



Finite Element Analysis of Roadside Safety Devices

Although significant advancements have been made over the past three decades, the roadside safety problem remains a major source of injury, death, and economic loss. One direct means of addressing this problem is through the continued development of improved roadside safety features.

In recent years, roadside safety research has focused on computer simulation technology to better understand behavior of roadside safety devices when hit by vehicles. Toward this goal, the Center for Transportation Computational Mechanics was established at the Texas Transportation Institute (TTI) under joint funding by the Federal Highway Administration (FHWA), the Texas Department of Transportation (TxDOT), TTI, and Texas A&M University. The purpose of the center is to contribute to the solution of the roadside safety problem through the use of computer simulation technology by building validated models of selected roadside hardware devices and establishing expertise that can be utilized by TxDOT, other highway agencies, and private industry to address safety problems.

What We Did...

Roadside safety features to be modeled and simulated as part of this project were selected in consultation with TxDOT personnel. Modeling systems in support of ongoing, TxDOT-sponsored roadside safety projects received priority.

After the selection of a safety feature, researchers reviewed available literature and test data to examine failure mechanisms and identify critical components of the system, thus providing a basis for initial modeling and validation.

Comparison of each key component or subsystem within selected roadside safety features to experimental data established the accuracy and validity of each component. Full-scale load tests of selected components and materials helped quantify material

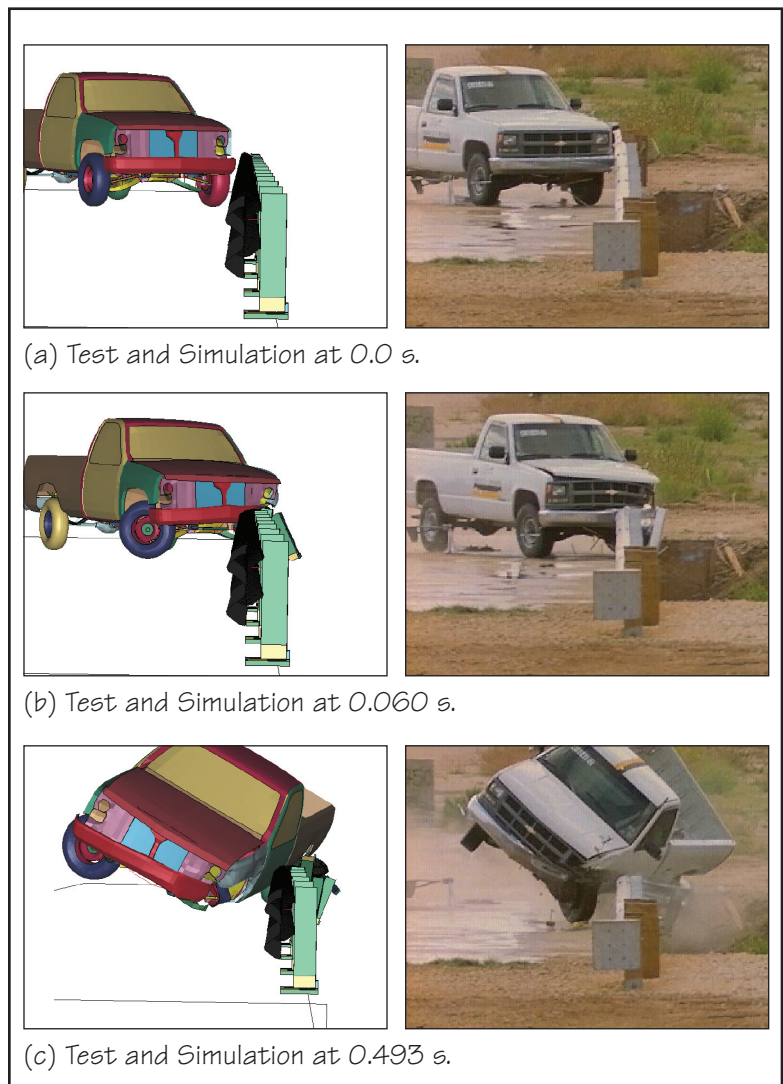


Figure 1. Comparison of Tubular W-Beam Test and Simulation.



properties and assisted in validation. The approach followed was to develop the system model from a set of validated component models.

