A2A04: Committee on Roadside Safety Features
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Improving Roadside Safety by Computer Simulation

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The overall level of safety provided along highways in this country has improved greatly over the last several decades. The clearest demonstration of this improvement in roadside safety is the continuing drop in fatality rates. For example, from 1966 to 1996, the fatality rates of single-vehicle, ran-off-road crashes dropped by more than two-thirds from 1.9 to 0.6 fatalities per 100 million vehicle-miles of travel. Some portion of this reduction can be attributed to improvements in vehicle design and increased usage of occupant restraints; however, improved roadside safety design and features also contributed to the reduction.

The clear zone concept is perhaps the most important contributor to roadside safety design. Based on this concept, roadside hazards are removed or relocated further from the traveled way whenever possible. Cutting down trees and placing utility lines underground are examples of roadside hazard removal, while extension of culverts and drainage structures is a good example of relocating hazards further away from the roadway. When hazards cannot be removed or relocated, breakaway devices or protective safety features, such as traffic barriers and crash cushions, have been utilized to minimize the danger to motorists.

PROBLEMS TO TACKLE IN THE FUTURE

Despite the great strides made in roadside safety over the last few decades, many major roadside safety issues have yet to be addressed in any serious manner.

Installation Details

Although safety features are subjected to a costly array of full-scale crash tests to ensure acceptable safety performance, significant differences often exist between the tested and field installations. Virtually all full-scale crash tests are conducted on flat ground while very few safety features are actually installed in this situation. Additionally, most ground-mounted devices are tested in a strong soil condition, whereas field applications may vary from weak soils to portland cement concrete. Crash test installations are typically constructed with tight tolerances that are unlikely to be achieved in actual field constructions. Restricted site conditions can also present special problems to highway designers.

Nontracking Impacts

Crash testing of roadside safety devices is typically limited to tracking impacts. Unfortunately, crash data indicate that approximately half of all ran-off-road accidents involve nontracking vehicles, i.e., sliding sideways into an object. Also, nontracking impacts are found to be more severe than tracking impacts for both barrier systems and breakaway devices. Roadside safety features successfully tested for tracking impacts may or may not perform satisfactorily in nontracking impacts.

Roadside Geometry

Crash data indicate that roadside geometry, including slopes, embankments, and ditches, contribute to more than half of all ran-off-road accidents involving serious injury or fatality. These roadside features are believed to be the leading cause of rollover in single-vehicle, ran-off-road accidents. The number and type of roadside configurations that can be evaluated through full-scale crash testing is severely limited by site constrictions at existing test facilities.

Future Vehicle Trends

The safety performance of most roadside safety features has been shown to be sensitive to vehicle characteristics, including total mass, height of the center of gravity, and bumper and hood geometry. Because major changes are made to the vehicle fleet in 5- to 7-year cycles, while most safety features are expected to have serviceable lives of 20 years or more, the field performance of many safety devices has been significantly affected.

SOLUTIONS

As described above, a number of difficult problems remain to be solved in the continuing effort to improve roadside safety. Roadside safety problems have traditionally been evaluated primarily through the application of full-scale crash testing. The high cost associated with full-scale testing is probably the greatest barrier to solving most of these problems. It is cost-prohibitive to require full-scale crash testing of all safety devices for all possible variations in installation details. Further, although procedures for side impact testing of breakaway devices have been developed and implemented, currently no procedures exist for conducting nontracking impacts that involve the vehicle rotating at impact. Finally, even though ongoing changes in the vehicle fleet can be projected into the future to estimate some of the characteristics of automobiles, it is impossible to build such a vehicle for crash testing of roadside safety features.

Computer simulation of vehicular impacts (Figure 1) using an advanced, nonlinear finite element code, such as DYNA3D, is the only practical alternative to full-scale crash testing for the large array of safety performance evaluations that are needed. Theoretically, this type of simulation could be used to investigate all of the safety issues summarized above. Further, after a computer simulation has been developed and successfully validated against full-scale crash testing, the cost associated with conducting parametric studies to investigate the effects of installation details, impact conditions, roadside geometry, and vehicle characteristics is relatively inexpensive. Computer simulations also provide a great deal of information that is frequently unavailable from full-scale crash testing. For example, finite element modeling provides designers with an accurate picture of the stress distributions in critical components of a safety device throughout the impact event. Unlike full-scale crash tests that normally only yield pass or fail recommendations on a particular design, computer simulations can be used to identify areas where a design needs additional reinforcement or areas where a component has excess capacity.

