

Modelling advances enhance riser fatigue prediction accuracy

Mark Dixon illustrates how more accurate fatigue prediction using the latest advanced modelling to look at aspects such as touchdown zone fatigue enables operators to select the most cost-effective riser system for deepwater field developments.

Mark Dixon explica que una predicción más precisa de la fatiga, empleando modelos avanzados para estudiar aspectos tales como la fatiga en las zonas inferiores, permite seleccionar los tubos de subida más rentables para prospecciones en aguas profundas.

Mark Dixon décrit comment des prédictions plus précises de fatigue faisant appel aux outils de modélisation sophistiquée les plus récents qui portent sur divers aspects (dont la fatigue dans les zones de contacts) permettent aux opérateurs de sélectionner le système à colonnes montantes le plus rentable dans le cadre du développement de gisements en eaux profondes.

Steel catenary risers (SCRs) offer a number of advantages in deepwater production - not least being the fact that they are compatible with all host types, and can often be the cheapest riser option, depending on specific field, environmental and load constraints. In terms of design, however, the issues to consider, though few, are complex. The deeper the water the larger the diameter (especially in more hostile environments and with hosts that have limited station-keeping), and the greater the design challenge becomes for an SCR, especially from a fatigue perspective, to the point where the costs become prohibitive, or risks too great, in deepwater.

Traditionally fatigue assessment of SCRs will be highly conservative due to a lack of precise understanding of the cyclic stresses to which the SCR is subjected, and erring – necessarily given the massive cost of failure – on the side of extreme caution. Now, however, where initial analysis indicates insufficient fatigue life in an SCR, the latest advanced riser modelling capabilities independently developed by DeepSea Engineering & Management, the deepwater consultancy geared to optimising design to maximise return, enables considerably more detailed and accurate modelling to be undertaken. This in turn facilitates significantly greater accuracy in fatigue prediction, allowing undue conservatism to be overcome and system design to be optimised for maximum cost-efficiency, while always retaining full technical assurance. SCRs – renowned as a cost-effective option at 1500 m, but widely viewed as apparently unviable at depths below 2000 m – could prove after all to be the optimum riser system for some deepwater projects.

Accurate fatigue prediction

This advanced riser modelling achieves more accurate prediction of riser system behaviour by permitting a number of issues to be considered, accounting for all the major physical influences. Advanced touch down zone (TDZ) modelling of the riser/seabed interaction, for instance, will enable factors such as trench formation and development, time-dependent and loading-dependent effects

of seabed behaviour, and varying seabed properties along the riser to be accounted for – none of which are considered in conventional modelling. Equally, accurate modelling of pipe-in-pipe SCRs can be undertaken, looking at individual representation of the flowline and carrier pipes and the spaces and gaps between the spacer and inner surface of the carrier pipe. And the ability to undertake time domain vortex induced vibration (VIV) analysis using computational fluid dynamics (CFD) coupled with finite element (FE) structural dynamic analysis, provides the most accurate modelling and therefore greatest understanding of this cause of riser fatigue currently available.

The tools required to achieve this complexity of riser modelling are not industry-standard, and require appropriate expertise in the model development and successful use. However, with a combination of structural mechanics expertise, knowledge of subsea architecture and ability to apply advanced analysis techniques efficiently to complex non-linear problems DeepSea is able to assist operators in the design and analysis of deepwater SCRs, addressing technical, economic and risk management aspects of the design.

Touchdown zone fatigue analysis

Riser-seabed interaction is a particular area in which this advanced modelling expertise can offer significant benefits. Fatigue in the touchdown zone (TDZ) of an SCR on the seabed is the governing factor in the SCR's durability, and is heavily influenced by the riser-seabed interaction. Yet it is in this interaction modelling of the riser and seabed that the greatest uncertainty in the analysis of SCRs lies.

It is known that the fatigue is proportional to the soil reaction force, which increases with soil rigidity, but complex interactions of the seabed soil composition, its non-linearity, and the random and cyclic nature of loading, make it difficult to predict SCR behaviour in the TDZ accurately. It is with this in mind that DeepSea has developed its advanced model, applying its expertise and in-depth knowledge and drawing on published results of other work, including two JIP studies Carisima and Stride.

