Finite Element Simulation of a Strong-Post W-Beam Guardrail System

Ali O. Atahan
Department of Civil Engineering
Mustafa Kemal University
Tayfur Sokmen Campus
Serinyol, Hatay, 31040 Turkey
aoatahan@mku.edu.tr

Computer simulation of vehicle collisions has improved significantly over the past decade. With advances in computer technology, nonlinear finite element codes, and material models, full-scale simulation of such complex dynamic interactions is becoming ever more possible. In this study, an explicit three-dimensional nonlinear finite element code, LS-DYNA, is used to demonstrate the capabilities of computer simulations to supplement full-scale crash testing. After a failed crash test on a strong-post guardrail system, LS-DYNA is used to simulate the system, determine the potential problems with the design, and develop an improved system that has the potential to satisfy current crash test requirements. After accurately simulating the response behavior of the full-scale crash test, a second simulation study is performed on the system with improved details. Simulation results indicate that the system performs much better compared to the original design.

Keywords: Computer simulation, LS-DYNA, strong-post guardrail system, cost-effective methods, roadside safety, vehicle collisions

1. Introduction

It is of public interest to develop safer roadways and more crashworthy roadside safety features that minimize the risk of serious injuries and fatalities of vehicle occupants. For the past 60 years, full-scale crash testing has been the most widely accepted means of certifying the impact performance and dynamic characteristics of various roadside safety features. In this method, the design of roadside hardware, such as guardrails, concrete barriers, and crash cushions, is constructed experimentally through an iterative process of design, build, test, redesign, and retest. The cost associated with this method is high, and researchers do not necessarily have complete control over the impact scenarios, test articles, and test conditions. The vehicle fleet has also evolved. Automobiles in use today cover a wider range of sizes and shapes than ever before, and there is a need to use different materials for certain parts of roadside safety hardware. As a result, many of the factors used in the design of roadside safety structures should now be reconsidered. However, it is economically impossible to perform full-scale crash testing on a wide range of parameters.

To evaluate and enhance the crash performance of roadside safety hardware more efficiently, engineers are beginning to rely heavily on sophisticated numerical crash simulations [1]. The primary focus of finite element crash simulations in the roadside safety area has been evaluating the crashworthiness of roadside safety devices. A nonlinear finite element code, LS-DYNA, developed by the Livermore Software Technology Corporation, has become the choice of roadside safety engineers to simulate dynamic three-dimensional motor vehicle impacts of roadside safety structures [2]. When using LS-DYNA, the objective is to make manmade roadside structures and features more crashworthy. It is also intended to ensure that these features are capable of transferring the high-speed collision energy from the colliding vehicle to the feature in a controlled manner so that the vehicle slows or stops, the vehicle remains upright, and the occupants experience minor or no injuries.

In this paper, results of two succeeding simulation studies are presented to demonstrate the capability of LS-DYNA to supplement full-scale crash testing. A strong-post W-beam guardrail system was selected for the study. The system was subjected to full-scale crash testing under the National Cooperative Highway Research Program (NCHRP) Report 350 test 3-11 conditions [3] and failed to meet the requirements. After this crash test, LS-DYNA was used to simulate the impact behavior of the system, pinpoint the potential problem areas, and develop and analyze possible alternatives for improvement. Based on the results

SIMULATION, Vol. 78, Issue 10, October 2002 587-599

of the computer simulations, the crash test performance of the guardrail system improved significantly.

2. Advantages of Computer-Simulated Crash Tests

Recent computer simulation studies of roadside safety devices involve nonlinear finite element programs such as LS-DYNA to model crashes of vehicles with roadside safety features. Since the analysis of roadside safety features involves dynamic loading, inelastic deformations, and nonlinear material behavior with possible failure, the standard linear-elastic analytical methods become incapable of capturing the response behavior accurately.

The high cost of full-scale crash tests greatly limits the number of tests that can be conducted to investigate the safety performance of any roadside safety feature. With computer simulations, however, a variety of impact scenarios that typically cannot be studied by traditional crash-testing methods can be investigated. Using the LS-DYNA, with its material definitions and models, users have the flexibility to simulate a crash from different angles and speeds without the cost of repairing or replacing the structure or vehicle for each test. These impacts can also be graphically viewed from different angles so that users can fully study how the structure or vehicle reacts to complex dynamic forces. Elements, such as the wheel assembly or hood of a car, can be removed to see how internal elements are affected during the impact, which is fairly difficult to study in an actual crash test.

Although it is not feasible to test all of the variations in actual tests, simulations allow more design variations to be analyzed at a fraction of the cost of extensive physical testing. Different impact scenarios, test articles, and test conditions can be easily studied to fully explore the performance of roadside safety features. For example, in Europe, the height of the W-beam in a weak-post guardrail system is slightly lower than that in U.S. practice [4]. The difference in performance can be determined with the use of simulation studies. Furthermore, crash-testing procedures are limited with 25 degrees, while in Europe, most truck accidents occur at an angle greater than 25 degrees [5]. Since no crash tests are performed with such angles, computer simulations become the only option to evaluate the performance of roadside safety features in those cases. Moreover, the effect of real-world conditions such as roadside terrain, which has not been a part of conventional crash-testing procedure, can also be investigated via computer simulations. It is possible to add to these cases when applications of computer simulations greatly improve understanding of the crash performance of roadside safety features.

With the use of simulation results, researchers can assess deficiencies and make adjustments to existing roadside safety features. Simulations also allow optimization of roadside safety hardware and development of improved roadside safety structures. Note that although the increasingly sophisticated finite element codes and advanced computer hardware cannot replace full-scale crash tests altogether, which will always be necessary for validation purposes, computer simulation technology has the potential to reduce the number of crash tests conducted and thus reduce the overall project cost significantly. Also, with the utilization of computer simulation technology, a larger part of the design space can be searched quicker.

3. Description of Roadside Safety Application Studied

3.1 G4(1S) Strong-Post Guardrail System

The G4(1S) strong-post W-beam guardrail system is used extensively in the United States and Europe. In past years, several studies have been undertaken to evaluate the performance of this system. The G4(1S) system evaluated in this study is composed of a W-beam rail supported on W150 × 13 steel posts spaced at 1905 mm. A picture of the system is shown in Figure 1 [6]. The typical post length is 1829 mm, with 1118 mm of the post below grade. Posts are connected with a standard 12-gauge W-beam, which has a nominal thickness of 2 mm. The system uses 356-mm long, W150 × 18 offset blocks between the post and the W-beam to prevent potential wheel snagging on the posts. A 32-mm diameter through bolt is used to connect the flange of the W150 × 18 offset block to the center of W-beam rail.

4. Previous Crash Test

The Texas Transportation Institute has performed a number of full-scale crash tests on the G4(1S) system to evaluate its crashworthiness according to the NCHRP Report 350 test 3-11 procedures. In one of the earlier tests (TTI Test No. 405421-2), a 2000-kg pickup truck traveling at 99.7 km/h and contacting installation at 25.7 degrees failed to meet the NCHRP Report 350 criteria [6]. The vehicle impacted

Figure 1. A picture of the G4(1S) system before crash test 405421-2.