CURRENT STATE OF THE ART

For computer simulation to solve the wide-ranging problems summarized above, the procedures need to be widely used and accepted by the safety community and to have an established record of accurately predicting crash test results. Unfortunately, computer simulations of roadside safety features have yet to meet all of these requirements. The application of generalized, nonlinear, large deformation, finite element modeling to the roadside safety field is a relatively recent event, with the earliest applications dating only to 1992. Although many designers are now relying heavily on these codes for safety hardware development, most development efforts are still centered on static and dynamic testing programs. Even when computer simulation is used to lead development programs, the codes are most valuable for modeling component and subassembly testing rather than evaluation of safety performance through simulation of full-scale crashes. Relatively few applications in a computer simulation have successfully predicted the outcome of future full-scale crash tests. Although the Federal Highway Administration is beginning to utilize these codes to support overall policy decisions, there is still no place for computer simulation in the compliance testing of roadside safety features.

INTERMEDIATE GOALS

As discussed above, advanced, nonlinear, finite element codes are still not at a stage that allows computer simulations to be used to resolve the remaining roadside safety problems. The primary goals for the intermediate future should therefore be associated with advancing the state of the art for computer simulation. Finite element simulations of ran-off-road crashes involve detailed models of both the roadside safety features and a vehicle. The finite element code then utilizes these models to predict the vehicle kinematics associated with a ran-off-road crash, which in turn is used to assess the risk of injury to which an occupant of the vehicle would be exposed. Improvements must be made in each of these areas before computer simulation can play a major role in solving the difficult roadside safety problems outlined above. Further, some additional knowledge about the expected distribution of impact conditions and future vehicle characteristics should be garnered if computer simulation is to reach its full potential in this field.

Vehicle Models

Finite element models for computer simulation of ran-off-road impacts must include detailed descriptions of each structural component on the vehicle that would be expected to carry significant loads during an impact. As mentioned, ran-off-road crashes frequently involve nontracking impacts; therefore, an impact could occur at any point around the circumference of the vehicle, so a general vehicle model must include all structural components. Although several extremely detailed models are now available, the number of different types of vehicles that are represented is extremely limited. Further, none of the existing models have been validated against full-scale crash tests for the wide range of impact conditions that have to be studied. In addition, the detailed vehicle models now in use still have some significant limitations, especially in the suspension and tire representations. These areas of the vehicle models are especially critical for simulation of ran-off-road accidents because of the strong correlation between tire and suspension damage and vehicle rollover. Therefore, significant effort must be directed toward refining existing vehicle modeling techniques to provide better tools for analyzing ran-off-road impacts. It also is critical that these models be kept up to date with respect to current trends in the vehicle fleet.

Safety Hardware Models

Although a wide range of safety hardware models has been developed over the past several years, most of these models lack sufficient validation. Hardware model deficiencies can generally be lumped into two categories: materials limitations and difficulties in modeling connections. Materials such as wood and soil are particularly difficult to model because of the great inconsistencies from one installation to the next. Characterization of these materials must begin with the identification of the expected variability from specimen to specimen or from site to site. Other types of nonhomogeneous materials, such as portland cement, asphaltic concrete, and fiber-reinforced plastics, also present significant problems to material modelers. Many types of connections common in roadside safety applications produce relatively difficult modeling problems. For example, the connection between a guardrail and a wood block must be carefully modeled in order to produce the correct behavior when the bottom W-beam element digs into the wood block and the post bolt is pulled through the rail. Roadside safety hardware models must be carefully validated against detailed component testing to ensure that the overall impact modeling is reasonably accurate.

Risk Assessment

When sufficiently accurate vehicle and hardware models are generated, computer simulations will be able to correctly identify occupant compartment kinematics associated with a ran-off-road crash. The overall risk of occupant injury or fatality, however, remains to be determined. The problem associated with linking vehicle kinematics to occupant risk is not unique to computer simulations, and has plagued full-scale crash test programs for many years. The problem is further complicated by the widespread availability of front and side air bag systems, which may significantly affect the measures of occupant risk used by the roadside safety community. Better measures of occupant risk must be developed to address the more advanced occupant protection systems now available in the vehicle fleet.

The computer simulations involving detailed occupant and protection system models may offer one mechanism for developing the required links between vehicle kinematics and occupant risk. The only mechanism for developing such a link, however, is to conduct detailed investigations into real-world crashes. By reconstructing ran-off-road crashes to identify vehicle and occupant kinematics, it would be possible to develop better links between existing occupant risk measures, such as the head injury criteria or thoracic trauma index and the probability of injury.