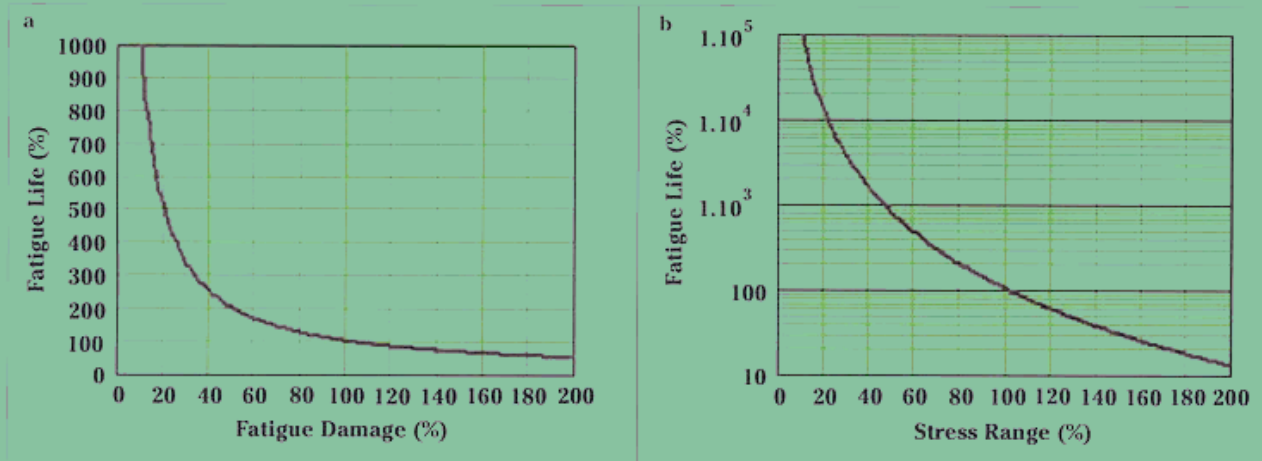


Fig. 1. Left is a graphical representation of relationship between fatigue life and fatigue damage (curve F2). Right shows the relationship between fatigue life and stress range (curve F2).

This riser-seabed interaction modelling allows the influence of physical phenomena (such as axial friction, lateral resistance, soil suction forces, vertical seabed stiffness and trench formation and development) on the SCR performance to be identified and quantified. As a tool that can represent these aspects accurately, this can help to improve operability of the design while retaining sufficient conservatism, and can be applied either at concept selection and pre-FEED stage (demonstrating viability and providing key data into the FEED scope of work) or, more typically, at detailed design stage (verifying the design, validating the linear soil stiffness selection, and maximising technical assurance by addressing the risks associated with soil response uncertainties).

DeepSea, for example, has undertaken such advanced modelling looking at:

Riser-seabed vertical interaction and its influence on SCR fatigue.

The influence of the seabed profile on SCR fatigue (including influence of trench profile on fatigue damage).

A comparison point as to the influence of an elasto-plastic seabed on the fatigue life prediction for an SCR (establishing whether accounting for the seabed behaviour provides additional margins for the design requirement).

THE ISSUE

In terms of touchdown zone fatigue, the high degree of conservatism in design has arisen because traditional modelling used in current design practise deploys an elastic (or more crudely a rigid) seabed, and does not allow for soil softening under repeated loading, despite the fact that this phenomenon is well recognised. This introduces significant conservatism in fatigue life predictions such that, while not a problem in more moderate water depths, for deep and

ultradeep developments ignoring this critical factor means these conventional linear seabed models may not allow SCRs to pass minimum fatigue life requirements. This substantial safety margin can be better managed by more accurate modelling.

It is believed that most of the fatigue in an SCR's TDZ comes from the lifting and setting down of this section, where it undergoes cycling bending between zero and the maximum curvature, which changes with seabed stiffness. A small change in seabed stiffness can result in a small change in bending stress, but this causes a significant change in fatigue life. The need for riser-seabed interaction modelling to be as realistic as possible is evident.

Accurate modelling is not simple, however. The soil (lying on the interface of seabed to water) undergoes cyclic loading and generally does not obey well-established laws of soil mechanics used in most geotechnical engineering. Further, dynamic motion of SCRs causes repetitive loading and unloading of the soil under the pipe, causing soil degradation and creation of a trench (reaching, in some reported cases, over 100 metres in length and five diameters in depth) which changes the seabed profile in the TDZ, and results in reaction load redistribution on the SCR, significantly influencing its fatigue life.

DeepSea's model, valid for cohesive soils, therefore takes into account all aspects of the soil behaviour characteristics (compressive, unloading, peak-to-peak stiffnesses, hysteresis and so on), and seabed profile (being capable of gradual trench development) and axial variation of soil response through the TDZ.

Several projects have been undertaken by DeepSea to investigate the influence of the non-linear soil response characteristics on SCR fatigue life, on risers ranging from 12 to 24 inches diameter, with and without insulation coating, in over 1000 metres water depth, for projects in the Gulf of Mexico and West Africa.

