When the Pressure is On: Preventing Well Blowouts

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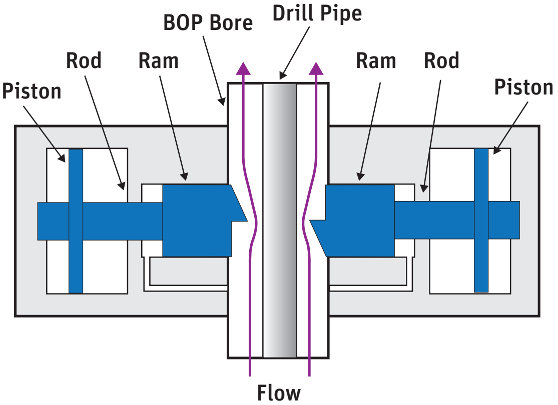
By **Amy McCleney**
Research Engineer – Computational Fluid Dynamics
Southwest Research Institute
San Antonio, U.S.A.

To understand what stopped emergency devices from deploying fully during an offshore well catastrophe, researchers turned to ANSYS Mechanical and ANSYS Fluent to model fluid–structure interactions. The result of this landmark work has the potential to change the regulatory framework for blowout preventers and is helping manufacturers better ensure the integrity of their products.

A year after it made history for drilling the world's deepest oil well, the Deepwater Horizon rig lay wrecked on the floor of the Gulf of Mexico.

Heralded as a model of safety by the U.S. Minerals Management Service, the rig sank after an explosion that killed 11 crewmen and set off the largest oil spill in U.S. waters. Millions of barrels of oil were released into the Gulf of Mexico.

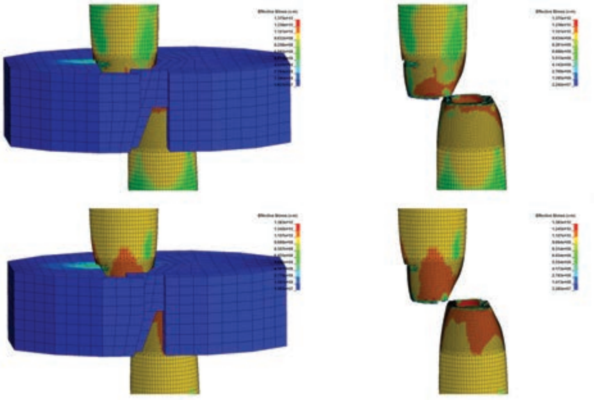
Investigators could not reach the seabed to find out what happened firsthand, but they did have access to real-time data. In the end, they determined that a chain of malfunctions contributed to the disaster, including a blowout preventer (BOP) that failed to



Simplified diagram of a blind shear ram

work as designed. Instead of shearing the drill pipe and sealing the wellbore, the faulty BOP allowed pressurized contents to travel unimpeded up the pipe, igniting a fireball that could be seen 40 miles away.

To understand what happened, prevent similar catastrophes and help BOP manufacturers better manage product integrity, the Southwest Research Institute (SwRI) developed and validated a model to analyze how offshore BOPs are likely to function during an emergency. Working with drawings and mechanical CAD files furnished by three BOP manufacturers, SwRI coupled ANSYS Fluent CFD and ANSYS Mechanical to analyze the equipment under the high-pressure, high-flow conditions experienced in deep-water Gulf of Mexico.



ANSYS Mechanical simulation showing stresses on the cut pipe

Obviously, there is no way to replicate the highly complicated process of pinching and cutting off high-strength steel pipe under full-scale field conditions: The extreme pressure and flow make it impractical, if not far too dangerous. SwRI coupled ANSYS Mechanical and ANSYS Fluent to model how extreme pressure and flow features affect a solid BOP structure.

CLOSING THE INTEGRITY GAP

SwRI's work was funded by the U.S. Bureau of Safety and Environmental Enforcement (BSEE) as part of their effort to advance the design of BOPs so they function effectively during a blowout.