Full-scale crash simulations on the system models used a detailed finite element model of a 4405-lb (2000 kg) pickup truck, denoted 2000P, one of the design test vehicles recommended by National Cooperative Highway Research Program (*NCHRP Report 350*). The results of the initial full-scale simulations were used to evaluate the impact performance of the roadside safety feature.

When design problems were identified through simulation or crash testing, various design modifications were examined to address the deficiencies and improve impact performance of the system. Researchers modified the finite element model and conducted additional simulations to assess any improvement. The results of the simulations were used to develop recommended improvements for full-scale crash testing and potential implementation.

Three distinct roadside safety issues were investigated with the aid of computer simulation:

- An alternative to the popular T6 tubular W-beam bridge rail addressed problems with vehicle instability observed in full-scale crash testing.
- A retrofit connection to TxDOT's grid-slot portable concrete barrier limited dynamic barrier deflections to levels more practical for work zone deployment.
- Crashworthy mow strip configurations provided vegetation control around guard fence systems to reduce the cost and risk associated with hand mowing.

What We Found...

T6 Bridge Rail

The Texas T6 bridge rail is a breakaway bridge rail system that is designed for use on culvert headwalls and thin bridge decks. In full-scale crash testing, the Texas T6 bridge rail system did not satisfy *NCHRP Report 350* criteria for high-speed (i.e., Test Level 3) applications. Although the bridge rail contained and redirected the vehicle, the vehicle rolled onto its impact side as it exited the installation.

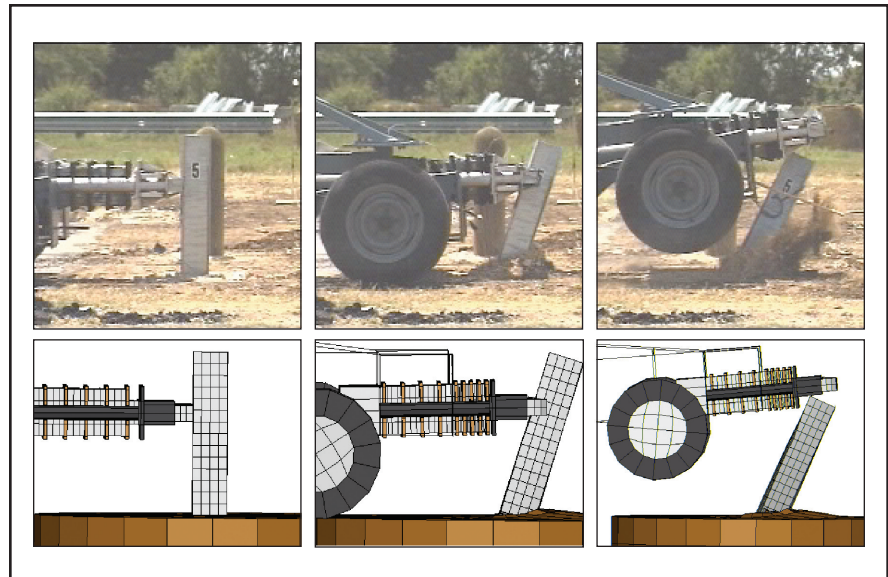


Figure 2. Sequential Comparison of Test and Simulation for Steel Post in Soil.

A finite element model of the rail was developed to capture the performance trends of the existing T6 bridge rail system (Figure 1) and evaluate potential design modifications. The goal was to achieve a system that will meet *NCHRP Report 350* criteria without significantly altering the basic design concept of the system (i.e., a relatively flexible, breakaway design capable of being installed on thin deck structures and culverts).

