the reality that the fatigue waves and associated wind and current vary continuously in direction and intensity. Therefore, in a natural environment, the TDP would move continuously, whilst in fatigue analysis, the TDP movement is limited to the discrete TDP locations associated with the seastates analyzed. This results in the artificial concentration of damage at these locations.

This situation can be improved most efficiently by increasing the number of wave directions, and secondly the number of seastates in each direction. The appropriate numbers of wave directions and fatigue seastates to use in fatigue analysis depend on the site specific long term wave conditions including directional variations and vessel motion characteristics, and are usually determined by sensitivity studies and by the criticality of fatigue performance of the SCRs in question. A sensitivity study was conducted to determine the effect of damage spreading for two fatigue seastate blocking schemes, one with 4 wave directions and a total of 65 seastates and the other with 8 wave directions and a total of 95 seastates. For the first scheme, it was found that including the vessel mean offsets resulted in a 1.5 times increase in minimum fatigue life at TDP, relative to the no mean offset case. For the second scheme, this ratio was found to be 2.5. The second scheme was adopted by the riser design teams. The effect of this spreading is demonstrated in Figure 6.
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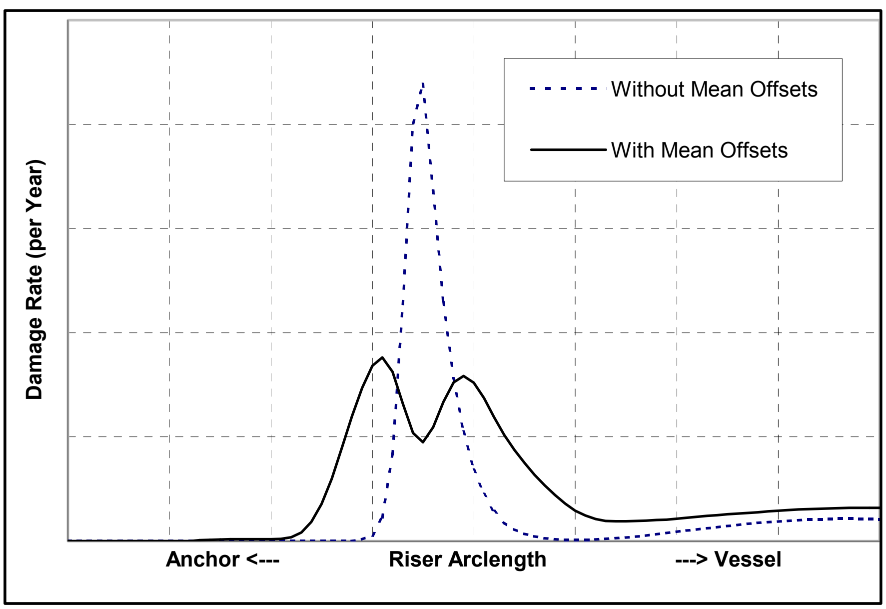

<u>Figure 6:</u> TDP Region Wave Loading Fatigue Damage Along Riser Length – effects of Mean offsets

Such analysis is of course time consuming but we believe essential to accurately model the behaviour of the risers and avoid unnecessary and expensive fabrication modifications in order to prove adequate fatigue.

Corrosion Fatigue

A number of tests on samples from actual pipes were conducted in the operating sour environment to obtain both endurance and crack growth data. From that data design fatigue curves for sour service were developed.
It was found that the sour service curve has significantly different slope to the in air fatigue curves. The results of the testing demonstrated the importance of testing in the actual environment, at the proper

frequencies and at the stress ranges appropriate to the SCRs. Basing the design on simpler reduction assumption from in air curves is believed to be conservative.

Verification

The company appointed the riser verification contractor while the design was near completion. The verification contractor was given the design basis and was left to analyse the risers based on their own approach and tools. It is important to emphasize that the verification contractor did initially used methods which were very different to the designers and in some respect conservative. This resulted in large number of interface meetings extending the duration of the verification period significantly. One of the key lessons learnt is that engage the verification contractor early on so it understands the methodology and assumptions used and the reasons behind it.