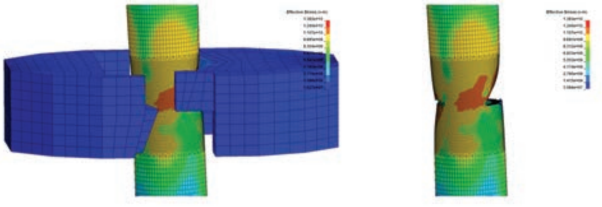
"ANSYS software was part of the first-ever modeling approach that demonstrates how pipeline flow conditions can affect BOP performance."

A FIRST-OF-ITS-KIND SIMULATION

BOPs have one job, and it is a big one: They are the last line of defense during an uncontrolled release of crude oil or natural gas from a well. When activated, the BOP's blind shear ram — an emergency hydraulic device with two sharp cutting blades — closes around the drill pipe connecting the rig to the well, pinching it shut then severing it. This seals off the wellbore.

In the case of the Deepwater Horizon, however, the blind shear ram did not work as planned. The blades punctured but failed to cut clear through the pipe. It was not pinched shut. As a result, a hazardous mixture of oil, gas, drilling fluids and contaminants ranging from sand to rock cuttings surged from the out-of-control well to the surface.

For BOP manufacturers eager to avoid incidents like that, understanding the dynamics of the event is essential.



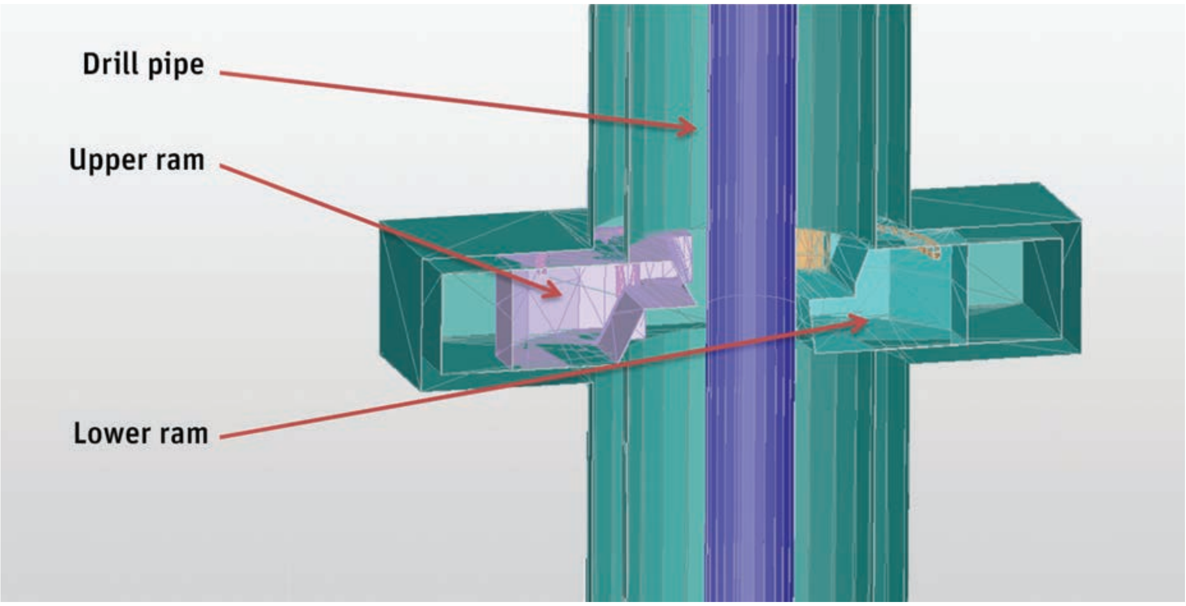
ANSYS Mechanical simulation showing stresses on the pipe

The regulator requires independent third-party verification of the capability of a blind shear ram to cut and seal pipe under all operating conditions, but lacked testing criteria, making it impossible for BOP manufacturers to comply. Historically, manufacturers measured BOP integrity based on material properties but had no way to assess how the blind shear ram would perform during either normal or extreme conditions.