Proposed modifications to the T6 system include revision of the breakaway post attachment detail and incorporation of a tubular thrie-beam rail element instead of the original tubular W-beam. During computer simulation of this alternative, the vehicle experienced significantly less roll angle and was inherently more stable than in the comparable simulation with the standard tubular W-beam rail element. The results suggest that the tubular thrie-beam system has a high probability of passing *NCHRP Report 350* Test Level 3 impact performance requirements.

Grid-Slot Portable Concrete Barrier

The crash performance of the TxDOT Type 2 precast concrete traffic barrier (PCTB[1]-90) with joint type A was unproven with respect to the *NCHRP Report 350* guidelines. A full-scale crash test was therefore conducted to evaluate the impact behavior of the barrier. Although the test vehicle was contained and redirected, large barrier deflections occurred when one of the barrier joints separated. TTI researchers and

TxDOT engineers worked together to evaluate the crash performance of this barrier system and determine whether cost-effective modifications can be made to the barrier to meet *NCHRP Report 350* criteria and limit dynamic deflections to practical levels.

During the project, TxDOT engineers and TTI researchers jointly developed several retrofit connection designs with the intent of reducing dynamic barrier deflections. When developing these retrofit design options, factors such as impact performance, cost, ease of field installation, and aesthetics were considered. The research team performed computer simulations to help assess the ability of the selected retrofit connections to meet *NCHRP Report 350* impact performance criteria prior to conducting the full-scale crash testing. Limitations in the ability of existing material models to accurately capture concrete fracture and failure led to some simplifying assumptions regarding the model of the grid-slot connection. Nonetheless, the simulations assisted in the impact performance evaluation of the existing and modified designs.

A steel strap bolted to the toe of the barrier across the joint between adjacent barrier segments is considered to be the best retrofit alternative for limiting barrier deflections from among the connections investigated. A subsequent crash test demonstrated that this connection limited the barrier deflection to only 4 feet under design impact conditions compared to other



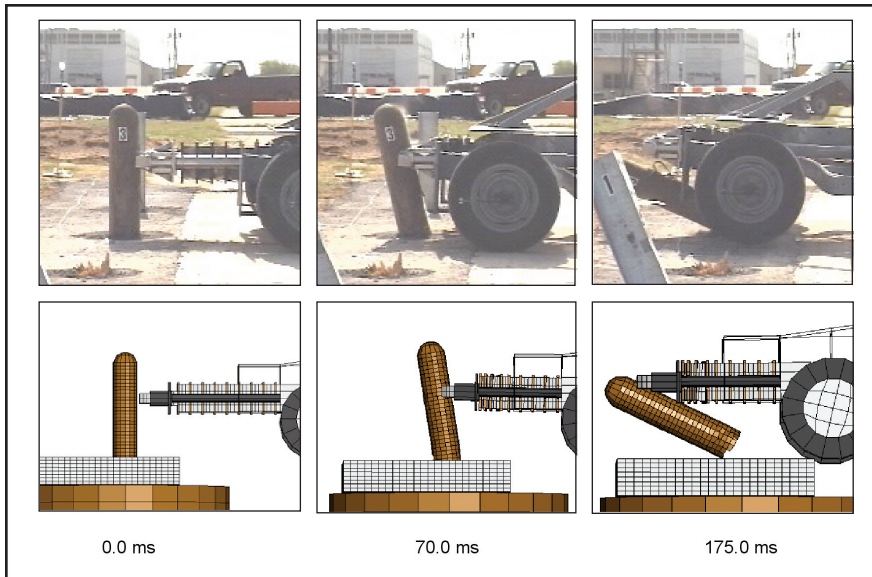


Figure 3. Sequential Comparison of Simulation and Test Results for Wood Post in Asphalt.

options that had deflections ranging from 9 feet to 12.4 feet.

Guard Fence Encased in Mow Strip

Design variables that were considered in the investigation of guard fence encased in mow strip include mow strip material type, mow strip thickness, size and shape of leave outs, type of backfill material used in the leave outs, and type of guard fence post. Given the large number of design variables and treatment options that exist for this practice, full-scale crash testing of the entire matrix would be cost-prohibitive. Rather, subcomponent testing and full-scale simulations were performed to develop a better understanding of the response of mow strip systems subjected to dynamic impact loads.

