In-Depth Solution

Technip automates evaluation of 20,000 simulation runs to ensure that subsea pipe structures can survive worst-case scenarios.

By Esen Erdemir-Ungor, Design Specialist, Technip, Houston, U.S.A.

Jumpers are piping components of subsea oil production systems that connect one structure to another, such as for linking satellite wells to a manifold, the platform or other equipment. Designing these very important components is difficult because both of the connection points are free to move — within allowable limits — due to thermal expansion, water currents and other factors. Jumper designers need to evaluate every possible combination of movement, expansion and rotation to determine which combination applies the most stress to the jumper, then design the jumper to withstand it.

Technip recently designed four jumpers, each connecting a pipeline end termination (PLET) — the end connecting point of a pipeline — to the manifold of a producing well or another PLET. Technip is a world leader in project management, engineering and construction for the energy industry. With facilities in 48 countries, the company operates a fleet of specialized vessels for pipeline installation and subsea construction.

LOADS ON THE JUMPER

Undersea pipelines are governed by strict codes developed to ensure pipeline integrity to prevent an oil spill. The jumper needs to withstand loads applied to both ends of the pipe while keeping stress in the jumper within the limits specified by the code.

When oil or gas is transported in the pipeline, the pipeline undergoes thermal expansion, and this expansion is transmitted to the jumper. In this Technip application, thermal expansion was calculated to be a maximum of 40 inches in the x-axis and 30 inches in the z-axis. Further displacements of up to 2 inches in the x-, y- and z-axes were possible due to variation when the position of the structures was measured and when the jumper was cut and assembled to its final size. Rotations of up to 5 degrees in either direction in the x- and z-axes were also possible. The net result was a total of three displacements and two rotations on each end of the jumper that needed to be considered at each extreme of its range of motion. To fully understand every load case that could be applied to the jumper, it's necessary to consider every possible combination of these 10 different variables, a total of 1,024 load cases.

Technip engineers had to take into account variability in the position of the PLET and manifold. There is a target location for the two structures, but the position can vary within the project-specified target box. As a result, the length of the jumper can be anywhere from 900 inches to 1,500 inches; furthermore, the gross angle of the jumper with respect to the PLET and manifold also can vary. This

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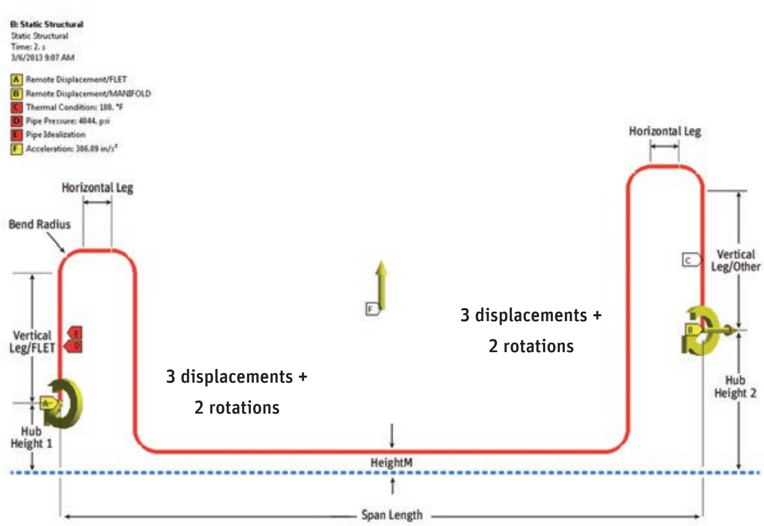
gross angle is important because it determines the angle at which thermal expansion is applied to the jumper. The position of the PLET and manifold are measured prior to jumper installation. The jumper is then cut and welded to the length and angle determined by the measurements just before it is installed. The engineering team addressed these variations by considering four different scenarios for the jumper: maximum length, minimum length, maximum gross angle and minimum gross angle. So a complete evaluation requires that the 1,024 load cases be evaluated for each of these four scenarios, resulting in a total of 4,096 load cases for each jumper design.

Using conventional analysis tools, it would be impossible for an engineer to solve this many load cases within a normal design cycle. The standard practice has been for experienced engineers to use their judgment and instinct to pick out a relatively small number of load cases that they believe will generate the highest level of stress. But operators of wells and pipelines are becoming much more sensitive to potential hazards. In this project, the customer asked that every single load case be evaluated to make certain that the jumper could withstand the absolute worst case. Just a few years ago, such a task would take so long that organizations would rule it out for production jobs. But recent advances in optimization tools now make it possible to rapidly evaluate large numbers of design cases to ensure robustness.