To close the gap through simulation modeling, SwRI considered three factors:

- The mechanical force required to deform and shear the drill pipe
- The hydrostatic force within the BOP
- The hydrodynamic force caused by acceleration of the fluid as it flows around the angled surfaces of the shear ram

Fluid–Structure Interaction
ansys.com/fsi



CAD model for CFD simulation

"ANSYS software allowed fluid–structure interaction (FSI) simulation under a variety of flow conditions."

Their analysis assumed a worst-case scenario — a release volume of 100,000 stock tank barrels per day (stb/d) under flowing pressures and fluid properties representative of outer shelf Gulf of Mexico conditions.

Using ANSYS Mechanical, SwRI first modeled the interaction of the closing blind shear rams and drill pipe. Next, they used ANSYS Fluent CFD to predict how hydrodynamic forces would change as fluid moved through a gradually closing pipe, with the expectation that the local flow in the annulus — the void between the drill pipe and the blades — would accelerate as it moved through the reduced cross-sectional area remaining open to flow.

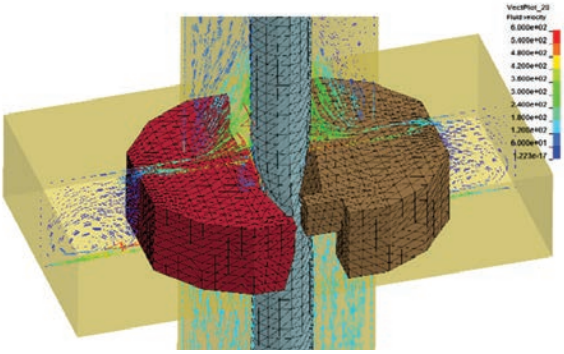
The team at SwRI's fluids engineering department simulated three different rams closing at different speeds. ANSYS software allowed fluid–structure interaction (FSI) simulation under a variety of flow conditions, including changes in density, viscosity, flow rate and pressure. Turbulence was also considered.

That initial stage was followed by a mesh refinement study and a four-tier fluid–structure interaction simulation that added a layer of physics each time. In this approach, geometries from ANSYS Mechanical were imported into ANSYS Fluent to solve for the hydrodynamic forces on the rams.