Case Study

A typical case study illustrates the interactive design process for a production semisubmersible with SCR's. Figure 7 outlines the overall procedure. Basic input field development data drives the overall sizing of the semisubmersible, consistent with construction, transportation, and installation restrictions.

In parallel, the basic flow path size and strength requirements of the most critical SCR (typically large-diameter export riser) establish the allowable extreme upper end motion and, hence, the top angle and the resultant tension at the hang-off porch on the platform.

Hull Configuration Optimization

Next, the design process focuses on wave frequency motion optimization using linearized tools that can be run efficiently. The wave frequency performance of the design will drive the selection of the hull dimensions of the semisub, so that acceptable SCR fatigue life is achieved. Figure 8 illustrates successful optimization of SCR wave frequency fatigue results as achieved through the optimization sequence described above. An iterative process is used to work through a range of dimensional variations of the hull (draft, column shape, pontoon shape, column inclination, etc.). Only hydrostatically stable, viable design configurations are tested for dynamic motion performance.

For all configurations that deliver acceptable extreme motions, fatigue life is checked by the riser contractor. For efficiency, this can be done using a simplified riser model based on the resonant behavior of the SCR and modal superposition. Typically, several SCR types (production, injection, export) are required for a development. Each of these types will have different fatigue characteristics that will need to be assessed to determine the governing case. Some SCR porch locations may also be shown to be more critical for motion of the Semi than others.

After initial screening, a final step is shown where, for example, the riser contractor analyzes the 10 best-performing configurations in more detail. This is done with non-linear tools to more accurately assess and compare performance. In principle, a final hull configuration selection is made based on construction cost consistent with acceptable riser fatigue performance. In the typical case where there is not a great difference in steel weight / construction cost between the successful alternatives, then the most efficient fatigue performance can be selected to provide design margin for the riser system.

Mooring Optimization

Referencing again Figure 8, the selected Semi hull form is an input to the Mooring optimization so that low frequency motion and lateral offset can also be optimized to deliver improved SCR fatigue and ultimate strength performance. Figure 9 details the mooring and low frequency optimization process. Key input parameters include basic SCR and Semi characteristics together with mooring layout constraints such as field architecture or natural features on the seabed.

Initially, a mooring design candidate system is developed to satisfy basic mooring criteria (API RP 2SK, for example) at the target maximum offset assumed within the SCR design. A fully coupled analysis of the SCRs, moorings, and Semi is then performed. Most software available for this challenging task are time domain based and require considerable time to run. A number of input height/period wave conditions must be run to assess fatigue in combination with the scatter diagram for waves in the area. Judicious selection of the most critical sea states may be required to address practical time constraints. Critical fatigue sea states must be selected with consideration of both SCR sensitivity (including all types of SCRs) and also likelihood of occurrence of the sea states. Time series of coupled motions for each sea state are typically the output from this phase of the analysis.

Riser porch motions from the coupled analysis are provided to the riser contractor as input for SCR fatigue and strength evaluation. The SCR fatigue analysis was assessed with the full time series provided from the coupled analysis. Wave energy spreading due to wave change over the mean was also used in the analysis. This approach which is physically realistic spreads the damage due to wave frequency motion over a larger section of the SCR.

The mooring design optimization continues through several trials to determine the lowest cost mooring system that satisfies the fatigue and ultimate strength requirements of the SCR design. Adjustments in the SCR design may be required if a satisfactory fatigue solution cannot be reached. In this case, a revision of the input mooring design may be required, because of the large tensions and “mooring effect” of the SCRs. One of the key design variables in this stage of the design is SCR hang-off angle, which can make a significant difference in SCR performance, but also has a strong effect on mooring and coupled response. Figure 9 illustrates iteration in both mooring system and hang-off angle as shown.
Returning finally to Figure 7, the optimized Semi hull form and mooring/SCR system is re-checked by the riser contractor for satisfactory performance using a full suite of fatigue and extreme sea states. If fatigue life is determined to be unsatisfactory in this detailed stage, then one additional “lever” can be employed before recycling the complete design. This step involves consideration of “re-positioning” of the Semi. In other words, the Semi is periodically moved on its moorings so that new sections of the SCRs contact the seabed, thus enhancing spreading of damage zones at a new set of TDPs. Re-positioning may be a natural by product of drilling or completion activity from the Semi, or it may be a prescriptive program involving deliberate yearly mooring moves.

