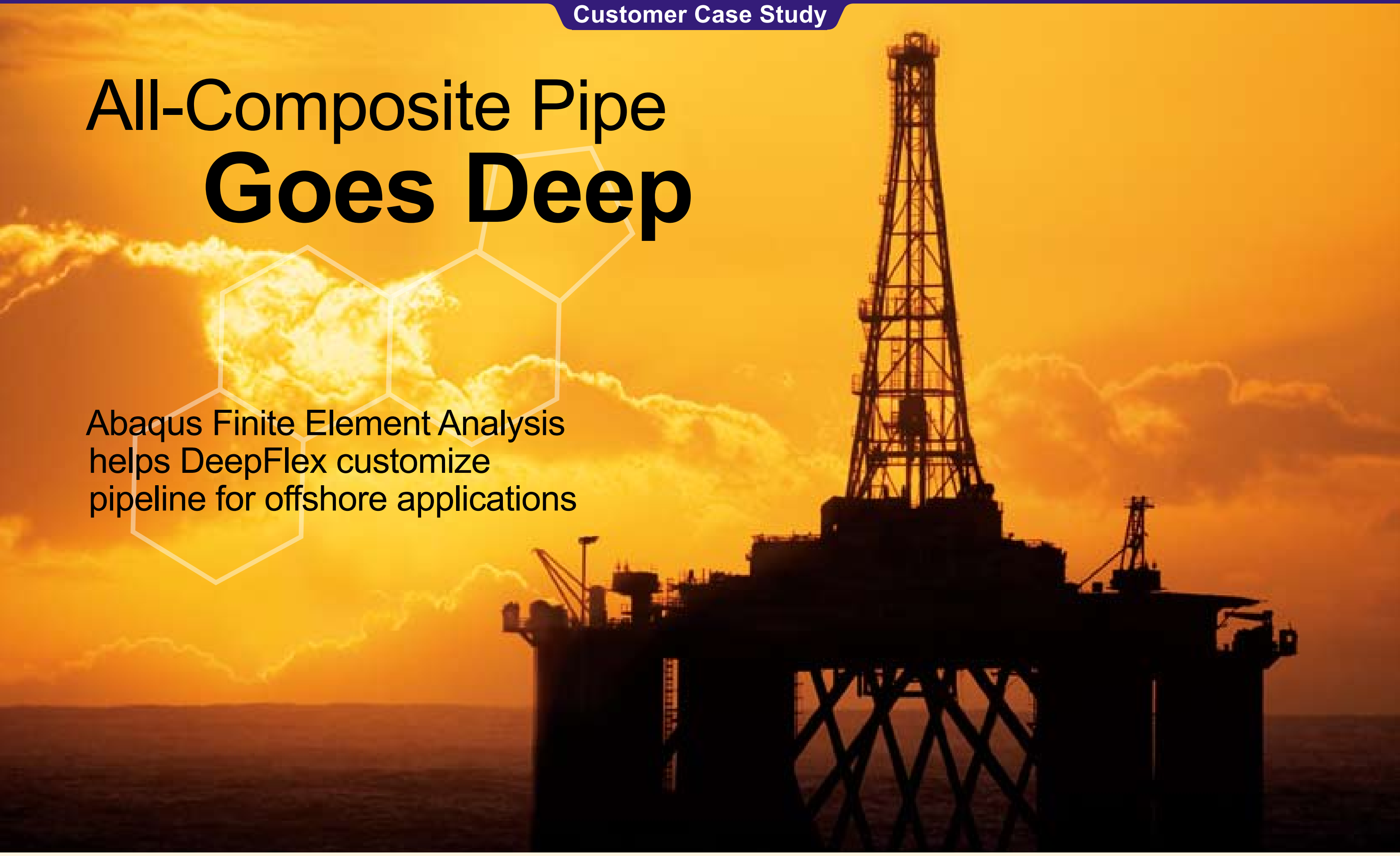


All-Composite Pipe Goes Deep

Abaqus Finite Element Analysis helps DeepFlex customize pipeline for offshore applications

Deepwater production is a challenging reality for many oil and gas companies. Limits on existing petroleum resources require the search for new fields to be conducted farther offshore and in deeper water than ever before. But operating in a harsh ocean environment, and thousands of feet below sea level, puts demands on pipelines that are much greater than those onshore or in shallower water. Traditional steel pipe can have performance limitations under such conditions.

