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When the Rubber Leaves the Road

By James Case

Most drivers probably give little thought to guardrails, the manmade barriers that prevent errant cars and trucks from plunging over cliffs and roadside embankments. Highway safety experts do pay them considerable attention, and will continue to do so as long as 40,000 people continue to be killed each year on U.S. highways.

Given such numbers, even small advances in highway safety pay significant dividends in human survival. Accordingly, the National Cooperative Highway Research Program (NCHRP) has issued a report delineating acceptable levels of danger from roadside hazards of every sort, including guardrails (poorly designed guardrails can cause more damage than the hazards they're meant to protect against). Highway safety engineers now compete to discover ever more cost-effective means of meeting the NCHRP guidelines for guardrails and other roadside appurtenances.

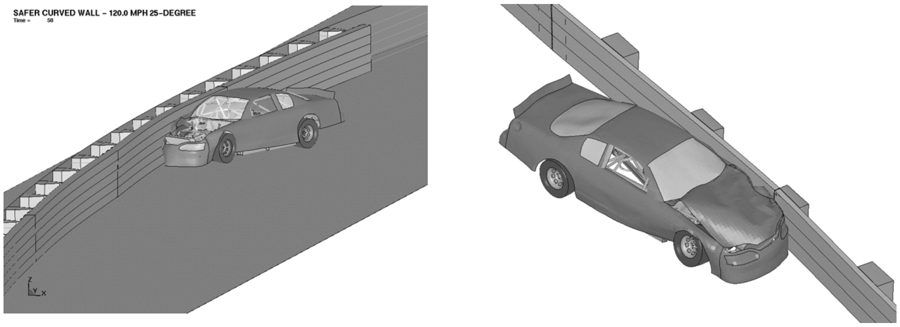
W-beam guardrails—named for their shapes in cross-section, which resemble rounded-off versions of the letter in question—are common in many eastern states. They are relatively cheap, and easy to manufacture and install (and are the type discussed in this article). Although their performance in crash tests depends heavily on the manner in which adjacent sections are joined, and on how the rails are attached to the supporting posts, a few generalizations seem well established.

Tests conducted by the New York and Pennsylvania departments of transportation during the late 1960s established that in crashes of most types, "weak-post" W-beam guardrails inflict damage significantly less severe than their "strong-post" equivalents, since the guardrails themselves often remain intact even when the posts supporting them rupture. This is particularly true in sideswipe situations, where the natural elasticity of a metal guardrail can actually guide an errant vehicle back toward (or even onto) the highway. High-speed action pictures of such collisions can be quite spectacular, and computer simulations often mimic them in surprisingly fine detail.

Simulations vs. Crash Tests

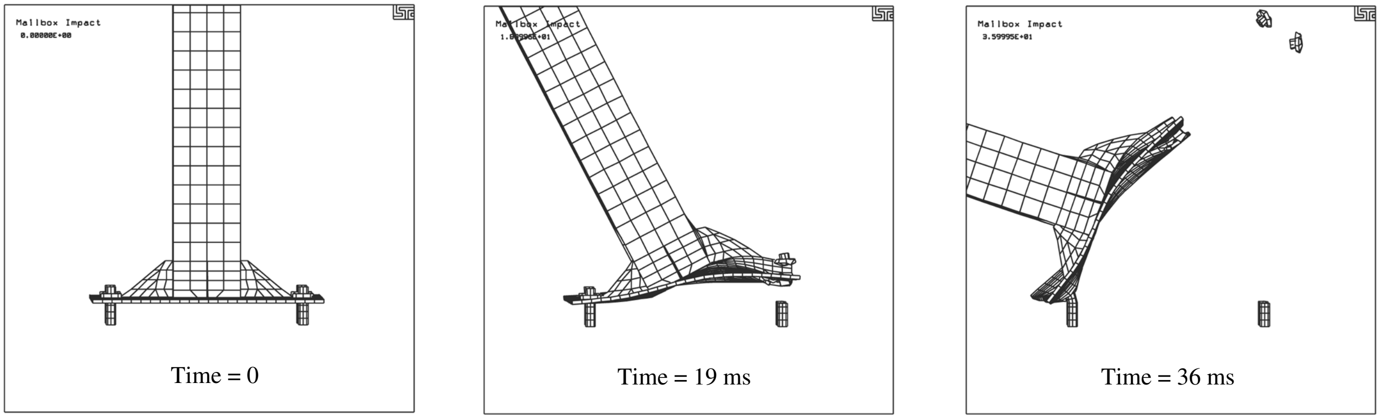
The Midwest Roadside Safety Facility (MwRSF) at the University of Nebraska–Lincoln is an important conductor of both crash tests and computer simulations. Its stated mission is "to improve the safety of public roadways through the design and testing of roadside hardware." Crash tests, despite their considerable cost, furnish relatively little information, points out John D. Reid, a director of the Center of Excellence in DYNA3D Analysis, sponsored by the Federal Highway Adminstration at MwRSF, and an associate professor of mechanical engineering at UNL. There is just so much to be learned from film, a few accelerometers, and scattered onboard "load cells." A computer simulation based on the analysis of a nonlinear finite element model of the crash vehicle and/or its immobile target typically supplies far more information, including stresses/strains throughout the system, cross-sectional analysis, forces transmitted from one part to another during contact, forces transmitted through connections, a camera's-eye view from any vantage point, and so on.

