Deep-water challenges

Studies of platform and pipe dynamics facilitate advances in oil exploration on the high seas

Igor Zolnerkevic

P-37 platform in Marlim Sul Oil Field, Campos Basin, Brazil: teamwork to prevent movement caused by wind and currents

GERALDO FALCÃO/PETROBRAS

For over three decades, engineers from several Brazilian universities and research institutes have joined in an effort coordinated by the Petrobras Research Center (Cenpes) to develop technologies that will enable the company to explore for oil in increasingly deep waters. While the challenge in the 1980s was to reach oil reserves below a depth of one thousand meters in Campos Basin, Brazil, today Petrobras can safely explore for oil reserves in the so-called pre-salt layer in Santos Basin at water depths of up to 3,000 meters. This breakthrough enabled Brazil to achieve oil self-sufficiency in 2005. The country currently produces nearly three million barrels per day—80% of which come from maritime reserves—and production is expected to exceed six million barrels per day by 2020.

One of the most challenging problems that Petrobras needed to solve in order to achieve global leadership in maritime oil exploration was that of finding solutions to prevent its platform vessels and semi-submersible rigs from moving around while extracting oil from the ocean floor, even when subjected to strong winds, waves and currents. Another critical problem was how to optimize the technology for preventing undersea current-induced vibrations from rupturing the long, slender pipes called risers that carry the oil and gas from the well on the ocean floor up to the platform.

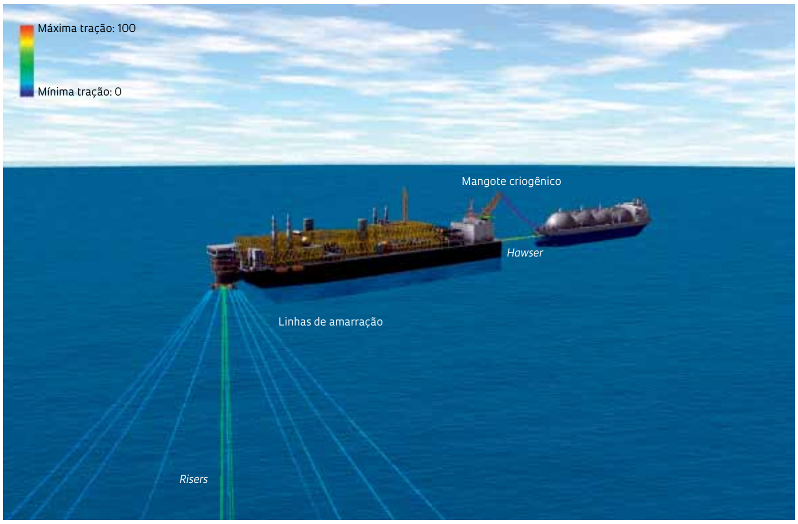
To address Petrobras' demands, in the mid-1990s, engineers from the Polytechnic School (Poli) of the University of São Paulo (USP) organized around two thematic projects supported by FAPESP. Researchers who had previously worked independently joined forces and established laboratories that today are international benchmarks in offshore engineering. "The groups involved in this research are recognized worldwide in the oil and gas industry and are frequently engaged in research that leads to innovation and spawns patents," said Luiz Levy, Cenpes' manager of optimization technology for operations and logistics.

Coordinated by Hernani Brinati of the Department of Naval and Oceanic Engineering at Poli, the project was entitled *Methods of nonlinear dynamics applied to the design and analysis of anchoring systems*. Between 1998 and 2004 the project engaged some ten researchers from Poli, the Institute of Mathematics and Statistics at USP, and the São Paulo Institute for Technological Research (IPT). Their objective was to investigate how advanced mathematical tools—methods of nonlinear dynamics—could be used to create models that simulate the behavior of future designs for platforms anchored in the high seas, with the goal of proposing improvements in construction design. "We wanted to tackle engineering problems that are of interest to Brazil, but from a more conceptual standpoint," Brinati recalled.