Enter the next generation: all-composite flexible fiber reinforced pipe (FFRP), a lightweight, nonmetallic, unbonded pipe developed specifically for use in subsea and deepwater floating system applications. The need for FFRP becomes more critical as the industry moves out to 3,000-meter water depths. Constructed from extruded polymeric layers reinforced with laminated glass-fiber tape stacks, FFRP is the patented brainchild of Bruce McConkey and Mike Bryant, and has been successfully commercialized by DeepFlex Inc. It is in use in the Gulf of Mexico, with ongoing projects in West Africa and Far East Asia. "Due to its unique performance characteristics, FFRP has the potential to enable new development scenarios in deep and ultra-deepwater fields around the globe," says Bryant, Chief Technical Officer at DeepFlex.

New material, new design challenges

Earlier generations of fiberglass-reinforced plastic bonded pipe systems have been in use for over 40 years in onshore oilfields and some shallow water applications. But DeepFlex faced the challenge of designing and producing a completely new all-composite type of pipe that could withstand the greater external hydrostatic pressures, higher internal wellhead pressures, and temperature extremes that accompany deepwater work.

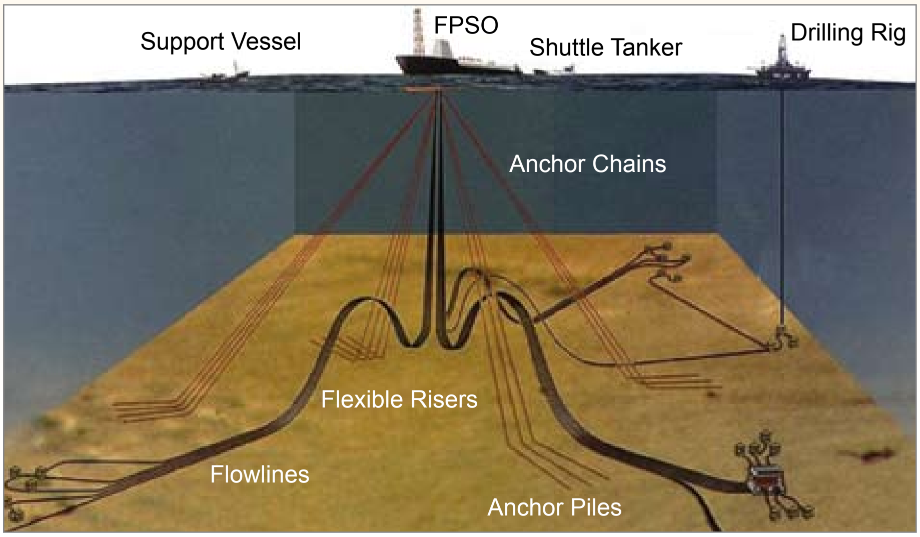
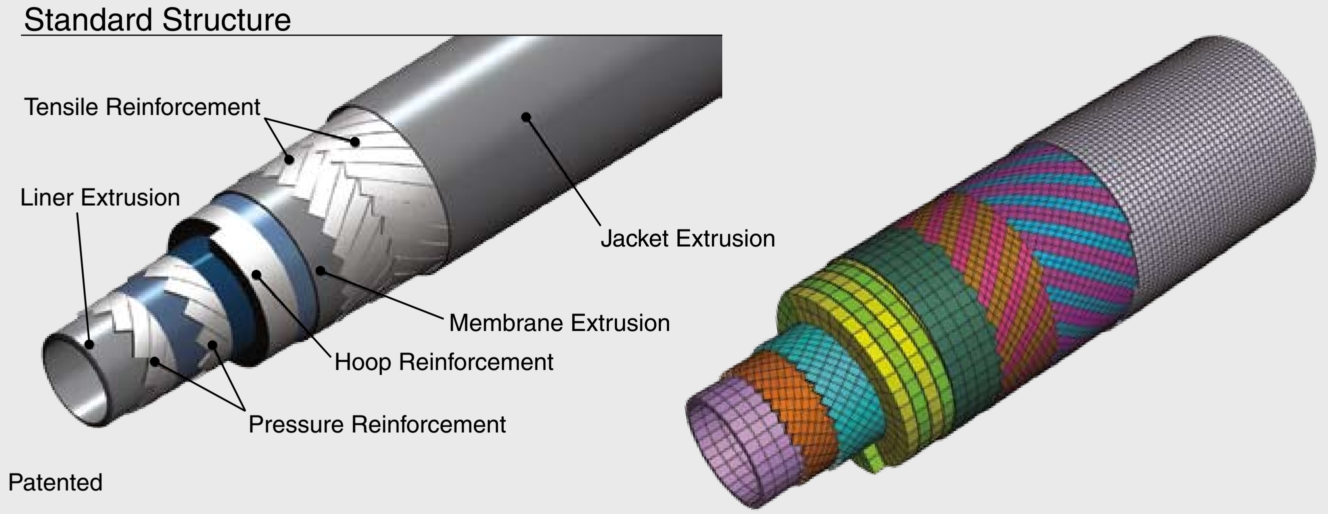


