Crush simulation of cars with FEA

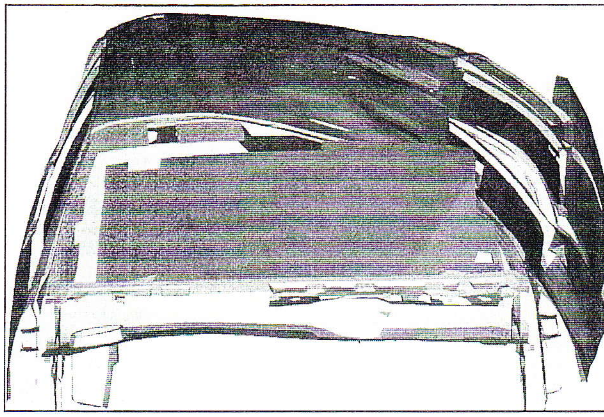
While crash analyses have been carried out with success, a crush analysis is much more difficult to achieve. **By Klaus-Jürgen Bathe**

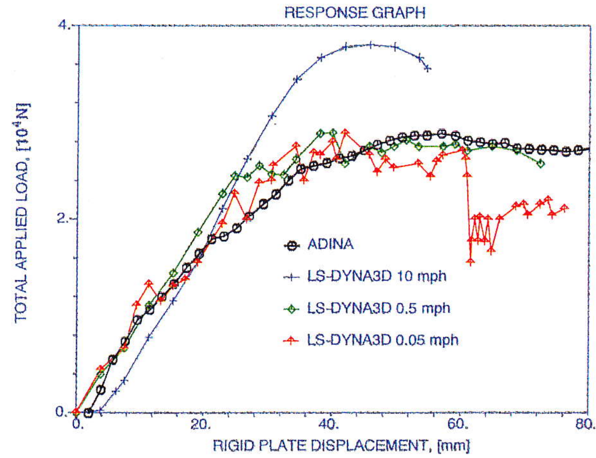
FINITE-ELEMENT ANALYSIS procedures are now used abundantly in the automotive industry. Linear static and dynamic analyses are conducted in a routine manner, and nonlinear analyses are increasingly pursued.

Two analysis fields in which highly nonlinear conditions are simulated are the crash and crush analyses of complete motorcar models. The purpose of a crash analysis is to see how the car will behave in a frontal or sideways collision. In a crash analysis, the crashing of a car at about 30 mph into a rigid wall is simulated. Various crash codes, such as LSDYNA, PAMCRASH, and RADIOSS, are used. The codes have been developed based on explicit time integration, special shell elements for this specific analysis, and modeling assumptions regarding the dynamic behavior involved. The analysis results have been compared with laboratory test data, and the simulations have proved very valuable.

In a crush analysis, a quite different physical phenomenon is considered. Here the purpose is to establish the ultimate strength of the car body in a static situation. The ultimate strength affects the behavior of the car under various operating conditions, such as when the car overturns in an accident. The laboratory experiment to identify crush behavior is performed by crushing the car slowly (at about 0.02 mph), using a device to push a thick steel plate onto the car roof and measuring the load-deformation relation.

While crash analyses of cars have been carried out with much success, a crush analysis is much more difficult to achieve. The reasons for this greater difficulty lie in the fact that a slow-speed, almost static analysis requires increased robustness and efficiency in the solution algorithms. Specifically, for the crush analysis, the shell elements must be of high predictive capability, and be robust and computationally efficient for static analysis. The contact algorithm must allow three-dimensional multiple-body and self-body contact on the outer and inner surfaces of the car shell, be robust, and give fast convergence in the iterations for static





Crush analysis of motor car model. Physical speed of crushing is 10 mm/sec. (about 0.022 mph). ADINA implicit dynamic results at 10 mm/sec. and LSDYNA explicit dynamic results.

equilibrium at the different deformation states.

In a crash analysis, the inertia effects "smooth out" the nonlinearities and deficiencies in the solution algorithms. In addition, explicit time integration is usually employed, which means that no iteration is used in the step-by-step solution (as is required in a static nonlinear analysis). A simple time-marching-forward solution is produced. This analysis procedure is attractive because difficulties with respect to convergence in equilibrium iterations do not exist.

In a static nonlinear analysis, iteration for equilibrium is

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required in each load step. In a dynamic nonlinear analysis using implicit time integration, which reduces to a static analysis if the time scale is long, the same iterations are performed, but inertia forces for each time step are included. While no iterations are performed in an explicit time integration, the time step used in the solution must be smaller than a critical time step, for the solution to be stable. The critical time step varies during the solution process, because it depends on the geometry and material conditions that change during the analysis history. If a step larger than the critical time step is used for only a few solution steps, "merely" a significant error is accumulated in the analysis. However, if the time step size continues for more than just a few steps to be larger than the critical time step, the solution errors grow to become extremely large, indicating the numerical instability of the solution.