The use of fixed platforms of steel or concrete that rest on the seabed is not feasible for most of Brazil's oil wells, which are in water depths of over a thousand meters. The solution is to use floating structures known as floating production, storage and offloading units, or FPSOs, which are moored in place above a well by means of a system of cables and chains fixed to the seabed by anchors and piles.

"Failure to properly position the platform can be disastrous," explained Celso Pesce, of Poli, one of the project managers who developed the Offshore Fluid-Structural and Mechanical Interaction Laboratory at Poli and who were in charge of the small-scale experiments that verified the dynamic behavior and stability of the anchoring systems. "If it moves around because of a defect in the anchoring system, the risers can rupture, which disrupts production and pollutes the environment."

The more traditional turret-type mooring system was already prevalent in Campos Basin, and nowadays it is the one most widely used by FPSOs conducting long-term prospecting tests. In this system, each of the tens of cables is connected to the turret—a single vertical axis 10 meters



Computer simulation of a turret-type anchoring system, done in a Numerical Test Tank (TPN)

in diameter that passes through the ship, and around which the vessel can rotate. The closer the axis is to midship, the easier it is for the FPSO to align with the direction of the current and avoid any unstable movement. The farther the axis is from the stern, the more movement the vessel imposes on the system of risers. One of the problems that the researchers looked into was how to determine the ideal turret position for ensuring vessel stability and riser integrity at the same time.

The alternative to the turret system is to spread cables over the entire length of the vessel. In the 1990s, researchers from Petrobras developed a new spread mooring system, the Differentiated Compliant Anchoring System, or DICAS, which uses lines made of materials of varying stiffness—steel or polyester, for example. The lines are distributed around the platform according to the direction of the wind and currents in the area of the well. "Our research during that period contributed to the adoption of the DICAS system, as well as the use of polyester cables, beginning with Brazil and now used throughout the world," said Kazuo Nishimoto, the project manager in charge of implementing the mathematical models in computer simulations.

Those pioneering simulations led to an ambitious project, the Numerical Test Tank (TPN), coordinated by Nishimoto with involvement by researchers from Petrobras, IPT, USP, the Federal University of Rio de Janeiro (UFRJ) and other Brazilian universities. Increasingly sophisticated computational simulations created by the TPN group proved to be essential for the design of the Brazilian platforms, from the semi-submersible P-18 inaugurated in 1994 to the recently built P-73, an FPSO, in view of the fact that it is impossible to build water tanks of the size needed to perfectly simulate deepwater conditions.

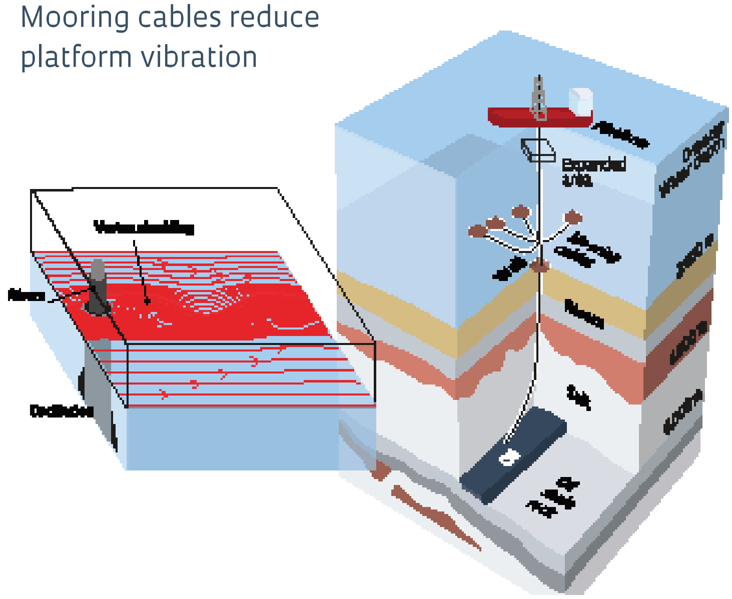
The TPN—housed at Poli since 2010 in a building constructed with funds from the Brazilian Innovation Agency (Finep) and Petrobras—is used to develop simulations of nearly every offshore oil operation in a computer cluster thousands of times faster than a single conventional computer, which are visualized in a virtual reality room. Since not all maritime conditions can be reproduced through calculations, the TPN also features a water tank with wave, wind and current generators that help to "calibrate" the computational simulations.

