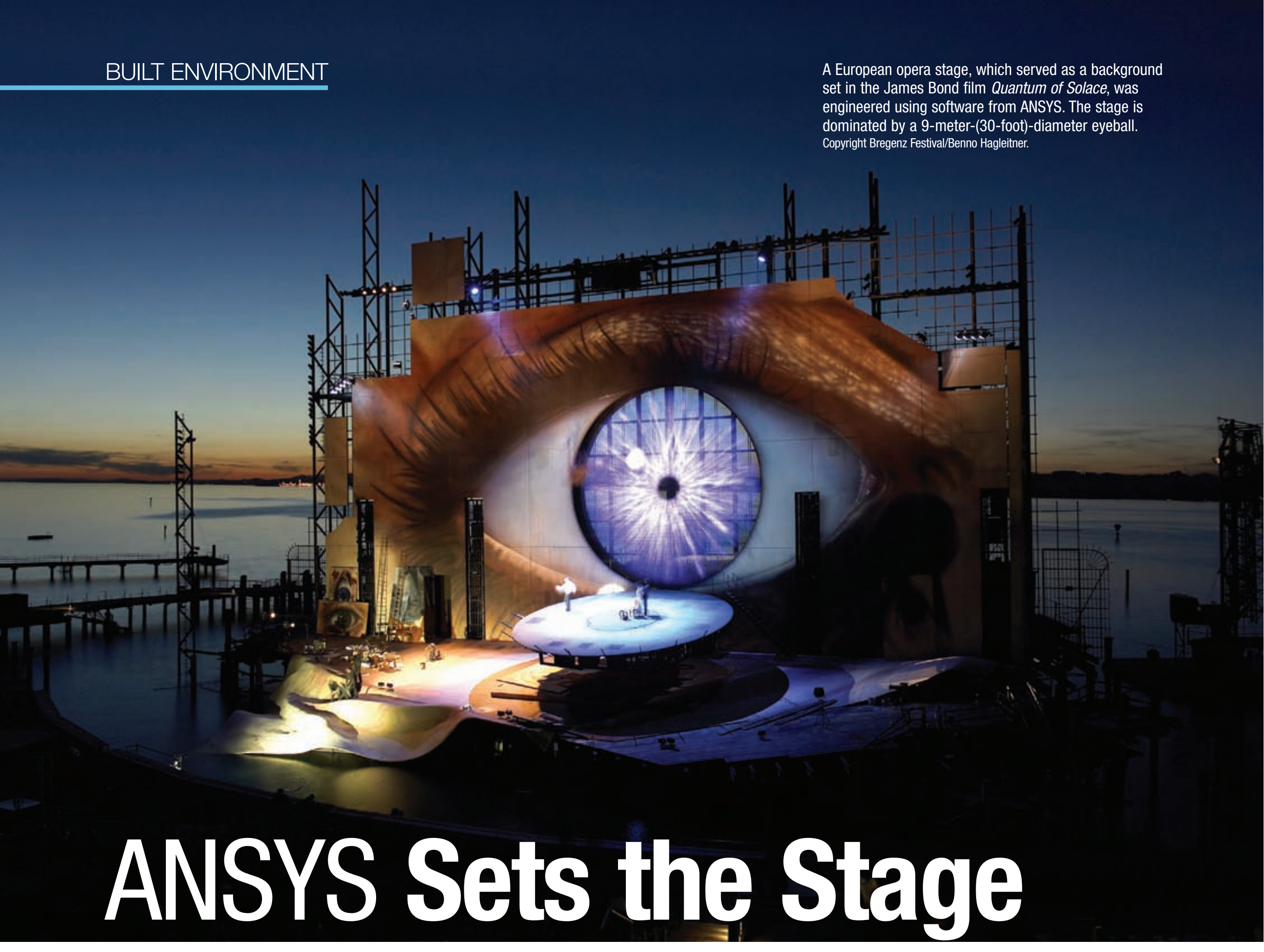

A European opera stage, which served as a background set in the James Bond film *Quantum of Solace*, was engineered using software from ANSYS. The stage is dominated by a 9-meter-(30-foot)-diameter eyeball.
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ANSYS **Sets the Stage**

Simulation was used to design the floating stage set used in the latest Bond movie.