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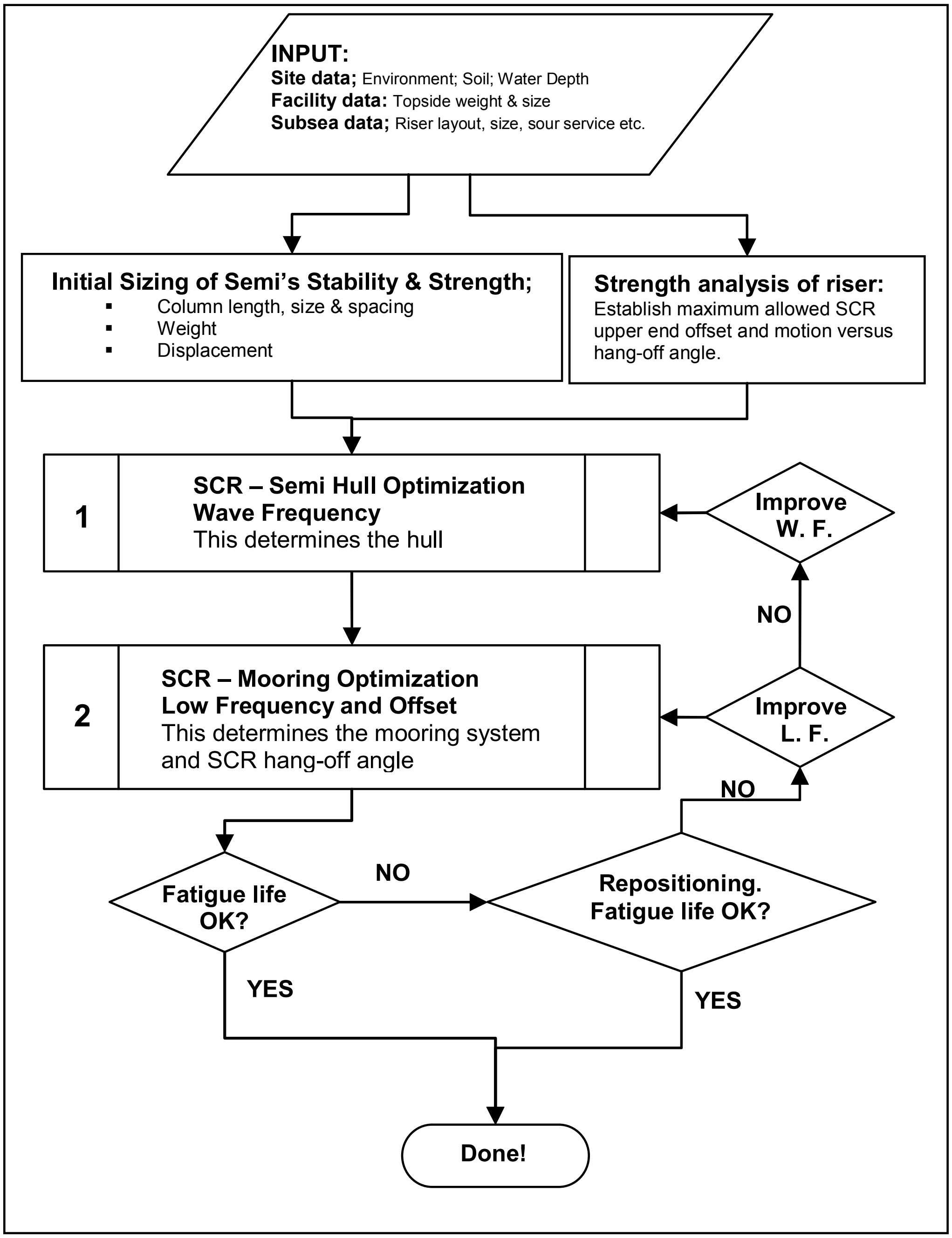

Figure 7: Schematic design loop for determining optimal Semi hull and mooring system for a specified SCR configuration.

