Realistic Simulation Makes a **Safe Impact on Train Design**

Swiss-based Stadler Rail Group produces about 700 light and commuter rail vehicles per year. All of its products meet stringent requirements governing safety equipment, strength of train units (cars and engines), and, above all, passenger and crew protection from the force of impacts.

A recent order from the Netherlands for 43 of the latest generation of Stadler's GTW articulated rail cars presented the company with a new challenge: the train units had to meet as-yet unreleased crashworthiness standards that the country had adopted in advance of their approval by the European reviewing committee. These standards required that the units provide passenger zone protection during a 36 km/h (22.4 mph) front-end collision between two units with a vertical offset of up to 40 millimeters.

Two developments drove the new requirement. First, head-on impacts could easily include a small offset because two train units had differing amounts of wheel wear or braking inclination. A second reason was more urgent: a recent numerical simulation of an offset collision indicated that the previous design of a crash module (a safety device on the front of the train car) might not prevent damage to the passenger zone of the train units during such an impact.

Side view of two aluminum crash modules modeled in Abaqus FEA software to simulate a crash. The impact is offset to determine whether the teeth at the front of the modules can prevent either module from climbing over the other. Vertical stripes on the module sides represent trigger slots, points of weakness built in to induce controlled plastic failure.

"Numerical simulation suggested that the crash module could undergo global shear deformation and fail at the fixation point, falling off the front structure," says Dr. Alois Starlinger, head of structural analysis, testing, and certification at Stadler. "In such a shear mode failure, the module would not absorb any significant energy." In a worst-case scenario, both trains would climb over each other, deforming the passenger zones severely.

To satisfy the new safety requirement—which is scheduled to become the standard throughout Europe in 2008—Stadler Rail designed a new crash module with an anti-climb feature. Engineers validated the module design through a combination of dynamic physical testing and simulations in Abaqus finite element analysis software.

A "crash" design project

The crash module is a tapered rectangular tube that is 12 inches high and wide at the front, 30 inches long, and 14 inches high and wide at the rear, where it is welded to an end plate bolted onto the crash wall of the train unit. Partitions divide the module into chambers that provide stability to counter eccentric forces. On the front of the module are five horizontally aligned teeth, 70 mm apart with a depth of 40 mm, designed to engage the teeth of a similar module on an oncoming rail car and prevent climb.

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Side view of the crash modules after physical testing of an offset crash. The modules performed successfully, absorbing the energy required to protect the passenger zone. The teeth kept the two modules engaged, and the aluminum deformed as desired, absorbing the impact of the crash with a controlled deceleration of less than 5 g. Note the close convergence of the Abaqus simulation and the physical testing.

Once the teeth have engaged, the rest of the crash module is optimized for controlled structural deformation from the front to the back. Targeted slots on the sides create intentional weak points that initiate buckling and subsequent energy absorption. In developing the design, engineers built on lessons learned while producing crash modules for previous generations of GTWs.

For the new design, the engineers selected an aluminum alloy, AW 5754. This alloy combines low yield strength with good plastic forming characteristics, enabling it to undergo large deformations without fracture. An important engineering goal was to create modules that could absorb up to 900 kilojoules of crash impact while decelerating the train unit at 5 g (g-forces) or less, as far as was practicable.

To capture the material behavior of the module, Stadler extracted information from its own materials database, compiled from exacting physical tests. Engineers incorporated the data into an Abaqus model, then calibrated the metals simulation by extracting aluminum samples from a series version crash module and testing the samples to create stress-strain curves. By comparing these curves to results generated by Abaqus simulations, the engineers were able to fine-tune the behavior of the FEA analysis so that it closely matched the real-world characteristics of the aluminum alloy in a crash module.

Now the engineers were ready to build a model of the crash module and analyze its behavior on impact. Simulation of the head-on offset impact followed a number of parameters:

- Collision masses (train units): 100,000 kg each
- Closing speed (combined speed): 36 km/h
- Maximum energy to be absorbed by crash components of both train units: 2,230 kj
- Maximum energy to be absorbed by a single train unit: 1,115 kj

Because of the complexity of the analysis, engineers chose to run nonlinear dynamic simulations with Abaqus/Explicit so they could observe the elastic-plastic behavior of the metal, measure progressive damage and failure of welding, analyze the large deformations of the module, and model contact and friction. “Abaqus was able to capture all the forces and materials behavior we needed,” Starlinger says. “General contact capabilities of the software were particularly useful.”

The finite element model and the analysis task before it were both dauntingly large. There were 450,000 elements in the model, and the dynamic simulations captured a period of 0.4 seconds broken down into 200,000 “snapshots.” To promote a speedy run time, the engineers ran the software on an SGI Altix 350 with 4 Itanium processors with activated parallel processing.

Train units were modeled in 3-D with running bogies (wheel, axle, and frame assemblies) and suspension characteristics to capture any lift-off of the wheels and axles on impact. Contact conditions were defined between the wheels and rails, as well as between the bogies and train unit body. Forces applied on impact by attached articulated units were modeled axially with 1-D and mass elements.

Safe, speedy arrival at results

Abaqus simulation results correlated very well with physical dynamic tests. The anti-climb teeth prevented either train unit from moving over the other, and the module body underwent controlled deformation to absorb 1.1 megajoules. Aluminum buckling decelerated the train unit at an average of 1.25 g.

“Our goal was to achieve an overall compressive strength for the train unit to 1,500 kilonewtons, without undergoing any yield and deformation in the passenger structure,” Starlinger says. “In fact, our crashworthiness engineering improved the compressive strength to about 3,600 kn, with only small amounts of plastic deformation in the passenger zone.” He adds, “And we proved out the anti-climb device against offsets as high as 80 mm.”

In addition to the accuracy of the Abaqus simulations, their fast run time (18-46 hours) was important. “We were able to release the crash module for production exactly eight months after the contract was signed,” Starlinger says. “The whole GTW Arriva went into operation ten months later, which is probably a record for starting a design from scratch in passenger train service.”

Stadler plans to build on its experience and continue making each new train design safer than the last. Starlinger sees Abaqus software as an important part of that process. “In its own way,” Starlinger concludes, “FEA is now as essential to ensuring train safety as brakes.”

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