Longer Life for Deep-sea Lifelines

Abaqus FEA helps Technip engineers custom design umbilicals for deep offshore oil and gas wells

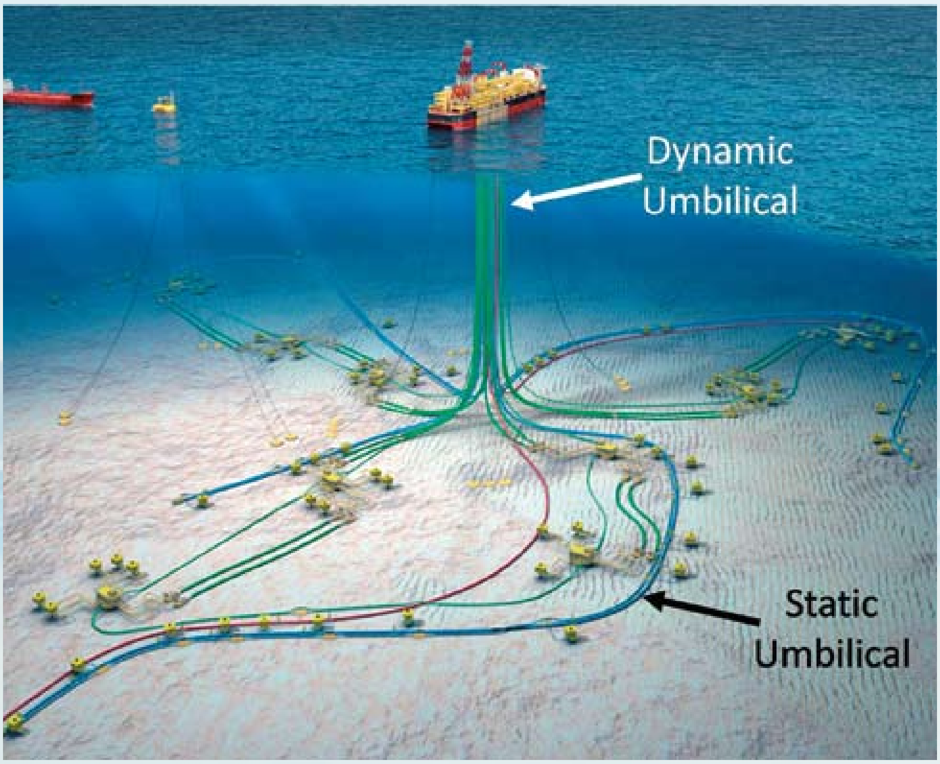

Figure 1. Umbilicals deployed from an installation vessel provide deep-water oil and gas fields with power, communication, and the necessary fluids required for hydrocarbon extraction.

Umbilicals are the lifelines of deep-sea fields, connecting the well to the mother ship, offshore platform, or onshore terminal. They are critical—providing the power, control, communication, and fluid injection that keep deep-water wells healthy and pumping around the clock (see Figure 1).

Durability is essential whether the umbilical is hanging in the water column (dynamic), resting on the sea bed (static), or connecting important field infrastructure. That's because pressure and temperature extremes, wave and current action, and sour fluids all conspire to break, or at least damage, the umbilical and its contents.

Given their important role in deep-sea hydrocarbon extraction, the cost of installation, the difficulty of on-site repair, and the expense of a field being down, it's no surprise that umbilicals need to be designed and built to last. Typical umbilical design life is 25 years, but at Technip Group's DUCO Ltd.—considered the world leader in umbilical design and manufacture—they use the ISO standard and set design fatigue life at 10 times the design life. "For a 25-year design life, we design for 250 years in terms of fatigue," says Ian Probyn, senior engineer, R&D, at DUCO. "With offshore umbilicals, failure is not an option."

Deep-water installation

Building failure-proof umbilicals is difficult enough, but it's made even more so by the challenges of deep-water installation. Wound onto storage reels and then mounted on a specialized installation vessel, the umbilicals need to deploy in a highly controlled manner to reach a precise target on the ocean floor.

The umbilical is fed through a Vertical Lay System (VLS) that controls the unspooling by applying a holdback tension to the umbilical as it hangs from the ship. The holdback tension is typically created by four caterpillar tracks with V-shaped pads, which apply a radial crush force to the umbilical using friction to control the deployment.

As the depth of a deep-sea well increases, the tension and the crush load required to hold the weight of the lengthening umbilical also increase. Up to 30 tons per meter of radial load can be applied to a steel tube umbilical during deep-water installation.

Needless to say, this kind of pressure on the umbilical can cause deformation to the tubes, which have point contact (where tubes in adjacent counter-rotating layers cross) due to the umbilical's helical construction. DNV (Det Norske Veritas), Norwegian risk-management specialists, recommends that three percent residual ovality (permanent tube deformation following crushing) is acceptable; higher levels of deformation can negatively affect the umbilical tubes' resistance to hydrostatic pressure as depths increase. Residual ovality can also impair fatigue resistance to pressure cycling over time. As a result, understanding umbilical crush behavior in detail is critical to ensuring product integrity, establishing load limits, and designing out failure.

As projects get more expensive, there is more risk, and customers want more of the engineering work done up front. "Being able to prove that the design fits the purpose is critical," Probyn says. "With realistic simulation, we're able to see inside the umbilical. That's something you can't do with physical testing. FEA provides that level of detail."

Simulation customization for design flexibility

U.K-based DUCO first chose Abaqus FEA for their umbilical R&D in 2005. "We did an evaluation," says Dave Fogg, R&D team leader, "and Abaqus stood out because of its Explicit solver capability for analyzing highly nonlinear, dynamic behavior." This capability is important, he adds, given the helical structure of the umbilical, interaction between the components, and bending stiffness due to friction.