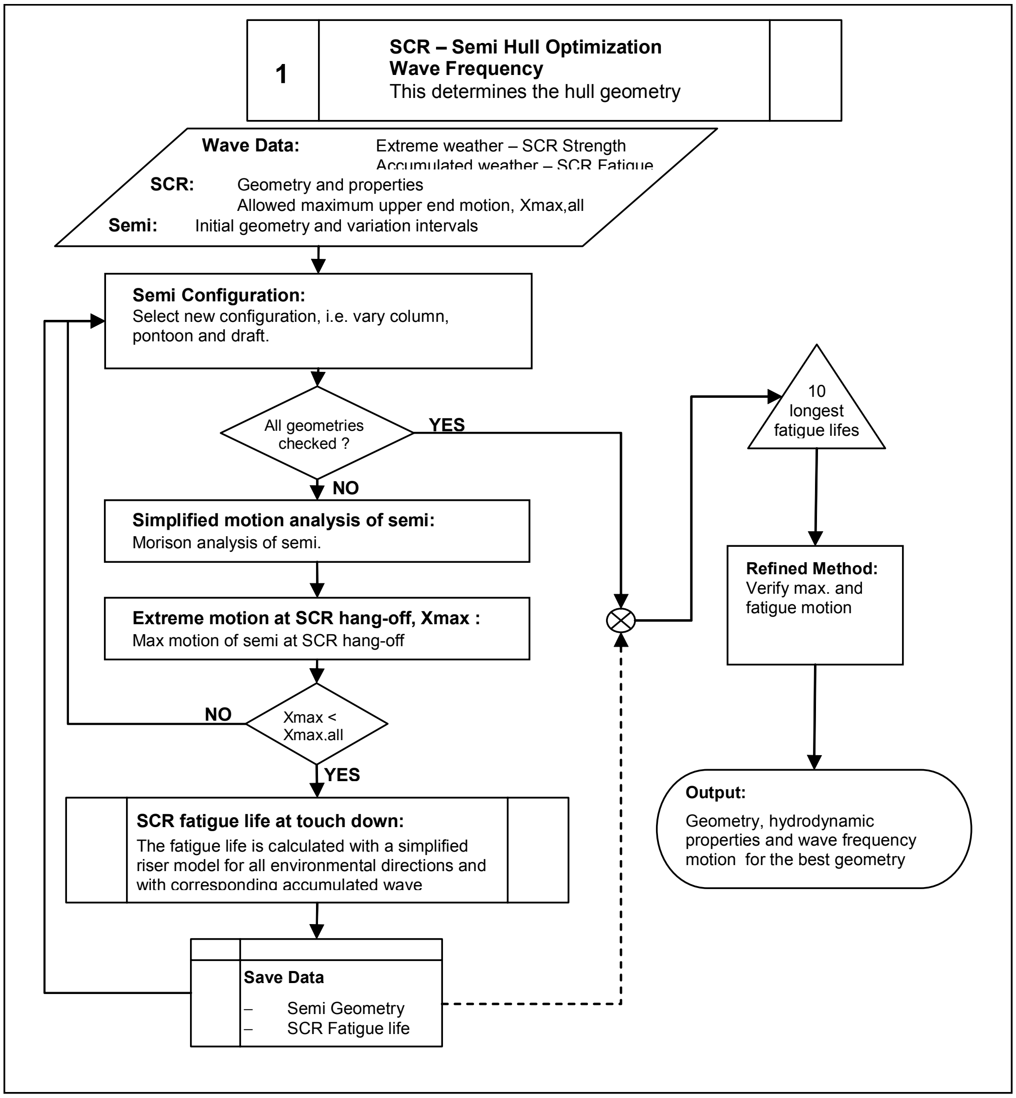

Figure 8:. Schematic design loop for doing wave frequency optimization of Semi hull.

