Keeping Dry in The Netherlands

Simulation Leads to Successful First-time Operation of Inflatable Dam

"The simulation proved the mechanism would work without high stresses."

Customer:
Hollandsche Beton-en Waterbouw bv,
The Netherlands

Software/Services:
MSC.Marc®, MSC.Software Professional Services

Summary:
The design/build engineering company Hollandsche Beton-en Waterbouw bv (HBW) investigated and validated the concept of a new, very large, inflatable dam with the help of MSC.Software Professional Services and products such as MSC.Marc. Using MSC.Marc nonlinear simulation software, HBW could understand the dam's performance and the inflation/deflation procedure, as well as ensure that stresses were within the specified margin of safety. Thanks to the implementation of VPD tools, HBW realized design improvements in the inflatable dam's flexible structure and completed the design. When a heavy storm hit the Netherlands in 2002, HBW's dam automatically deployed within one hour -as predicted by MSC.Software tools.

Protecting the northwestern province of Overijssel in the Netherlands from flooding are three inflatable storm surge barriers designed by Hollandsche Beton-en Waterbouw bv, a design/build engineering firm headquartered in the Netherlands. Lying at the bottom of the Ramsdiep and Ramsgeul waterways near the city of Kampen, the inflatable dams are automatically deployed when the water reaches 0.5 meters above NAP (Normal Amsterdam Level), which is average sea level at the Dutch coast. The average water level at the dam is 0.4 meters below NAP. Because an inflatable dam of this size had never been built before, the concept had to be validated before it could be built. MSC.Software Professional Services was engaged to investigate the concept, as well as to make design improvement recommendations, using MSC.Marc nonlinear simulation software.

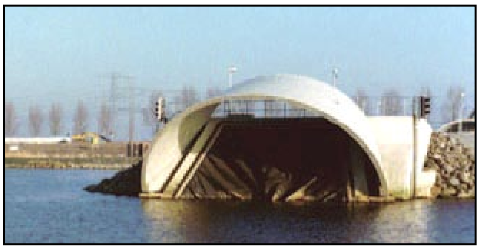
Hans Dries, project manager of HBW, said, "A prototype is typically a pass/fail situation - it either works or it doesn't. When it doesn't work, it's a guess as to exactly why. When it does work, it's difficult to know if it was on the cusp of failure or over-engineered. Simulation of the inflatable dam provided the information that allowed us to understand its performance and ensure stresses were within the specified margin of safety. With the inflatable dam, there was no alternative to simulation for validating the design."

The inflatable dams were designed to work in conjunction with dikes currently undergoing improvement in Overijssel, a home to rare and endangered flora and fauna; dikes, homes, and farms with cultural and historical significance; and unusual locks and pumping stations. Other methods considered for protecting the area could have resulted in flooding an area with unique cultural and historical significance that requires complex resource management.

The inflatable dams are 75 meters long, 13 meters wide, 8.35 meters high and made of rubber sheet reinforced with nylon cord. Automatically deployed by opening pipelines connecting upstream water with the interior of the inflatable dam, compressors located at each of its two ends simultaneously inflate the membrane with air. The top of the inflatable dam is kept above the normal upstream water level with an internal air pressure between 0.2 and 0.4 bar, with peaks of 0.44 bar. As the water level rises, deformation of the membrane increases. The dams are deflated by opening the air valves and pumping the water out. As the dam deflates, the membrane collapses into a sill on the bottom of the river, where rollers move the membrane equally over the width of the sill.

MSC Software

> *"MSC.Software Professional Services has improved our knowledge of this kind of flexible structure."*



Because approximately 90% of the 2,000 inflatable dams worldwide are built in Japan, engineers there have developed the only code that exists for inflatable dams. Based on a 2D cross-section, the Japanese code requires a safety factor of 8 between initial tensile strength and static load. The safety factor is intended to consider issues such as wave loading, stress concentration, aging, fatigue, and water saturation.

Rubber Membrane Analysis

An FEA simulation using MSC.Marc was performed to calculate the effect of static stresses on the nonlinear material characteristics of the membrane, as well as to understand performance of the inflatable dam and the inflation/deflation procedure. Scale models in the hydraulics lab were utilized for correlation with the FEA analysis and for investigating dynamic effects.

Input for the analysis included environmental factors, such as temperature and pressure, and the material properties of the fabric resulting from test coupons. The fabric for the membrane was made of rubber reinforced with nylon cord that is 16 mm thick, weighing 20 kilos per square meter. The membrane for one of the dams weighs in at 33 metric tons.

The kinematic and constitutive equations of nonlinear material performance, as measured, are based on small strains, the so-called engineering values. In the MSC.Marc analysis, the strains are measured in the large strain formulation. Therefore, to be able to apply the material data in the correct way, strains and stresses had to be converted between both formulations.

This particular analysis was very difficult because the membrane is built from a composite of rubber and nylon cord and is quite thin in comparison to its size, resulting in huge displacements that cause instability in the model. Maarten Oudendijk, project manager, MSC.Software, said, "This is a very thin component, and you have to apply loads and boundary conditions in such a way that the analysis remains stable. By applying consistent and very high tensile force to stretch the membrane, it was possible to keep the model stable. As the stresses and loads were applied for the analysis, then the boundary conditions that kept the model stable were relieved."

Clamp Design Solutions

The edges of the membrane are clamped to a sill at the bottom of the river so it is like a deflated balloon lying on the bottom of the river. However, stresses were higher than acceptable at the clamping points in the first analysis. The critical problem was discovered at the beginning of the 45-degree angle where the membrane leaves the clamp on the upstream side of the dam. Oudendijk said, "The main issue was how to clamp the membrane. By clamping it in certain locations, you automatically can get very high peak stresses. Moving away from the boundary, peak stresses will vanish because the stresses are redistributed. So we needed a solution for affixing the membrane so it would not break at the points with very high stresses, where you get a kind of domino affect, and each cord begins to break." Factors related to the excessive stress were identified in the first analysis, enabling recommendations for improving the clamp design. Also in the first analysis, the model of the membrane was clamped so that it could not move.

In real life, when a membrane is clamped and pulled on, it will move. Oudendijk said, "We knew how to design for lower stresses and our customer knew the limitations for manufacturing the clamp. Together we worked very closely to modify the design in such a way that the stresses would be reasonable. With the redesign, we modeled the clamping mechanism like a spring, allowing it to move a little. The simulation determined the force required to start moving the membrane in the clamp and proved the mechanism would work without high stresses."

Correlation to Reality

In order to prove the accuracy of the simulation, a 1/25th scale model was created in the hydraulics lab. Simulations showed that two stable shapes could be found. When the forces were applied to the prototype to create the final shape, just pushing the membrane changed the final shape from one stable position into the other one. However, the loads were lower, which indicated the membrane would not break. Another objective of the simulation was to determine if stresses after damage caused by a ship's propeller or anchor were acceptable.

Oudendijk said, "The simulations had a high degree of correlation with the scale model, demonstrating the deformations we identified using simulation were in agreement with reality. At that point, our client and the government of the Netherlands gained confidence in the analyses we had performed."

Epilogue

On Sunday, October 27, 2002, the sixth worst storm to hit the Netherlands since 1970 caused the inflatable dam to automatically deploy at about 5:00 pm. The gusts of wind reached 120 km/hour (72 mph) in the vicinity of the dam, which deployed in less than an hour. Within another hour, the waters receded and the dam deflated in an hour. Dries said, "The simulation performed by MSC. Software Professional Services has given us a good feeling for the behavior of the Ramspol rubber dam and has improved our knowledge of this kind of flexible structure."

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