Another benefit of Abaqus is its ability to customize scripting tools. This customization is important because each client comes to DUCO with their own unique umbilical requirements. Since each product is essentially one-of-a-kind, the FEA tool and simulation process need to be flexible enough to accommodate this high degree of design variability.

DUCO, in collaboration with French-based IFP, a public-sector research and training center, developed a proprietary, validated engineering software tool—FEMUS or finite element model of an umbilical structure. This tool interrogates a database that includes all of the information required to build a model (think of the database as containing the DNA for any umbilical design, such as the component, material, and dimensional data). It then automates 3D-model building by gathering all of the data into a Python script (programmable language file used by Abaqus), which it then executes within Abaqus/CAE to create the FEA model.

Once the data is loaded in Abaqus, the script does the rest: It builds the umbilical-specific geometry; constructs the assembly; applies the section properties, element types and materials; and creates the load steps, contacts and request for history and field output data. Developed specifically for Abaqus and for use by non-FEA experts, the interface's goal was rapid model building using proven techniques. That goal was realized: In approximately 10 minutes the team can have a run-ready base model inside Abaqus.

Inside the umbilical

During the VLS installation, the umbilical is subject to tension, bending, and the crushing load from the caterpillar pads. For the crush load portion of the analysis, the DUCO team used the 3D model in Abaqus/Explicit to capture all of the interactions in the helically-oriented structure. The 3D analysis gave them the relationship between the crush load and the resulting ovality of the tube while under that load.

When the umbilical leaves the caterpillar, the crush load is relieved and the tubes elastically relax, resulting in a reduction of tube ovality. For the recovery of the tube, a simpler 2D analysis in Abaqus/Standard was more efficient. In the 2D environment, the team conducted a number of analyses for each tube and built up the relationship between the maximum ovality under load and the residual ovality of the tube following elastic recovery. The results from the 2D and 3D analyses were then combined to determine the overall residual ovality of a tube for a given caterpillar crush load.

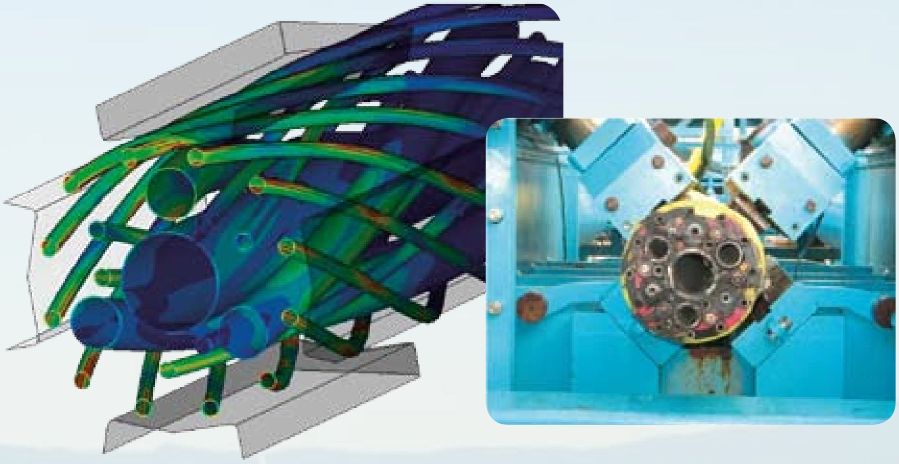

Figure 2. Comparison of the results of the umbilical FEA analysis (left) with the full-scale physical test using the four-track caterpillar crush rig (right) is used to validate the umbilical's residual ovality following the application of varying crush loads.

For further efficiency, all analyses were run on models constructed from a single pitch of the umbilical—the length at which the helical pattern starts to repeat—which in this case was several meters. The team used shell elements for the tubes and solid elements for the polymer sheath, outer sheath, and fillers. For the crush pads, they used rigid elements and dimensions that matched the umbilical pitch length.

In the umbilical installation analysis, the DUCO R&D team considered the key variables: tube wall thickness, VLS crush load, internal tube pressure, and caterpillar pad geometry. To gain confidence in the simulation results, they ran four simulations that matched the conditions of four full-scale physical tests for a combination of internal tube pressure and caterpillar pad angle.

Validated simulation process provides confidence

Even streamlined, an umbilical installation simulation can be compute-intensive. A recent DUCO analysis had approximately half a million nodes and a similar number of elements. To handle this, the team used a cluster of CPUs with significant capacity. "The goal was to deliver an analysis in a reasonable time," adds Probyn, "and we've succeeded."

Comparing results, the team found good agreement between the FEA predictions and the physical tests (See Figure 2). For most loads, the differences between the FEA and test results were well within the measurement tolerances. The FEA predictions also showed the same trend as the test data in predicting reduced residual ovality as the geometry of the caterpillar pad V-angle was altered from a high to low angle. In addition, the model and tests were in agreement when an internal pressure was present in the steel tubes during application of the crush load. All results indicated that residual ovality was below the recommended 3 percent limit for all loads—well within the nominal crush loads. This gave the team confidence that, in specific cases, crush loads beyond the typical values could be applied.

Overall, the analyses demonstrated to the DUCO team that FEA could accurately simulate complex loading conditions involving multiple component contact and nonlinear material behavior. "Now that we've fully validated the FEA, simulation can be employed as a virtual prototype to perform additional analyses, such as optimization and reliability studies," says R&D team leader Fogg.

With a validated realistic simulation process, DUCO's customers can have confidence that their oil and gas lifelines will be healthy long into the future.

For More Information

www.technip.com
www.simulia.com/cust_ref