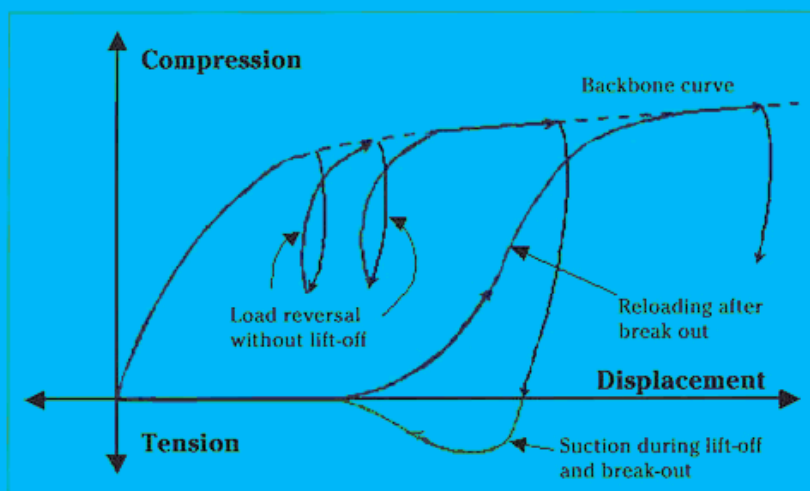


Fig. 2. Soil reaction-displacement relationship during loading-unloading-reloading for a Gulf of Mexico and West Africa soft deepwater clays.

Time domain analyses were carried out with regular and irregular seastates using the Abaqus general purpose finite element package, with motions selected to represent a range of floating platforms including spars, semi-submersibles and FPSOs. Interestingly, these analyses have shown increases in fatigue life predictions ranging from a factor of two to 10, depending on vessel motions, SCR configuration and the seabed soil conditions, although the results do not necessarily support the common belief that non-linear soil with plasticity will always result in less damage.

One study by DeepSea, for example, analysed and assessed the fatigue of one of the SCRs for a West African project. The objective was to provide a comparison with standard riser programmes vis à vis the influence of the seabed on the fatigue life prediction, and determine whether accounting for the

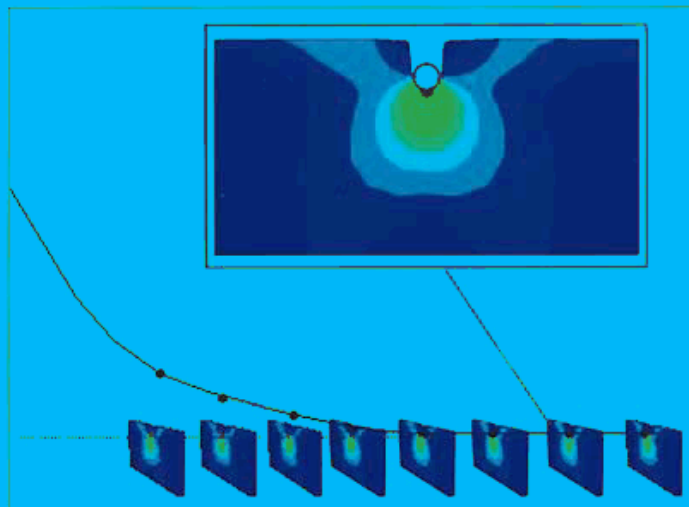


Fig. 3. Example of coupled 2D soil and 3D riser dynamics model.

seabed behaviour provided additional margins above the design requirement.

A more precise evaluation allowed greater design freedom for the SCR and avoided undue conservatism, but with technical assurance. An interesting theme of the findings was the soil reaction patterns where the peak reaction forces are lower for the non-linear seabed than those for an elastic seabed, but they tend to be spread over an increased length of the SCR in the TDZ.

Another project undertaken by DeepSea involved a study of the trench profile on SCR fatigue. As the SCR trenches into the seabed the touchdown point (TDP), and therefore fatigue point, changes location with alteration of curvature at the seabed. It is generally believed that this reduces fatigue damage

as the transition from the curved suspended portion of the SCR onto the section supported by the seabed is more gradual, but the actual curvature at the TDP and position of the TDP are governing factors in any fatigue differences between a flat and profiled seabed. Trench depths from three to six or seven diameters in particular will significantly alter the location of the fatigue point, distributing fatigue damage axially along the riser.

Seabed plastic deformation can be significant in extreme cases, during a three hour simulation, the resultant seabed plastic deflection extrapolated (without accounting for increasing soil stiffness with depth) results in a trench formation rate of approximately one diameter every two or so days. Such findings can be applied to determine more accurately the influence of the trench profile on fatigue damage.

While SCRs offer numerous benefits, the complexity of design and disproportionate escalation of technical issues to address in deeper water, and inability to demonstrate sufficient fatigue life using conventional modelling, has precluded their use on some ultradeep projects. By enabling the key physical influences such as touchdown zone fatigue to be analysed and assessed, however, advanced riser modelling as developed by DeepSea now considerably enhances accurate fatigue prediction, potentially opening up the options and enabling the most cost-effective riser design for a particular field development to be selected with full technical assurance.

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