Diagram showing intended applications of DeepFlex pipe in deepwater installations. All-composite flexible fiber-reinforced pipe can be used for dynamic risers, subsea flowlines and pipelines, subsea jumpers, and surface jumpers on hybrid risers or on platform decks.



On the left is a typical structure of a standard, all-composite Flexible Fiber Reinforced Pipe (FFRP) for deepwater petroleum product recovery, detailing the multiple layers of extrusions and reinforcement that give DeepFlex pipe its strength and flexibility. On the right, Abaqus FEA model of DeepFlex pipe showing meshed representation of the layers of extrusions and reinforcement.

Metallic reinforcement wrap can strengthen composite pipe, but the highly corrosive nature of seawater limits its lifespan. Another reason to avoid metal is that composite materials are inert in the “sour gas” (hydrogen sulfide) environment of many deepwater natural gas reservoirs. When creating DeepFlex’s all-composite product, “the feasibility of achieving the necessary collapse resistance without metallic reinforcement was a focus of our early developmental effort,” says DeepFlex Director for Applications Engineering Shankar Bhat, Sc.D.

Tough, flexible, lightweight

To maximize the strength of its composite-only pipe, DeepFlex created overlapping layers of composite reinforcement, using multi-start stacks of specially made pre-cured unidirectional glass fiber composite tapes. The pipe is continuous, and is made in long lengths limited only by storage capacity. Performance is impressive: tests of the 2-inch pipe, for example, have demonstrated its ability to survive the pressure found in the Marianas Trench, the deepest spot in any ocean of the world. A 4-inch pipe has been tested to a collapse pressure of 10,000 psi—over 6000 meters (22,482 feet) of seawater equivalency. “Our pipe is designed to take a tremendous compressive load with a generous safety factor,” says Bhat.

Pipes are offered at various internal pressure design ratings up to 10,000 psi working pressure. The FAT (Factory Acceptance Test) is carried out at 1.5 times the working pressure and burst ratings are a minimum of 2.5. No existing codes cover this new product directly, but “our goal is to meet or exceed API (American Petroleum Institute) 17 requirements when they are applicable,” says Bhat.

While the plies within each FFRP stack are bonded together by epoxy resin, each stack remains unbonded from the others, ensuring true flexibility under extreme conditions and increasing fatigue resistance in dynamic applications. Unbonded construction also allows the pipe to be produced and installed in continuous long lengths in the size range of interest to offshore oil and gas operators. In addition, the composite materials act as effective insulators, keeping product flowing through pipes at colder deepwater temperatures. The all-composite makeup results in pipe that is lighter than traditional steel or other types of flexible pipe—allowing significant reduction of loads on host facilities in deep water.

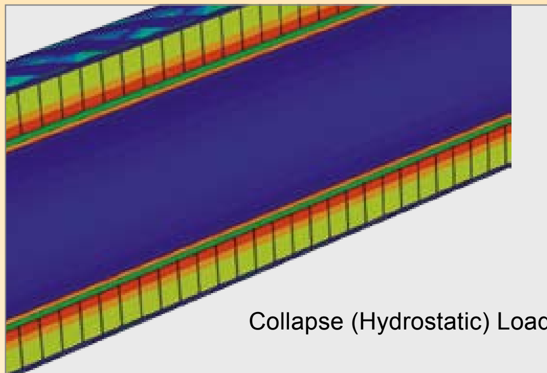
FEA provides insight

The unique way that FFRP is constructed permits tailoring to the variables of the particular environment in which it will be used: a cross-section lay-up allows each layer to be custom-designed to meet specific requirements for burst, collapse, axial extension, bending, and torsion. For meeting such exacting specifications, “we needed further insight into the performance of each layer of composite to optimize pipe cross section configuration,” said Bhat. To gain that insight, DeepFlex worked with structural mechanics consultants at MMI Engineering, Inc. (MMI), who applied Abaqus FEA software for realistic simulation computer modeling of FFRP.