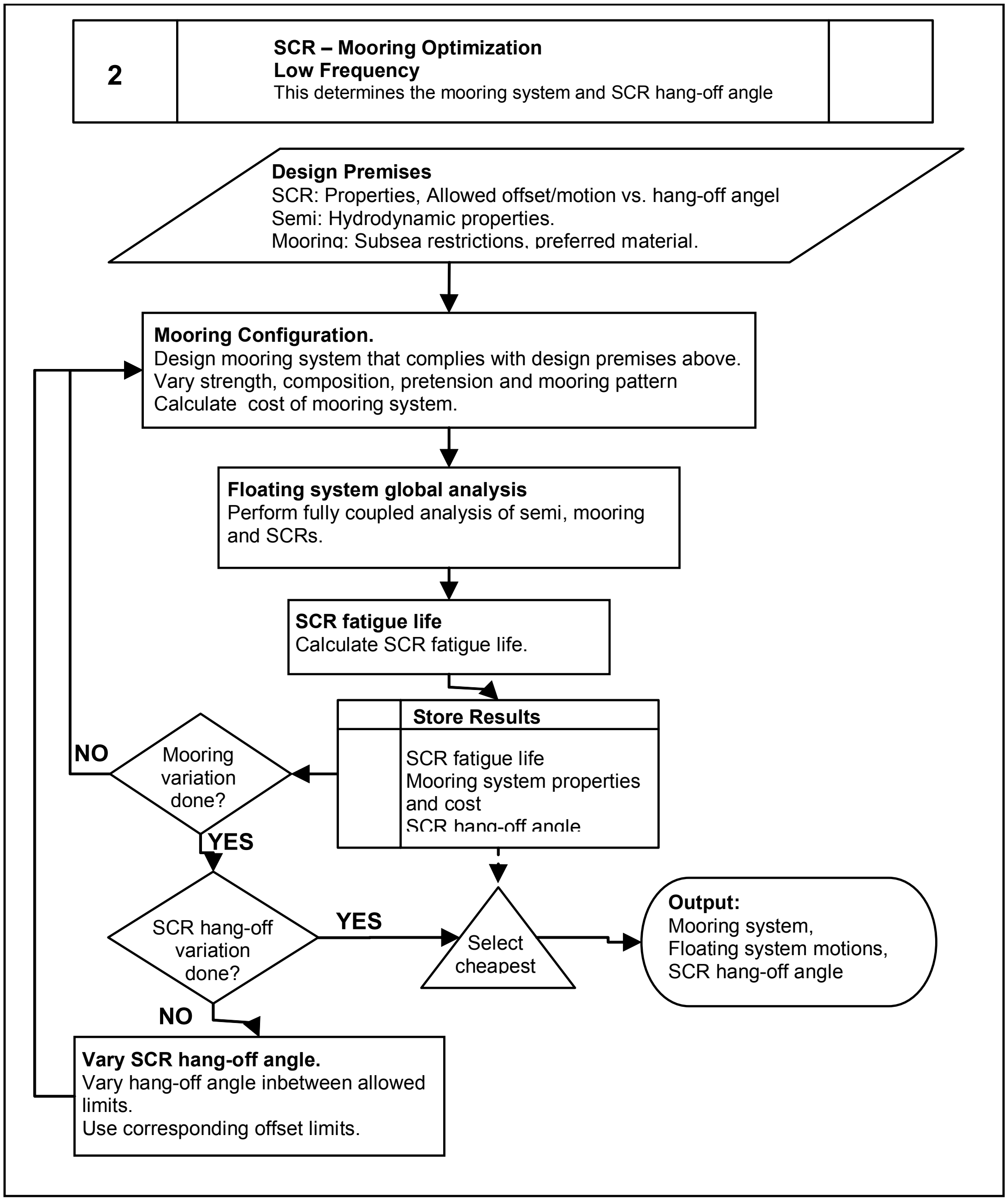

Figure 9: Schematic design loop for doing low frequency optimization of Semi hull