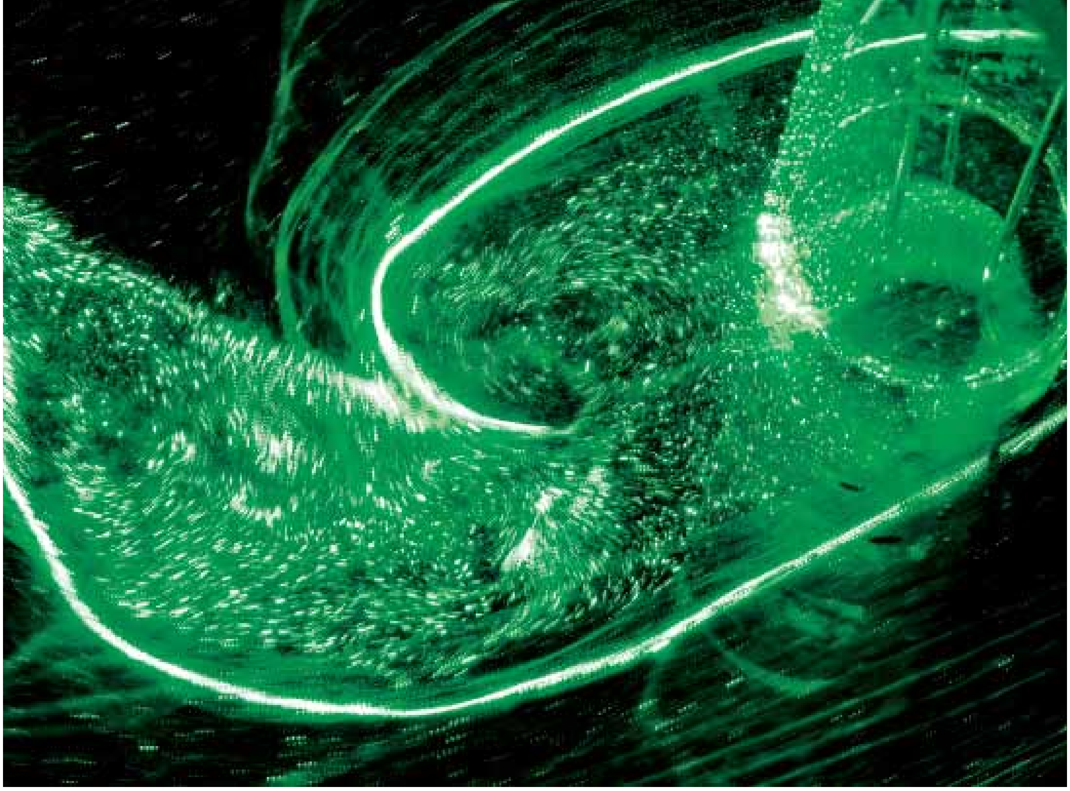
VIBRATING WITH VORTICES

Another FAPESP thematic project, coordinated by José Aranha of Poli's Mechanical Engineering Department, addressed a problem that remains a challenge for engineers, physicists and mathematicians the world over and whose economic impact on maritime oil exploration is beyond calculation: the phenomenon of vortex-induced vibration (VIV). The purpose of the projects, which ran from 1995 to 1999 and were renewed for 2002 to 2006, was to study the effect of VIV on oil platform structures, especially the risers, by analyzing the hydroelasticity equations, doing computer simulations of solutions to the equations and conducting experiments on a small scale. This collaborative effort involved researchers from USP, IPT and Petrobras, as well as from Cornell University in the United States, Imperial College and the University of Southamptom in the United Kingdom, and the German Aerospace Center.