As prototype testing began generating data during the design and development stages, DeepFlex supplied design information and pipe cross-section data to MMI for use in the numerical model creation and testing. “We were looking for a complex model able to handle the internal interactions of the materials in a more complete way,” says Bhat.

“DeepFlex has a proprietary method of sizing the pipes,” says Paul Jacob, Associate, MMI. “They would come to us with their pipe makeup for, say, 10,000 feet of water and 5000 psi burst pressure, and give us a cross-section and the properties we needed for our analysis. DeepFlex has an extensive prototype test program that provides overall results for product performance, but they wanted to build on this and gain

(Story continued on page 18)



(Top) Cross-section analysis of a portion of DeepFlex pipe with stress distribution registered during collapse testing.

(Right) A length of composite pipe (in red) positioned in a dynamic test machine used by DeepFlex to carry out bending and torsional stiffness tests with and without internal pressure. MMI used numerical results derived from such prototype testing to validate Abaqus (FEA) models and gain insight into the performance of structural elements of the pipe.

an understanding of how the various components in the pipe behave under loading. This is where a tool such as Abaqus FEA can provide the needed insight into product performance.”

MMI used the preprocessing capabilities of Abaqus/CAE to create meshed FEA models of the pipe that could be analyzed for performance characteristics. The Abaqus analysis products were then used to conduct the simulations. “We used a combination of Abaqus/Standard and Abaqus/Explicit in this project,” says Jacob. “Abaqus/Explicit was used to verify the interaction between components as it is easier to shake out numerical problems with contact. Once we had confidence in the contact interaction, we used Abaqus/Standard to complete our main set of performance analysis runs.”

Modeling composites at the right level of detail

“To model the composite components of the pipe, instead of creating the individual plies, we built up orthotropic solids of each composite section,” says Jacob. “We could have used Abaqus to model all the individual layers, but we did not need that level of detail at this point in our studies. Greater detail could be included at a later stage of product development if required.”

MMI began their numerical analysis by performing sensitivity studies with 2D models to determine where to focus on the interactions between composite layers within a pipe structure under various loading conditions. From these studies, MMI created 3D models with each composite component modeled explicitly with contact (such as friction between reinforcement stacks) where required. Boundary conditions and loads were then applied and benchmark tests were performed to confirm that the model behavior was realistic.

The FEA model included nearly one million degrees of freedom and the analysis was run overnight on a single processor 64-bit Intel Xeon processor machine with the Red Hat Linux 64 operating system. “We used the FEA results as a starting point for establishing an understanding of the failure limits of particular pipe specifications, simulating burst and collapse tests,” says Jacob. “The analysis helped us understand the mechanisms and responses of the structure under loading.”

Efficient modeling promotes efficient design

“We were looking to find out what the failure modes would be, how they would progress through the structure, for internal pressure, external hydrostatic collapse loads bending, torsion, and axial loads,” says Jacob. “This is where the DeepFlex all-composite pipe has its advantage, because you can design it efficiently: tailoring individual components in the cross-section to meet the demands of the different layers in loading conditions such as burst or collapse. With a steel pipe, there is one material and thickness; you don’t have that flexibility.”

MMI developed a method for assessing failures between the individual layers, using the “Model Change” command in Abaqus to alter the states between them and applying loads to the model structure gradually until components began to fail. “This approach allowed us to develop global characteristics for load extension, and bending, that took into account the effects of burst and collapse pressures,” says Jacob. “Analytically, that was the high point for me, as we were able to begin to understand the failure mechanism and load redistribution in the remaining components.”

MMI provided their FEA analysis data back to DeepFlex for use as part of their design process going forward. “MMI’s work was an important first step in our gaining a more complete understanding of the structural mechanics of pipe cross-sections,” says Bhat. “Going forward we will continue to use FEA to deepen our understanding, which will enable further customization of the high-performance composite materials that make our pipe so uniquely suited to deepwater operations.”

About DeepFlex, Inc.

Headquartered in Houston, with offices in the United States, Brazil and the United Kingdom, DeepFlex, Inc. designs, manufactures and installs premium composite flexible pipe used in the subsea oil and gas production environment. Established in 2004, DeepFlex works in the world’s major offshore producing regions to meet the needs of oil and gas companies of all sizes.

About MMI Engineering, Inc.

MMI provides engineering consulting services to global clients in the oil and gas, energy, utilities, security, government, industrial and commercial markets. MMI uses state-of-the-art engineering, science and technology in combination with practical design, construction and project management experience to meet their client’s unique needs.

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