The MwRSF employs LS-DYNA software from the Livermore Software Technology Corp. (LSTC) to analyze automotive impacts. LSTC is an offshoot of the Lawrence Livermore National Laboratory, where a team of engineers, mathematicians, and scientists led by John O. Hallquist developed LS-DYNA. Incorporated by Hallquist in 1987, the firm continues to develop and market LS-DYNA and a suite of related software products. MwRSF uses LS-DYNA in conjunction with HyperMesh from Altair for model development, and LS-POST from LSTC for processing results. A typical crash model might have 70,000 nodes and elements, with each node having 6 degrees of freedom and each element containing 12 "integration points" at which stresses and strains are calculated. Because the timesteps between stress/strain calculations are on the order of a microsecond, and because a crash event can last for 400 milliseconds, large quantities of CPU time are consumed in the analysis of a single impact. Small wonder that MwRSF is one of the largest users of the Nebraska supercomputer.



Installed in time for the 2002 Indy 500, the SAFER Barrier is one successful design project of the Midwest Roadside Safety Facility at the University of Nebraska.

Dubbed PrairieFire, the newest UNL supercomputer clusters 256 processors —along with 100 gigabytes of RAM and 2 terabytes of hard disk memory—in a 128-node configuration. That means that 256 otherwise independent machines are closely linked via a high-speed interconnect. The result is capable, when operating at peak efficiency, of about 250 gigaflops, roughly 400 times faster than a top-of-the-line desktop PC. It was—at the time of installation in January 2002—among the world's 100 fastest computers. An older and more conventional 32-processor machine is housed in the same building in downtown Lincoln, where both are used



Time = 0

Time = 19 ms

Time = 36 ms

Figure 1. *Pedestal base simulation sequence.*

to develop scalable high-performance code for various applications.

The Indy 500

Sponsored by the Indy Racing League and NASCAR, the MwRSF developed a barrier for high-speed racetracks. The SAFER Barrier, the first major result of this project, was installed at the Indianapolis Motor Speedway for the 2002 Indy 500 Race.

Carrying out both static and dynamic component testing, LS-DYNA computer simulation modeling, and a total of 20 full-scale vehicle crash tests, the researchers investigated several barrier prototypes. The full-scale crash testing program included bogie vehicles, small cars, and a full-size sedan, as well as actual IRL open-wheeled cars and NASCAR Winston Cup cars. For the race car impact tests, typical impact speeds ranged between 190 and 245 km/h at angles of 20–25.6 degrees.

The SAFER Barrier, with its combination of a steel tube skin and a foam energy-absorbing barrier system, is unique: It was built not only to withstand impacts at speeds of up to 320 km/hr at 25 degrees, but also to accommodate extremely restricted wall space (only 24–30 inches). For comparison, typical highway barriers are designed for 100–km/h) impacts at 25 degrees and almost always have an "open" area behind them (behind the SAFER Barrier is the racetrack's existing concrete wall).

Results of lab testing and of impacts during practice, qualifying, and the race have shown that the SAFER Barrier provides improved safety for drivers who hit the outer walls. (See illustrations on page 1.)

Rural Roadside Hazard

Another task recently undertaken by the MwRSF is the redesign of "neighborhood mailboxes." Such facilities are found in semi-rural areas, where families live sufficiently close to one another that several can conveniently share a single mailbox location. Typical configurations mount a dozen or so otherwise ordinary mailboxes atop a common pedestal. The United States Postal Service refers to such installations as Neighborhood Delivery and Collection Box Units, and currently requires that they meet the NCHRP crash test requirements. MwRSF simulations revealed that, whereas passengers could be injured even in rather low-speed impacts with existing neighborhood mailbox designs, their safety is significantly enhanced when weaker bolts are used to fix the pedestal to the underlying (buried concrete) foundation.

Figure 1 shows the level of detail employed in simulating a pedestal-separation event. The levels of detail deemed appropriate for modeling vehicle damage are variable. The front of the vehicle, which naturally sustains the bulk of the damage, is represented by numerous deformable elements, while the rear end is assumed for modeling purposes to consist of large rigid panels.

While the budget for the mailbox project did not allow for the destruction of actual automobiles, a dozen mock neighborhood mailboxes were struck by an effectively indestructible 827-kg "bogie" crash vehicle at 35 km/hr, to verify that the upstream bolts did indeed break under tension—as predicted—while the downstream bolts broke in shear. Moreover, the change in the bogie vehicle's velocity was between 0.7 and 1.6 m/s, with no detectable yaw in any of the 12 test runs. The redesigned "breakaway" pedestals were also subjected to a demanding 500-hour salt spray test to check for unwanted corrosion. None was expected, since the pedestals were of stainless steel, and none was observed.