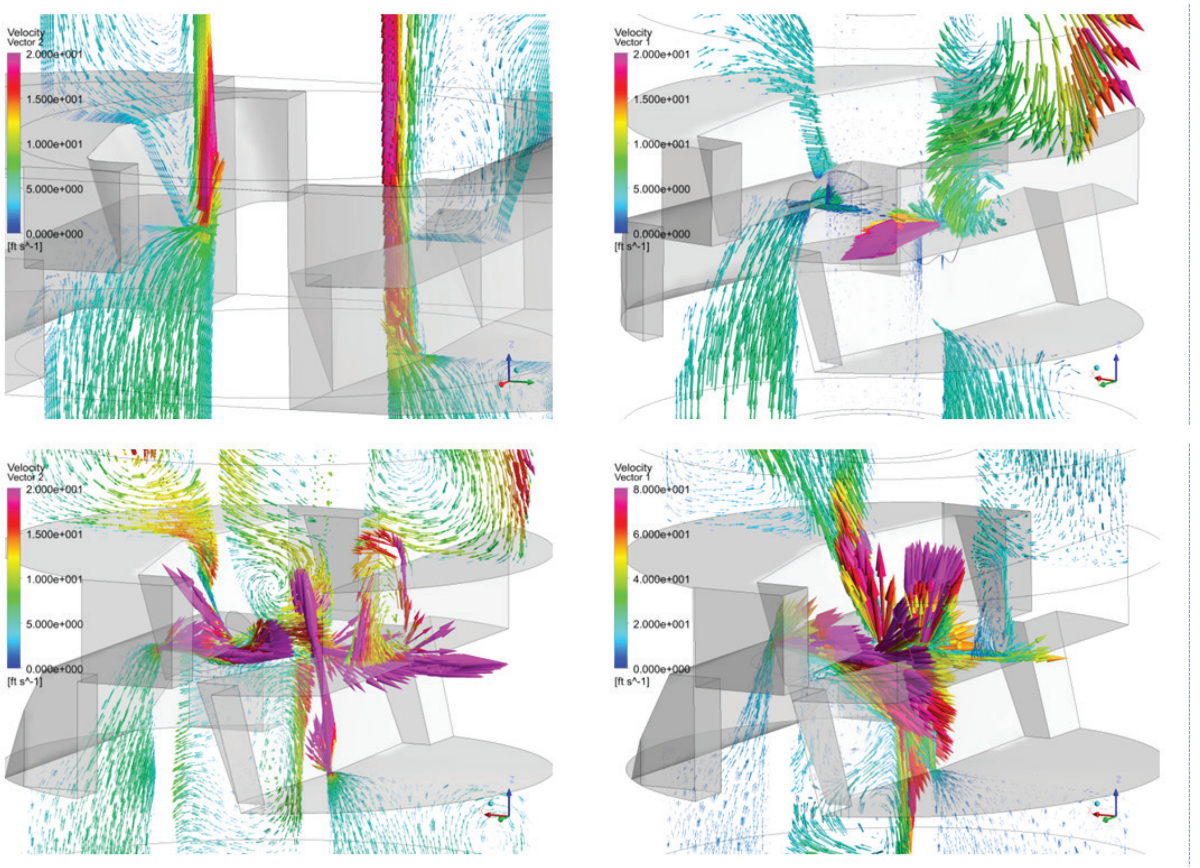
- The first tier, which served as a reference for tiers 2 through 4, included finite-element analysis of the shear rams and tubing geometry, without the addition of a hydraulic force.
- Tier 2 coupled FEA shearing forces and CFD fluid forces at various fractional openings of the annulus.
- Tier 3 was similar to Tier 2 but used different fractional openings.
- Tier 4 coupled FEA and CFD solvers to run the complete fluid–structure interaction problem.

UNDERSTANDING THE IMPORTANCE OF FLUID–STRUCTURE INTERACTION

Before SwRI's work, the effect of fluid hydrodynamics on blind shear rams was assumed to be negligible compared to mechanical and hydrostatic forces. Through their use of ANSYS Fluent and ANSYS Mechanical, SwRI demonstrated how the



Multiphysics CFD and FEA simulation



CFD flow fields with the ram closing on the pipe

> **"SwRI developed and validated a model to analyze how offshore BOPs are likely to function during an emergency."**

simultaneous effects of flow rate and fluid pressure interact with the structural dynamics of severing a drill pipe. They used both one-way and two-way coupling, but, after determining that one-way coupling was sufficiently accurate for this application, much of the study focused on one-way coupling. The work accurately predicted the hydrodynamic forces exerted on the rams as they close on the flow, demonstrating subsea BOP shear and seal capabilities under deep water, loss-of-control conditions. The results have the potential to change the regulatory framework around the shearing performance of BOP devices. At the very least, they indicate to BOP manufacturers that material properties testing alone is not enough to ensure the BOP's integrity.

SwRI regularly uses ANSYS software because of its dependability. In this case, where it was necessary to study fluid–structure interaction, the way ANSYS Fluent coupled seamlessly with ANSYS Mechanical was particularly useful.

SwRI's work with BSEE is not over: The team will build upon the work completed by adding erosion and multiphase simulation. The team will once again use ANSYS Fluent, which has an erosion package and highly trusted multiphase modeling approaches.

TOWARD AN EVEN SAFER INDUSTRY

The oil and gas industry makes safety a priority. Failures rarely occur, but as the Deepwater Horizon example indicates, when they do, the results can be catastrophic. Understanding how BOPs perform during a blowout has been an issue for operators and regulators alike.

By using ANSYS software to develop the first-ever modeling approach that demonstrates how pipeline flow conditions can affect BOP performance, SwRI is helping the industry and regulators address this concern and making it easier for manufacturers to comply with requirements.