Umbilical modeling aids fatigue prediction

As water depths increase, modeling techniques must keep pace.

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Until recently, interactions between internal components of an umbilical have been more or less neglected in modeling for fatigue prediction. However, in deeper waters and larger umbilicals, such interactions can contribute significantly to creating the conditions for umbilical failure. DeepSea has independently developed a suite of tools and processes for evaluating the internal performance of large umbilicals in deep water. These tools and processes allow the quantification of inter-component friction stresses as an integrated part of current project execution processes. They enable users to make informed adjustments to designs before building and testing them, thus enhancing the design process, reducing installation risk and helping to contain costs through the entire lifecycle of the dynamic umbilical.

The challenge

Steel tube umbilicals (STUs) link a host/control platform to associated wells and provide the hydraulic, electrical, signal and chemical functionality required for each well. Failure of even a single component in an umbilical will generally halt production because well control or flow assurance requirement has been lost. Locating a failure presents significant challenges — repair to a dynamic section is not feasible because of the high level of structural integrity required under the demanding conditions in which operations take place. Therefore, the processes and techniques used to design STU systems for maximum reliability and integrity need to model the actual behavior of the components as closely as possible.

To date, the relatively simple calculations used to analyze the behavior of umbilicals in shallower waters have yielded acceptable results. However, as requirements shift towards deeper water and larger diameter, heavier umbilicals, the interactions between the umbilical's internal components contribute additional stress and fatigue. Using traditional methods of design in these circumstances can lead to a non-conservative design, increasing the likelihood of umbilical failure.

The next generation of design

Current design practices approximate umbilicals as a single homogeneous structure. This approach leads to adequate modeling of the "global" behavior of an STU, i.e., the behavior of a long length of umbilical, but it falls far short of representing the behavior of the complex system of helically wound tubes and cables inside the umbilical. Sophisticated numerical tools such as ABAQUS are capable of modeling the complicated geometry and interactions inside an umbilical; however, they are very demanding of computing power and thus impractical for modeling the entire umbilical. DeepSea's approach combines proven global systems models with more complex 2-D and 3-D models to capture local stresses and contact between internal components. Starting with a global model of the umbilical system, constructed in an industry-recognized tool, force and curvature time histories of the components are generated. These are converted and then used as the input to local finite element models of the umbilical.

At this stage, either a quasi-3-D or a full 3-D approach can be adopted. In the quasi-3-D approach, axial tensions are applied to the umbilical; the radial forces are calculated and applied to the components via a specially developed helical element producing quasi-3-D modeling in a detailed 2-D finite element model of the cross-section.

A cut-away view of meshed umbilical components. (Images courtesy of DeepSea Engineering)

The quasi-3-D approach captures movements and deformation of all the layers and components as well as the frictional forces between them. It provides an extremely efficient process for establishing the friction stress contribution that should be included in fatigue analysis of the umbilical, accounting for the inherent asymmetry of an umbilical's lay-up.

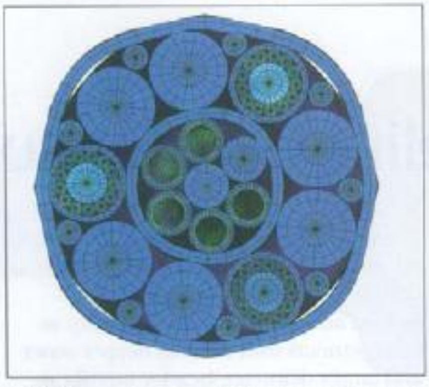
In a full 3-D approach, a representative 3-D length of the umbilical is modeled. This provides more accurate inter-component interactions, particularly for large STUs with multiple layers that are counter-wound.

In addition, full 3-D modeling permits better assessment of the installation conditions as the umbilical passes through the tensioner system because it captures the correct load transfer from the tensioner pads into the umbilical components.

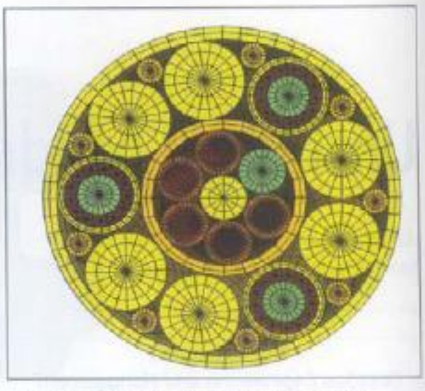
Benefits of advanced modeling

In the past, lack of knowledge about interactions between STU components has been a major issue in fatigue assessment of these structures. More accurate modeling can result in detailed targeted changes to designs and technical specifications, optimizing performance and minimizing manufacturing cost.

These improved modeling capabilities can also be applied to the installation



A deformed cross-section of an umbilical while crushed by pads.



An umbilical cross-section (meshed).

phase. Outcomes include more precise assessments of acceptable weather windows and a greater pool of installation vessels to choose from. All operations in the installation and the effects of wave and current loading during the operation can be assessed for their impact on the installability of the umbilical. When laying umbilicals in deep water, compression loading at touchdown point can be assessed with greater accuracy. This leads to greater confidence in the assessment, which can allow costly lay processes, such as lazy wave with distributed buoyancy, to be avoided, thus reducing both capital expenditure and lay time.

Case study

DeepSea has been frequently commissioned to assess crush loads during installation of steel tube umbilicals.

In one particular case the client's concern was the potential damage through crushing under tensioner pressure during installation. The project successfully modeled the complex interactions under tensioner loading between the counter-wound layers of internal components. A similar issue exists for umbilicals that provide individual conduits through which the steel tubes and electrical components are located. The internal friction associated with this type of umbilical construction requires detailed understanding, as the fundamental approach is for these conduits to minimize friction within the cross-section. This is beneficial for dynamic fatigue response, but some friction between components is required to ensure sufficient axial load sharing between steel and copper components and to ensure that the tensioner pressure is correctly transferred into the product during installation.

For the umbilical in question the transfer of the tensioner grip/pressure to the central tube was the focus of this study. Detailed quasi-3-D and full 3-D finite element modeling of the umbilical cross-section under tensioner crush loading and axial tension was successfully undertaken. This showed all internal contact and accounted for the manufacturing tolerances/gaps between components.

The results from the quasi-3-D model showed that there was sufficient contact between the outer counter-wound layers and the central tube after crush loading and axial pull was applied to avoid its slipping during installation.

The difference between the quasi-3-D and 3-D results indicate short samples (less than a pitch length) are less stiff radially than the full continuous umbilical, thereby resulting in greater radial deformation. This was expected as the total helix structural capacity is only available for loading over a long, continuous length of several pitches. The radial stiffness of the full 3-D model is a more accurate representation of the true physical situation.

Through use of the quasi-3-D and full 3-D modeling techniques, it was possible to demonstrate to the client with high confidence that the friction acting on the central tube due to load transfer from the tensioner pads was sufficient for installation without risk of damage, while ensuring good dynamic fatigue response. E&P