By Gerhard Lener, ZT Lener, Feldkirch, Austria

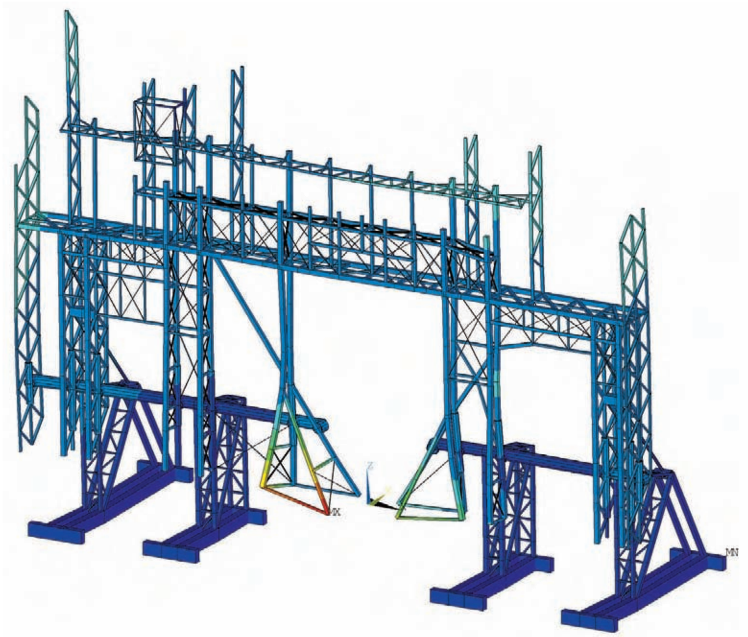
An important scene in the latest James Bond movie *Quantum of Solace* takes place in and around the Bregenz Festival's stunning open-air floating stage. This European stage, originally constructed for the opera *Tosca*, was built at a cost of nearly $8 million and features a huge eye, 31 meters (101 feet) high by 48 meters (157 feet) wide with an independently moving 9-meter-diameter eyeball. The structural design of the stage was validated to ensure that it could safely withstand environmental loads, loads caused by moving various elements of the stage and loading during assembly of the stage.

Finite element analysis predicted the stresses and deformations in the structure at various wind speeds, at different positions of the moving elements and in various stages of construction. Linear analysis was used to check the structure for serviceability, then nonlinear analysis was performed to ensure that the structure could withstand even higher loads without failing catastrophically. ZT Lener used the broad set of analysis capabilities in ANSYS Mechanical software to analyze the *Tosca* stage because it enabled evaluation of the structure from every possible standpoint — all within a single simulation environment.

Opera Stage also a Movie Set

A key *Quantum of Solace* sequence shot at the Bregenz stage occurs during a production of the opera *Tosca*. The eye portion of the stage changes throughout the performance of the opera to become a projection screen, an opening door, an execution platform and a ledge from which a stunt-fall into the lake is performed.

Bregenz is the capital of Voralberg, the westernmost state of Austria, located near the border with Germany and Switzerland. Every two years, the Bregenz Festival constructs a new floating stage on Lake Constance for presenting a single opera. The latest floating stage was built in 2007; its amphitheater has about 7,000 seats, and, over two years, approximately 320,000 people will have seen *Tosca*. These stage sets always represent complex engineering constructions that have to simultaneously fulfill artistic and strength requirements. Because no stage set is similar to a



ANSYS Mechanical tools predicted the stresses and deformations for the frame structure on the floating stage.

previous one, each becomes a new challenge for the entire team, which has to find solutions in many engineering disciplines.

Stage Presents Structural Challenges

The biggest challenge in the *Tosca* stage design was providing the strength needed to safely move the eye while staying within the weight limits of the foundation. The moving parts of the stage weigh about 250 metric tons, while the entire stage and foundation weighs only 463 metric tons. Another important limitation is that each component must be moved to the stage by a crane that can handle only about 12 tons. The small bridge between the stage and the land is limited to a mere 1 ton per square meter. This means that any larger components must be moved in smaller pieces and assembled on the stage itself.

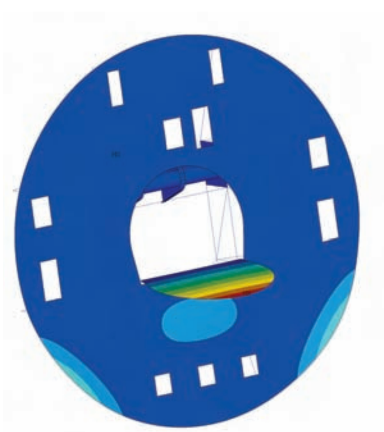
Further challenges resulted from the components' materials: The eye and eyeball are made of a composite construction with a steel frame and a wood outer surface. The composite construction increased the complexity of the analysis, since connecting the steel and wood in a shear plane provides additional stiffness beyond the sum of the properties of the two materials.

Broad Range of Analysis Tools

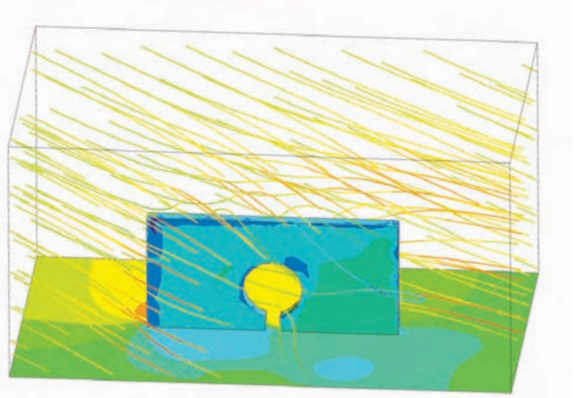
The stage design began as a 100-to-1 scale model, provided by the stage designer, that was used to create a 3-D Pro/ENGINEER® computer-aided design (CAD) model that guided the structural design. ANSYS Mechanical software was the ideal tool for simulating the floating stage because it provides a very wide range of tools — including linear and nonlinear analysis — addressing materials ranging from metal to rubber, a wide range of solvers and the ANSYS Workbench environment, which provides bidirectional communications with most CAD systems. In performing structural analysis for the last six floating stages for the Bregenz Festival, the design team has encountered a very wide range of structural analysis problems, and technology from ANSYS has been able to handle every one.