CONCLUSION

Transportation officials have made great strides in improving roadside safety along the nation’s highways over the last several decades, with a reduction of nearly 70 percent in the ran-off-road fatality rate. To maintain this rate of improvement in reducing injuries and fatalities, the safety community must begin to address some of the more difficult roadside safety issues. These issues include sensitivity of safety features to installation details, problems associated with nontracking impacts, contributions of roadside geometry to serious accidents, and the ongoing effort to identify future vehicle trends and their effects on roadside safety. The high cost of full-scale crash testing precludes a dramatic expansion of existing programs to address these issues. Computer simulation appears to be the only practical means for addressing these problems in the near future.

To achieve the objective of investigating these difficult roadside safety issues, significant effort must be devoted toward improving the capability of computer simulation for modeling ran-off-road crashes. These efforts should focus on developing better vehicle and roadside safety hardware models and on developing better links between vehicle kinematics and occupant risk. If a comprehensive effort is directed toward achieving these overall goals, we can continue our quest to reduce the injuries and fatalities associated with ran-off-road crashes.

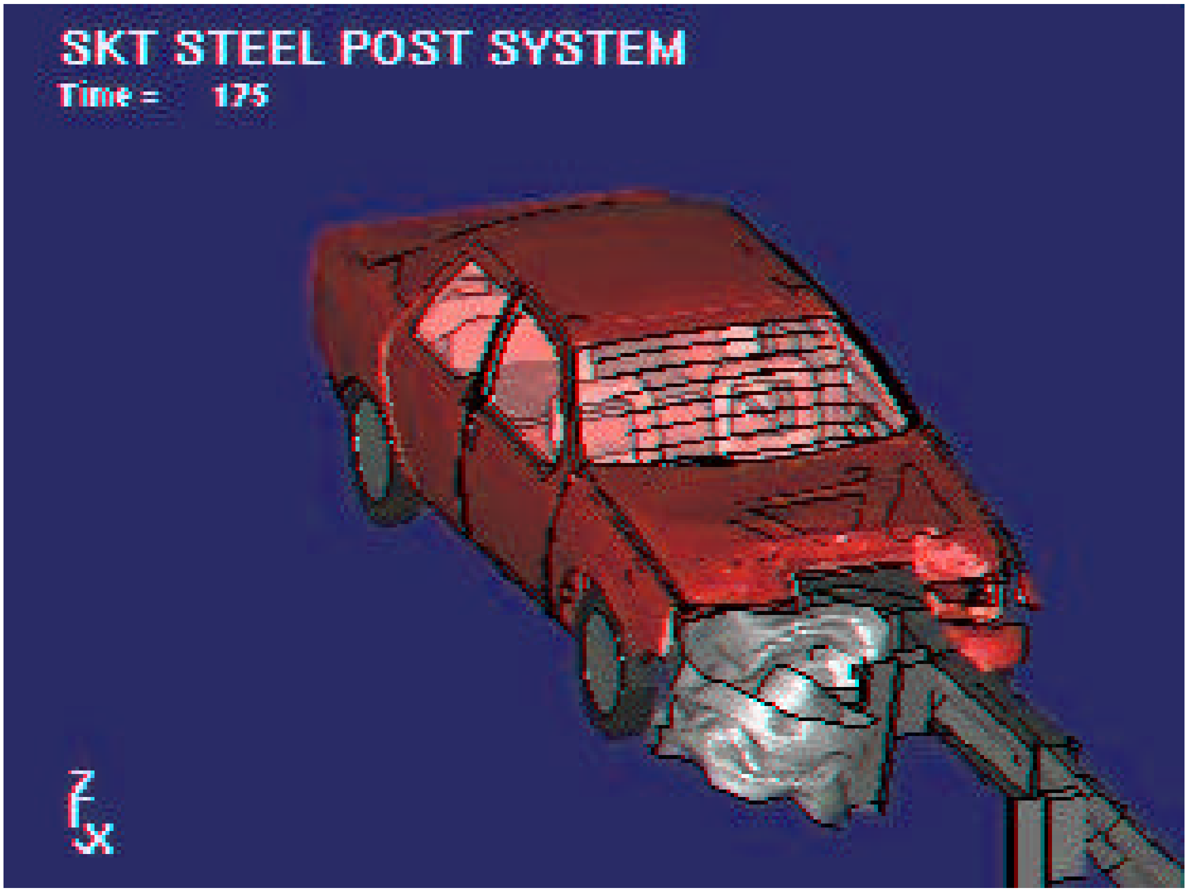

FIGURE 1 Computer simulation of a guardrail terminal impact.