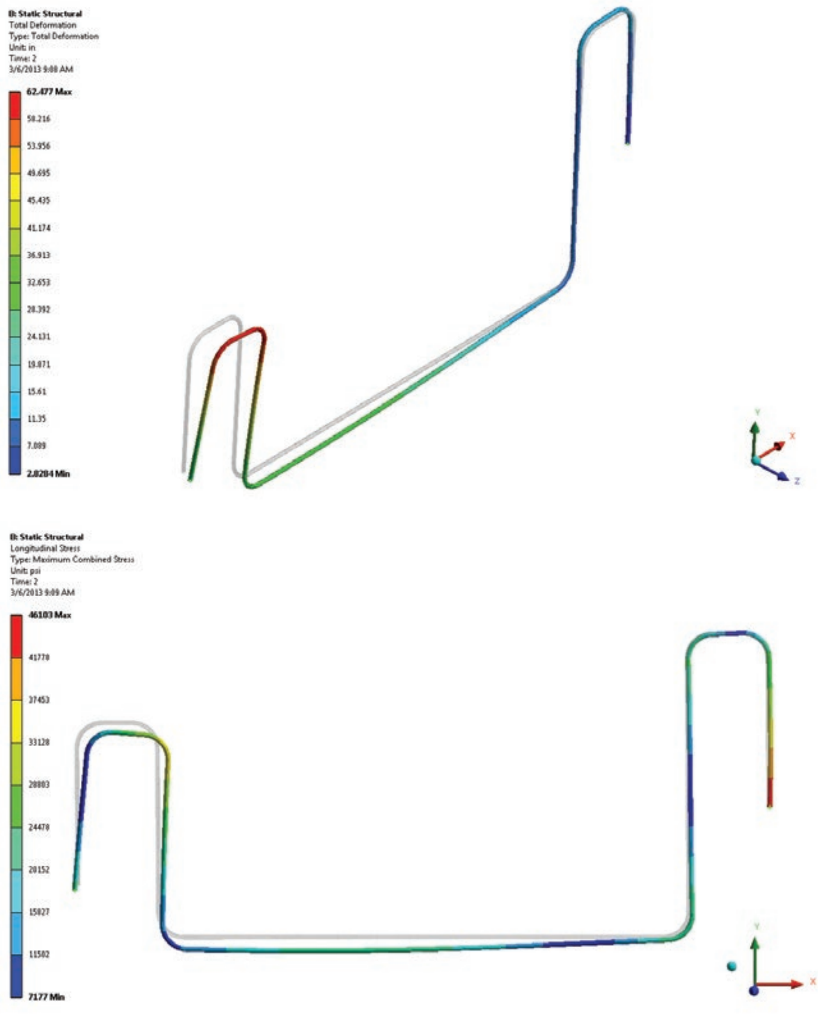
EXPLORING THE DESIGN SPACE

In this project, the first step was to create a simple jumper model in ANSYS DesignModeler based on a previous design. Engineers created three design parameters to define the geometry of the jumper that could be varied to improve its performance. Parameters included the length of two vertical and one horizontal sections of pipe that constitute the core of the jumper (geometric parameters) as well as three displacement and two rotation parameters at each end of the jumper (mechanical parameters), with two possible values representing each extreme end of its range of motion.

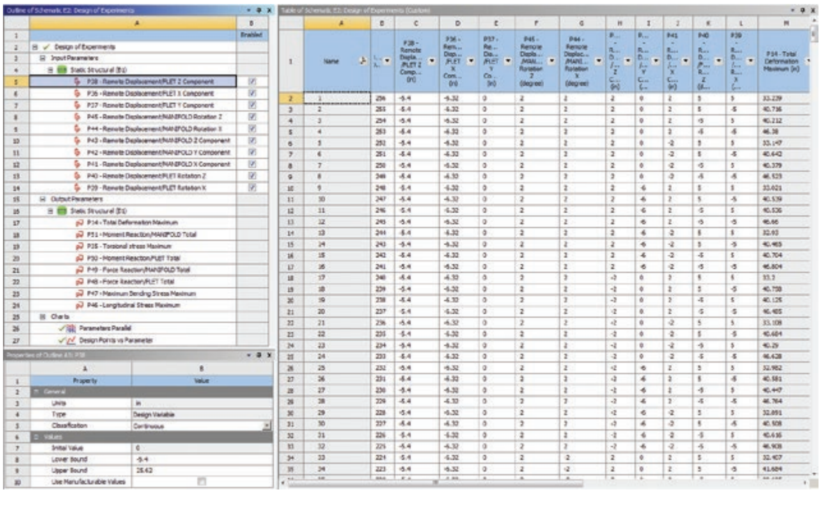
As the first step of the design process, engineers set up a short simulation run to explore the design space. They selected a previous design as the starting point, and the geometric design parameters were allowed to vary over a limited range in increments of 1 foot. Engineers used the Design Points option in ANSYS DesignXplorer to select a subset of about 200 load cases. They



▲ **Parameters were allowed to vary during optimization. The diagram shows loads that potentially can be applied to the jumper. Ten variables were applied to the remote displacements.**



▲ Total deformation (top) and maximum combined stress (bottom) at true scale



▲ The design of experiments capability in ANSYS DesignXplorer helped the simulation software to run thousands of load-case steps. Actual mechanical parameter ranges are shown.