Reid is careful to distinguish between parts that actually fracture, and those that merely stretch and/or bend. Current hardware and software combinations do a creditable job in simulating the latter, but lack the power to handle the far finer meshes required to analyze fractures. Fortunately, Reid says, many issues in roadside safety and crash worthiness can be resolved by current means, because stretching and/or bending are far more common than the actual breakage of metal auto parts. As he sees it, an accurate science of fracture mechanics lies well beyond the current horizon.

Post Design Considerations

A particularly important design problem tackled by MwRSF researchers has to do with breakaway posts for guardrails. Wood is often used for the purpose, being relatively cheap and widely available. But it is far from ideal, for a variety of reasons. The quality and fracture characteristics of wood vary widely, due to variations in post size, ring density, knot size and location, cracks, species characteristics, and moisture content. Wooden posts are also more prone than steel to deterioration from environmental factors, such as heat, moisture, and freeze–thaw cycles. Finally, because of the chemical preservatives used to control decay, broken wooden posts are considered an environmental hazard. Steel guardrail posts, in contrast, can be recycled after an accident. For these and other reasons, development of improved breakaway steel posts for guardrail support seems to be called for.

The breakaway base concept employed for neighborhood mailboxes is useless for guardrail supports, in part because such designs require significant on-site assembly. In addition to being of uniform strength, such guardrail supports must be easy to transport, virtually maintenance-free, and competitively priced with wood. As a practical matter, guardrail posts must ship as a single unit and be drivable (with minimal digging) in even the stoniest of soils. Steel appears to excel wood in all of the foregoing respects, and endless hours of R&D have been devoted to realizing its full potential. One recent report recommends a standard 12-gauge W-beam guardrail mounted some 32 inches above the ground on weak steel posts spaced twelve and a half feet apart with rail splices at mid-span, posts and rails being attached by single bolts of specific dimension using two nuts and two washers of definite size and shape. Finite element analyses of weak steel posts require surprisingly fine meshes, because the desired bending and shearing characteristics are achieved by drilling precisely sized and positioned holes immediately above and below ground level.

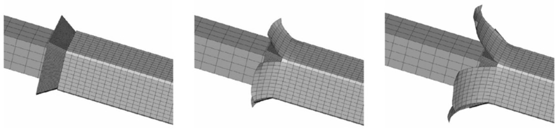


Figure 2. *Bursting process. A tapered mandrel is pushed down a box-beam rail, causing the rail to expand, primarily at the corners. Once the corner material stretches to its failure strain level, the tube "bursts" into four shards. Energy is absorbed through material deformation and fracture during this process at a rate determined by several factors, including rail thickness, size and material, and mandrel taper angle and length.*

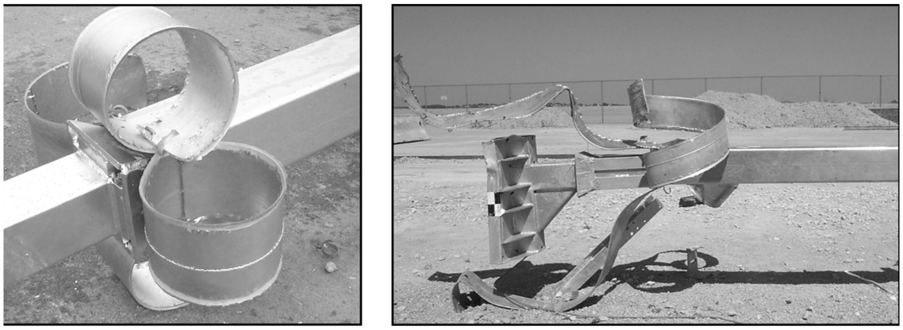


Figure 3. *Inertial effects on shard curls. Left, at speeds of 30 to 40 km/h, the shards come off the mandrel and form a relatively tight curl. Right, in full-scale crash tests at higher speeds (about 100 km/h), inertial effects cause a much looser curl on the shards.*

Disproportionately many hours of R&D have been devoted to endposts, which are subject to a wider variety of impacts than other posts. Sometimes the issue is resolved by employing wooden rather than steel posts in the end positions, or by bending the final section of the railing toward the ground and away from the highway, so that vehicles striking it are diverted back toward the highway, rather than striking the endpost head on. Recently, however, a remarkably simple design has begun to gain favor with highway commissions, especially in high-snowfall areas. Known as the *box-beam bursting energy absorbing terminal*, it works as indicated in Figures 2 and 3.

Although the female portion of the junction fractures on impact, finite element analysis of such terminals is rendered tractable by the symmetry of the situation and the predictability of the fracture locations. Theory and experiment agree particularly well in this application.

Guardrails redesigned by MwRSF have been installed in virtually every state in the union, as well as in Canada, Australia, and New Zealand. The facility counts the Midwest States Regional Pooled Crash Test Program among its leading customers. Full members of the program are Nebraska, Iowa, Illinois, Kansas, Minnesota, Missouri, Ohio, South Dakota, Wisconsin, and Texas, and Connecticut has become a partial supporter.

James Case writes from Baltimore, Maryland.