Nearly oscillation-free on the high seas

Mooring cables reduce platform vibration





Experiment in Poli USP's recirculating water tank uses laser light to show vortex shedding in the current flowing around a cylinder

ILUSTRATION POLI/USP **INFOGRAPHIC** TIAGO CIRILLO. SOURCE: PETROBRAS **PHOTO** PROF. DR. GUSTAVO R. S. ASSI

"VIV is one of the few phenomena in fluid dynamics that are still not well understood," said Pesce, who was a collaborator on this project as well. To visualize what VIV is, imagine a vertical pipe 25 centimeters in diameter and 2,500 meters long submerged under the water, like the risers hanging off a platform on the high seas. When a current passes around the pipe, the flow of water around it forms a series of tubular vortices, which are shed alternately on each side of the pipe.

The differences in pressure caused by vortex shedding produce complex oscillatory forces that induce vibrations in the pipe—a chaotic, turbulent movement that cannot be trivially determined. The real problem of VIV in the risers is further complicated by the fact that the pipes are subjected to ocean surface currents and deepwater crosscurrents, in addition to platform oscillations. Neither computer simulations nor experimental testing have yet been able to capture all the aspects of this phenomenon.

If VIV goes unsuppressed, resulting mechanical fatigue can rupture the risers. The most common commercial solution to prevent this from occurring are strakes, a kind of armor that encases each riser in a set of plates that form a helix along the pipe. Although strakes do indeed attenuate VIV, the task of installing them throughout the entire piping system is complex, accounting for half the cost of the riser system, which can amount to as much as five hundred million dollars—nearly as much as the platform itself. Strakes also increase the drag force of the water on the risers, and therefore require a more robust structure to hold them in place. The researchers' long-term objective, therefore, is to find solutions that increasingly minimize the use of strakes or replace them completely.

The project funds enabled Aranha and his colleagues to equip the Fluids and Dynamics Research Group (NDF) at Poli with computer clusters and build a recirculating water tank identical to the one at Imperial College, where VIV and other phenomena are being observed using laser beams and high-definition cameras that capture the dynamics of small-scale models of cables and pipes and their interaction with water in movement. "We are one of the ten most active groups in the world working in that field," said Júlio Meneghini, a specialist in computational and experimental fluid dynamics and coordinator of NDF.

According to Meneghini, the research studies conducted under the thematic project led to improvements in the description of VIV, which were incorporated into Petrobras' riser analysis software. Their conclusions have also produced about 50 scientific articles in high-impact international journals, in addition to three patent applications for VIV attenuation mechanisms. ■

PROJECTS

1. Methods of nonlinear dynamics applied to the design and analysis of anchoring systems – No. 1996/12284-6 (1998-2003)
2. Vibration induced by vortex shedding in maritime and oceanic structures – No. 1994/03528-3 (1995-1999)
3. Vortex-induced vibration (VIV) in maritime and oceanic structures – No. 2001/00054-6 (2002-2006)

GRANT MECHANISM
1., 2. and 3. Thematic project

COORDINATORS
1. Hernani L. Brinati (USP)
2. and 3. José A. P. Aranha (USP)

INVESTMENT
1. R$250,128.69
2. R$132,336.72
3. R$1,753,819.04

SCIENTIFIC ARTICLE

MENEGHINI, J. R. *et al.* Numerical Simulation of Flow Interference between two Circular Cylinders in Tandem and Side-by-side arrangements. **Journal of Fluids and Structures**. v. 15, n. 2, p. 327-350, 2001.

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More crude oil on the high seas
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