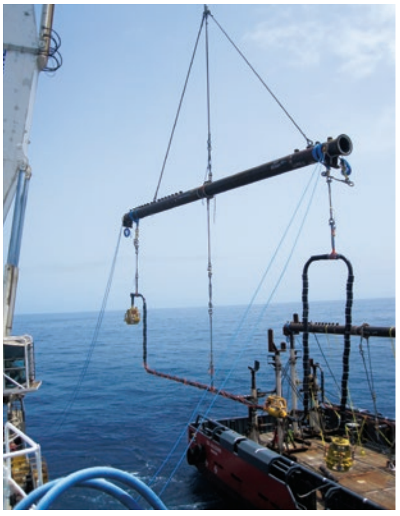
created a table with these parameters within the DesignXplorer optimization tool. A Technip engineer gave the Update command to solve the model for every combination of values in the table. The first design point, with the first set of parameter values, was sent to the parameter manager in the ANSYS Workbench integration platform. This drove the changes to the model from CAD system to post-processing.

DesignXplorer used parametric persistence to reapply the setup to each combination of parameters while file transfer, boundary conditions, etc., remained persistent during the update. The new design point was simulated, and output results were passed to the design-point table where they were stored. The process continued until all design points were solved to define the design space. The outputs of each simulation run included the minimum and maximum bending stress, shear stress, axial stress and combined stress within the jumper. Technip engineers examined the results, looking particularly at the sensitivity of the outputs with respect to design parameters and whether their variation with respect to the design parameters was linear or nonlinear.

DETERMINING THE WORST-CASE SCENARIO

As the second step, engineers fixed the mechanical parameters at the values that provided the worst results in the previous step with the goal of obtaining the geometric parameter set that could withstand the worst load combinations. Once the mechanical parameters were set at the current worst case (obtained from the first step), then the geometric parameters were allowed to vary over a greater range. Technip created a design-point table using the default settings in the design of experiments. Engineers employed goal-driven optimization for which the primary goals were that the stresses mentioned previously would not exceed allowable values. At the end of the second step, a set of geometric parameters that do not fail under the current worst-case scenario was obtained.

The third step confirmed that the optimized geometric parameter set would not have stresses higher than the allowable values under any possible load combination. Technip engineers created a design-point table using



▲ Jumper installation

the two possible extreme values (minimum and maximum) for each mechanical parameter while fixing the geometric parameters at the values obtained in the previous step. Since there are 10 mechanical parameters, this resulted in 1,024 (2^{10}) load cases. The Custom Design Point table option was used to import the 1,024 determined load cases. Engineers monitored the design-of-experiments runs, and if, for any load combination, the allowable values were exceeded, the design-point update was stopped, then the mechanical parameters that produced high stress were set to the new worst-case scenario. This started the iterative process between the second and the third steps. When all the runs in the third step were completed successfully, so that the allowable values were not exceeded within the pipe and the reactions at the ends of the jumper did not exceed connector limits, engineers moved onto the fourth step.

The 1,024 load combinations for each of the other three scenarios discussed earlier were run using design of experiments for step four. When all the design criteria were met for all 4,096 possible load combinations, engineers deemed the optimized parametric set successful, and the design for the first jumper was finished.

For the second, third and fourth designs, Technip engineers started with the optimal design that had been determined for the first jumper. They ran this design against the 4,096 load cases for each of the other jumpers. The maximum stresses were not exceeded on the last three jumpers — for each jumper design, engineers ran only the 4,096 cases needed to prove that the design could withstand every possible load case.

Variations in operating conditions may create uncertainty in subsea pipe structural design. Using parametric exploration and optimization tools from ANSYS, engineers checked the structural performance and integrity of these four jumpers over about 20,000 simulation runs. This capability will provide Technip with the significant competitive advantage of being able to prove to clients that its designs can withstand the worst-possible conditions encountered under the sea.

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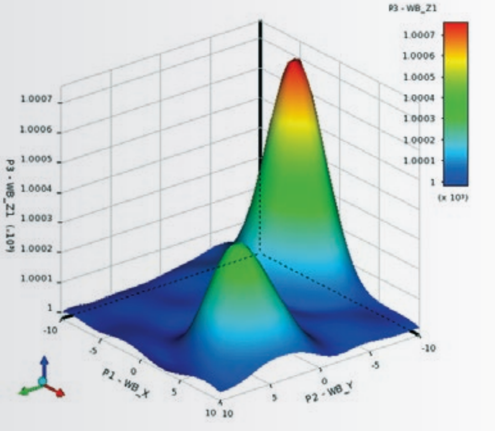
Scaling Design Parameters

By Mai Doan, Senior Application Engineer, ANSYS, Inc.

Technip's customer wanted a rigorous study of every possible combination of parameters, and ANSYS DesignXplorer was up to that task. However, many companies employ DesignXplorer to study the design space with as few solved design points as possible. Advanced DOE and optimization algorithms within this tool enable users to choose combinations of parameters that extract the maximum amount of information with minimum resources. Response surfaces (also known as metamodels) interpolate between the solved design points. If, for example, peak loads or optimal designs are predicted between solved design points, these can easily be verified on an as-needed basis. Using automated refinement and adaptive optimization, DesignXplorer focuses solver resources in the areas of the design space that are most likely to yield valuable results.



▲ Response surfaces show the relationships between design parameters and design performance.