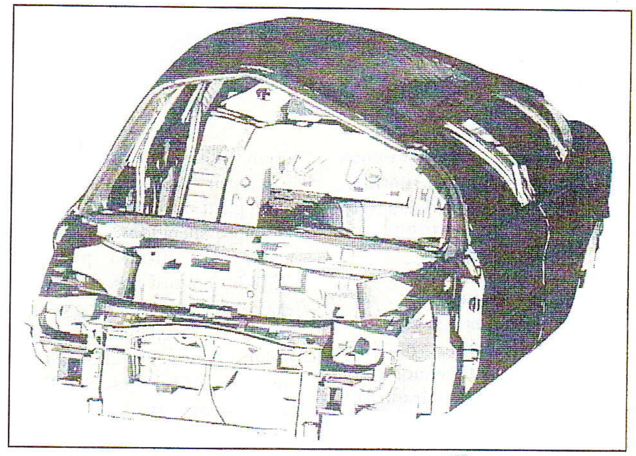
For a crush analysis, it may appear that a natural way to obtain the solution is to use the available crash analysis codes. However, there are difficulties with respect to the solution cost and the accuracy of the analysis results.

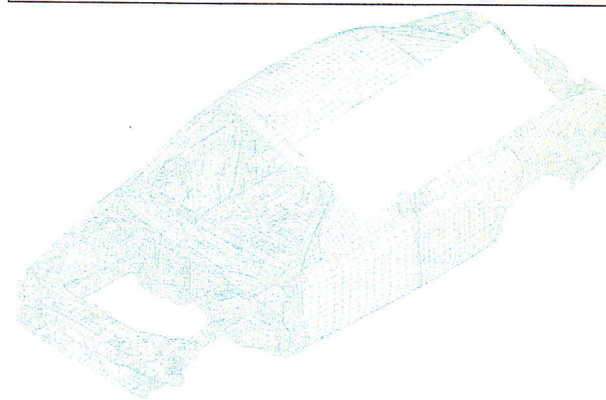
In a crush test, it takes about 10 to 30 seconds to crush the car to the required maximum displacement of the steel plate. Since the critical time step for explicit time integration in a crash code is on the order of microseconds, millions of time steps must be used to perform the analysis in a physically correct manner. The computational time for such a solution is very high, and ways have been sought to reduce the required number of time steps for analysis. In one approach, the speed at which the steel plate is applied is artificially increased. However, inertia effects then become important, resulting in an artificial increase in the computed crushing force. In another somewhat equivalent approach, the density of the material is artificially increased, again resulting in a higher computed crushing force. Given such results, numerical experimentation is required to assess the effect of changing the model and the load application.

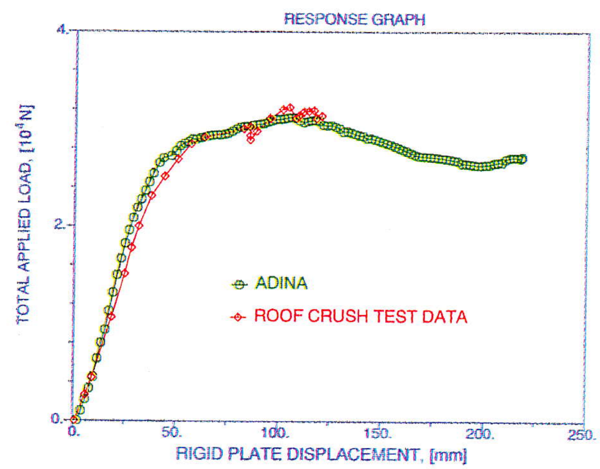
All in all, these approaches can hardly be recommended. Instead, if explicit time integration is used and reliable results are required, the actual physical conditions should be represented. This requires a huge number of solution steps and hence very large computation times.

The above considerations are elucidated on the facing page, which shows results computed with LSDYNA and ADINA in a crush analysis of a NASTRAN finite-element model. The actual physical condition is that the speed of load application (through the rigid plate crushing the car) is 10 mm/second (about 0.022 mph). The ADINA solution was obtained at that speed of load application using implicit time integration, which corresponds in essence to an incremental static solution.

The LSDYNA explicit time integration for the 0.05-mph speed required much more computer time, a computer run of weeks instead of the overnight run with ADINA. And the LSDYNA results are questionable because of the artificial oscillations in the computed response—the response should be static (see "What Can Go Wrong in FEA?", May.) If the load application speed is increased, the inertia effects reduce the response oscillations and increase the predicted collapse load, but it is virtually impossible to predict prior







Crush analysis of Taurus car model. Comparison of ADINA implicit dynamic results and laboratory test data (all at 10 mm/sec., i.e. about 0.022 mph).

to the analysis which artificial speed of load application should be used. For example, at a speed of 10 mph, due to the inertia forces, the predicted crushing force is much too large. With sufficient numerical experimentation, involving changes to the load application speed and perhaps to other parameters, LSDYNA results can be obtained that would match laboratory test results (which, unfortunately, are not available for this car), but such experimentation requires a lot of time and computational effort.

It is quite obvious that a solution that corresponds to the actual physical conditions and is computationally efficient is much more desirable. Such a computed solution is given above for a Ford Taurus model. The calculated crush results obtained with ADINA using implicit integration compare favorably with the laboratory test results. ■