ZT Lener employed the traditional version of ANSYS Mechanical software for the main structure because it allowed use of a script to generate input files that automated the process of analyzing the structure at intermediate positions. Engineers modeled the eye's steel supports with beam elements and its wooden surface using shell elements. Powered by two hydraulic cylinders, the eye rotates 90 degrees between the vertical and the horizontal position. Many structural members receive their highest loading in intermediate positions of rotation, so it was necessary to analyze the

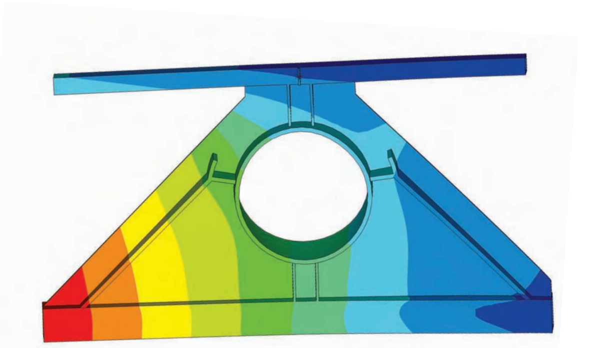
The eyeball portion of the stage is far more than a static background: The iris and pupil were engineered to rotate and fold out via hydraulics, creating a horizontal performance space. The iris also serves as a screen for special visual effects and a door that opens to reveal yet another scene. Copyright Bregenz Festival/Karl Forster.



The eye structure is a composite, a steel frame with a wood outer surface. Using the nonlinear capabilities of software from ANSYS, ZT Lener was able to accurately predict the physics involved in this complex analysis.



Engineers used simulation to predict the stresses and deformations in the structure at various wind speeds. Under wind loading, the eye structure deforms as much as 27 millimeters (5 inches). The engineering team also performed dynamic analysis on various parts of the structure to ensure that it would not resonate and cause vibrations that might interfere with a performance or damage the structure.



The triangular brackets that connect the eye to the rotating shaft are critical parts of the steel support structure. Based on the analysis results of the triangular support, engineers changed the wall thicknesses and positions of the stiffeners on the brackets to reduce deformations and stresses to safe levels.

structure at many different positions to be sure that no structural member is overstressed. The script moved the mechanism through a range of positions and tracked the highest stresses and deformations on each area of the model throughout the entire range. Under wind loading, the eye structure deforms as much as 127 millimeters (5 inches).

Analyzing Structural Details

The team modeled the triangular brackets that connect the eye to the rotating shaft, critical parts of the steel support structure, in the ANSYS Workbench environment. ANSYS Workbench makes it very easy to bring the CAD model into the analysis environment. Based on the analysis results of the triangular support, the team changed the wall thicknesses and positions of the stiffeners on the brackets to reduce deformations and stresses to safe levels.

Because of the transportation limitations already mentioned, it was critical to model the structure at various stages of construction. For example, the steel structure of the eye is much weaker before the wooden shell is assembled, but, on the other hand, it also experiences less wind pressure. Simulation verified that the stage could perform all movements at normal speed at a wind speed up to 50 kilometers per hour (kmh). There is a range of wind speeds above 50 kmh at which the stage can be moved — but at a slower speed. At wind speeds above this level, the stage needs to be moved to a specific position, where it is best able to resist wind loading, and held there.

Evaluating Ultimate Limits of Structure

The ultimate limits of the stage structures that take plastic elastic capacity into account were also evaluated with the loads multiplied by safety factors ranging from 1.3 to 1.5. The structure had to be designed to withstand these design loads and with elastic deformations under characteristic loads (safety factor 1.0). Dynamic analysis on various parts of the structure ensured that it would not resonate nor cause vibrations that might interfere with a performance or damage the structure. The mode shapes and frequencies of the eyeball were calculated to ensure that it would not resonate when several people moved on it at the same time. When the decision was made to film the James Bond movie on the stage, 1,500 kg (3,306 pounds) of lights had to be installed in the upper corner of the eye structure. This required a separate simulation, which indicated that the structure needed to be strengthened.

In constructing the floating stages for the Bregenz Festival, there is obviously no opportunity for building prototypes or making design changes along the way. Since the opening date of the festival is set long in advance, unlike many building projects, the completion date for the stage cannot be changed. The safety of the singers, the stage crew and the audience depends upon getting the design right the very first time. The use of ANSYS Mechanical software, whose accuracy has been proven on a very wide range of analysis tasks, gave the entire project team confidence in the analysis results. ■

CADFEM, an ANSYS channel partner in Germany, supported Lener in his use of software from ANSYS.