TECHNICAL PAPER

Title: **The Role of Modeling and Simulation in Extreme Engineering Projects**

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The Role of Modeling and Simulation in Extreme Engineering Projects

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Bechtel has constructed a vast array of major plants and infrastructure projects around the world. During the past few years, advanced technology tools have increasingly been used to support the design and engineering of many projects. In some cases, logistical barriers, schedule constraints, environmental factors, and risk have been crucial factors, and the use of simulation tools has played an integral role in addressing such issues.

Tools that specialize in modeling physical environments and conditions are particularly useful for many complex projects (plants and infrastructure). A multi-disciplinary approach to analysis and visualization can reduce risk and save money by developing models that simulate the physical environment a component or system may encounter before substantial time and/or cost has been invested in the project. In particular, models can be used to investigate safety implications of complex, off-normal conditions whose evaluation is not straightforward to the project engineering team.

TACOMA NARROWS BRIDGE MOORING SYSTEM

The towing in July of the first 14,000-ton (12,700-tonne) Tacoma Narrows Bridge caisson to its moored position at the east end of Puget Sound was a historic sight for the hundreds who witnessed it. What remains unseen, however, is the mooring system that restrained the caisson and its west-end counterpart until they took their underwater position 60 to 70 feet (18 to 21 meters) below the Narrows mudline.

The caisson mooring system is the result of 9 months of design work and close coordination between several engineering teams and individual experts. The system was designed to handle the tidal conditions — 8-knot currents and 17-foot (5-meter) tidal fluctuations — while responding to the volatile hydrodynamic zone in the Narrows created by vortex shedding from the existing bridge foundations.

The project's uniqueness presented the mooring design team with several challenges.

Here are some highlights:

1. The new structure will be the longest suspension bridge built in the United States in 40 years. Performing physical tests of the mooring system at a scale that would effectively model the forces on the caissons in the Tacoma Narrows environment was not feasible.

2. The new bridge foundations will be constructed approximately 80 feet (24 meters) from the existing bridge foundations. (The existing bridge will continue to operate after the new bridge is constructed.) This created an extremely tight constraint on acceptable movement of the caissons.

3. The caisson and mooring system will be subject to extreme environmental conditions, particularly tidal fluctuations, plus storm surge, wind, and waves. Designing a mooring system with allowances for the widely variant environmental conditions and their differing effects on each caisson was perhaps the biggest challenge.

Computational fluid dynamics (CFD) — a computer-based tool for simulating the behavior of systems involving fluid flow, heat transfer and other related physical processes — was used to predict the time-varying loads and moments on the new bridge caissons caused by the current flows in the Narrows. To accomplish this, the bathymetry of the riverbed and the designs for the existing and new bridge piers needed to be combined into one model, and software employing an advanced finite-element-based solver using large eddy simulation proved to be fast and stable. It was shown that CFD results for the loads on the caissons agreed very well with experiment scale model data from tests carried out at HR Wallingford in the UK. CFD modeling allowed the bridge caisson designers to assess risk and gain confidence in design margin, particularly for the "untested" West Pier. Based on results from the analytical and physical modeling, Tacoma Narrows Constructors selected a 2-tiered anchor system with 16 anchors on each level.

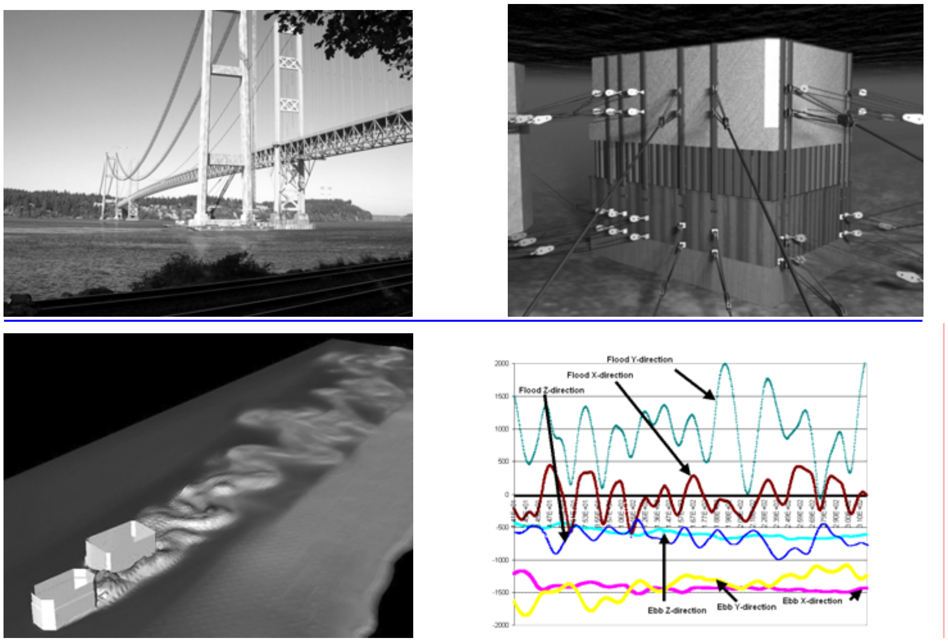

Figure 1 Rendering of new Tacoma Narrows bridge positioned next to existing bridge; caisson anchor system during installation; CFD analysis plot showing turbulence around two bridge piers subjected to current flow; plot of the time-varying load components subjected to the caisson during ebb and flood flows

CONSTRUCTING THE LARGEST NUCLEAR WASTE PROCESSING PLANT IN THE UNITED STATES

Beside the Columbia River in Washington, fifty-three million gallons of radioactive waste is stored in 177 underground tanks (60% of the nation's radioactive waste). This waste is a product of 50 years of plutonium production for national defense. The U.S. Department of Energy has commissioned the construction of a vast waste treatment plant (WTP) to convert this waste into stable glass. The waste in these underground storage tanks is a combination of sludge, slurry, and liquid, which will be transported to a pre-treatment facility to be processed in various vessels in preparation for vitrification.