The first step developed finite element models of the key components and validated them against component test data (Figures 2 and 3). Component modeling allows the researchers to gain confidence in the accuracy of smaller-scale models before assembling the full system model and using it in predictive simulations.

The results of full-scale vehicle impact simulations of a guard fence system directly encased in a pavement mow strip without leave-out sections around the posts indicated a low probability that such a system will meet *NCHRP Report 350* performance criteria. Researchers recommended that such practice be discontinued.

Additional predictive simulations

of different mow strip configurations indicated that impact performance should be acceptable under some conditions. Compliance with *NCHRP Report 350* guidelines was subsequently confirmed in two full-scale crash tests conducted as part of research Project 0-4162. There was no damage to the mow strip that would require repair other than replacing the sacrificial grout backfill around the guardrail posts in the region of impact.

The Researchers Recommend...

T6 Bridge Rail

The researchers recommend a full-scale crash test on a tubular thrie-beam system to verify the predicted impact performance. The tubular thrie-beam system could be improved prior to testing by redesigning the post baseplate connection to further increase its strength. The strength values should be chosen to reduce the number of posts broken to a total of six or seven posts. This would limit travel of the vehicle over the edge of the deck, which might further reduce the vehicle roll angle. Maintenance and repair costs could also be reduced.

If a crash test is successful, the tubular thrie-beam system would provide a replacement for the popular T6 bridge rail for use on high-speed roadways. As with the T6 rail, the tubular thrie-beam is designed to limit structural damage when installed on thin bridge decks and culverts.

Grid-Slot Portable Concrete Barrier

The addition of 4-inch wide \times 3/16-inch thick steel straps bolted to the face of the barrier segments across the joints substantially reduced the maximum dynamic deflection of the barrier. The maximum lateral barrier movement experienced in the test was 4 feet under design impact conditions. Use of the steel strap connection will, therefore, permit the grid-slot barrier to be used in more restricted work zone areas.

Subsequent to the crash test of this system, additional simulations were conducted to optimize the size of the steel strap. It was observed in the crash test of this connection detail that one of the steel straps failed in tension on the field side of the barrier. If the strength of the connection can be further increased to avoid failure of the strap without inducing failure of the anchor bolts, the barrier deflection can be further decreased. It was determined that if the size of the steel strap is increased to 6 inches wide \times 1/4 inch thick, tensile failure of the strap can be avoided and barrier deflections will be reduced to approximately 3.25 feet.

Besides the change in plate dimensions, all other details of the connection, including anchor bolt size and location, remain the same as those used in the test installation. Since this reduction in deflection can be achieved with only a small increase in material cost, it is recommended that the 6-inch wide \times 1/4-inch thick steel straps be implemented when site conditions cannot accommodate the larger deflections associated with the drop-in plate or grid connectors.

Guard Fence Encased in Mow Strip

The successfully tested mow strip systems have been implemented through a new standard detail sheet developed by TxDOT's Design Division. In addition to providing greatly enhanced impact performance, mow strip configurations featuring grout-filled leave-outs around the guard fence posts appear more practical based on ease of repair after an impact.

Any increase in post confinement beyond that provided by the grout backfill material used in the leave-out sections formed around the guardrail posts should be further evaluated. Additional guidance on acceptable mow strip variations is contained in Report 0-4162-2.



For More Details . . .

The research is documented in the following reports:

Report 0-1816-1: *Evaluation of Roadside Safety Devices Using Finite Element Analysis*

Report 0-4162-2: *Dynamic Response of Guardrail Systems Encased in Pavement Mow Strips*

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TxDOT Implementation Status—December 2004

This project involved primary research in the development of the DYNA-3D model for vehicle barrier interaction. While there was not direct implementation of the DYNA-3D model for TxDOT, the model was used to develop roadside hardware such as T6 bridge rail, guardrail to bridge rail transitions, and concrete barrier connections for full-scale crash testing and ultimate development into standard detail sheets that TxDOT now uses in construction plans.

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