Part of the engineering challenge is designing a system that can keep the solids in continuous suspension during processing while minimizing the risk of mixing system failure and alleviating the need for maintenance. Pulse-jet mixers (PJM) are an integral part of the black-cell conceptual design. Black cells are sealed areas of the plant where no human will ever enter—black cells are designed to need no maintenance, no equipment replacement, no repairs. Pulse-jet mixers are air-driven pumps installed inside stainless-steel tanks that process radioactive waste. Because they have no moving parts, they never require maintenance or replacement. The mixers agitate the radioactive waste and keep it homogenous, which is necessary to achieve the correct blend of waste fed to the melters. The agitation also ensures hydrogen gas will not build-up by preventing the formation of gas pockets.

The project's research program has focused on testing and evaluating the effectiveness of pulse-jet mixers for nearly three years. CFD models of all process vessels in the WTP have been developed to confirm the ability of the PJM's to meet stringent mixing criteria, or provide insight as to how the systems should be re-designed if performance is inadequate. State-of-the-art multi-phase modeling techniques were applied to prove out the basic design for fluidics mixing in the various process vessels. These models include the transient effects of solid-liquid mixing, such as accumulation, non-Newtonian yielding, air sparging, and heat transfer. This application of CFD has allowed the project to bypass extensive demonstration tests and keep pace with the plant's construction schedule.

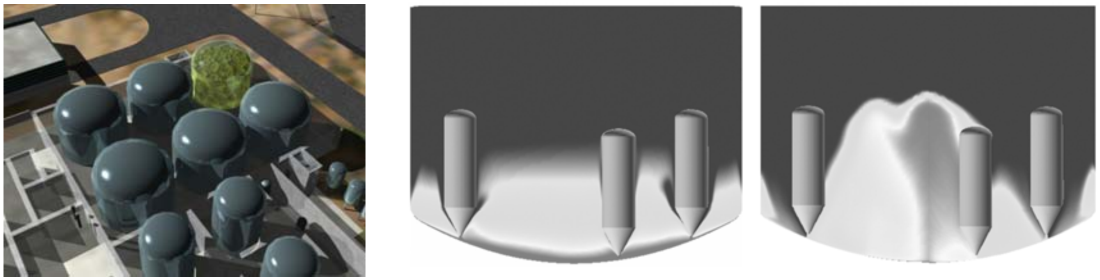

Figure 2 Waste processing tanks in section of WTP alongside a plot taken from a CFD analysis of solids suspension in a vessel using pulsed jet mixers showing settling during suction and liftoff during drive

CHERNOBYL NSC DESIGN

The Chernobyl New Safe Confinement (NSC) will shield the sarcophagus, or shelter, that was constructed soon after the nuclear accident in 1986, to contain the damaged Unit 4's deadly radioactive materials. Specifically, the NSC is designed to keep radioactive dust in and rain out and facilitate initiation of deconstruction of the sarcophagus and Unit 4. The NSC is intended to minimize occupational exposure for at least 100 years, with the expectation that improved storage or disposal methods will be available within that time.

The design team chose a movable, arch-shaped building whose large, preassembled pieces could be constructed and then slid in place over the Unit 4 shelter. After considering eight initial configurations, the team selected the one that met several of its key criteria, and then optimized the configuration with regard to chord depth and diameter and section shape. The site's contaminated topsoil layer would be removed before beginning construction to minimize schedule risk and radiation exposure to workers.

The project team employed state-of-the-art computer 3D animation and Virtual Reality (VR) development software, allowing for rapid prototyping. The VR team was given a series of hand-drawn blueprints, annotated in Russian, along with photographs of the site, aerial photos, and video footage of the area. Using the blueprints, they were able to create an accurate 3D representation of the building exterior. Details for the confinement structure were provided by way of 2D CAD drawings, which were used as a template to create a 3D model. The heavily damaged interior was modeled primarily from photographs and video footage. They then quickly developed 3D simulations and generated large scale animations by using distributed rendering technology. The simulations provided a view of the confinement construction and operations in dynamic form, which facilitated the project's review.

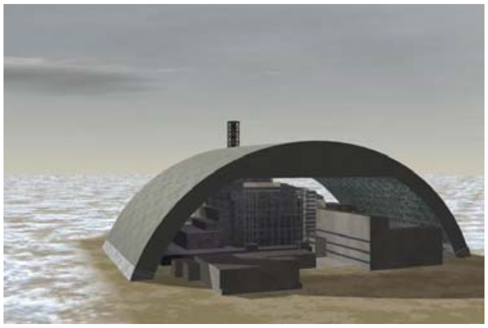

Figure 3 Chernobyl NSC conceptual design shows the assembled arch positioned over existing Unit 4 reactor

In summary, the cost of using simulation has decreased dramatically in recent years, to the point where it's typically well within the cost and schedule constraints of many project budgets. This allows the engineering teams to study the impact of environmental factors that in some cases are extreme from various perspectives. By "prototyping" the technical and conceptual aspects of such projects on the computer early on, many potential downstream risks can be minimized.