APPLICATIONS OF HIGH PERFORMANCE COMPUTATION MECHANICS IN IMPROVING ROADSAFETY STRUCTURES

Jerry W. Wekezer, Rafal Wuttrich
wekezer@eng.fsu.edu, wuttrich@eng.fsu.edu
Phone: (850) 487 6143, fax: (850) 487 6142
Civil Engineering Department
FAMU-FSU College of Engineering
Tallahassee, FL 32310-6046

INTRODUCTION

FAMU-FSU College of Engineering was established in 1982 with 35 students by two universities: the Florida Agricultural and Mechanical University and the Florida State University. The heritage and strength the two universities share in educating minorities and women has provided the College a unique perspective and mission. Today among more than 2000 students over half are minority students; more than 25 % are women.

The Civil Engineering Department has a current enrollment of 360 undergraduate and 41 graduate students. Two undergraduate options: Civil and Environmental are offered at the undergraduate level. A new Ph.D. program in Civil Engineering was introduced in the fall semester of 1997/98. Currently the Department consists of 15 faculty members in all major Civil Engineering areas.

Faculty and students are involved in a strong and dynamic research program. The Department utilizes most of its graduate students as research assistants. Participation in the research provides the students a unique opportunity to learn leading edge technologies in all areas of faculty interest.

Faculty success in acquiring sponsored research is illustrated in Table 1, which shows the dollar amount of current and pending research projects. Major sponsoring agencies include: the Florida Department of Transportation (FDOT), the Federal Highway Administration (FHWA), the National Science Foundation (NSF), and the Florida Department of Environmental Protection (FDEP).

The departmental research activities are focused around five major concentration areas: Structural Mechanics and Design, Transportation Engineering, Geotechnical Engineering, Hydraulics and Water Resources, and Environmental Engineering. One of the newest laboratories established at the Department is the Computer Impact Simulation Laboratory (CISL) which was funded by the NSF in 1996. The major research thrust in the Lab has been computational mechanics of vehicle impacts. The Lab was instrumental in conducting research in the area of roadside safety structures. Research efforts in the Lab were sponsored by the FHWA and the FDOT. This paper shows the recent results of this research.

Table 1. Funded and pending research at the Civil Engineering Department, FAMU-FSU College of Engineering.

Research revenue	***Total***	***Per year***
Contracted	$4,403,000	$2,076,000
Contracted per faculty	$339,000	$160,000
Pending	$656,000	$541,000
Pending per faculty	$55,000	$45,000

SHIFT TO COMPUTATION MECHANICS

Nonlinear, 3-D finite element dynamics codes and high performance computing are major tools used in the CISL. Two computer codes: DYNA3D and LS-DYNA3D are utilized for the computer analysis.

DYNA3D, an explicit non-linear finite element method (FEM) program, was introduced by Lawrence Livermore National Laboratory (LLNL) in 1976 and was developed during the following years (Hallquist et al., 1994). The program, classified for over a decade, was used for modeling of behavior of military constructions during explosions or impacts. Other original applications included earth and hardened shelter penetrations (fig. 1). With the changes in geopolitics, the code became public domain in the late 1980's. DYNA3D eventually branched out into its commercial version, the LS-DYNA3D code, which was introduced by the Livermore Software Technology Corporation.

Fig. 1 Explosions can be easily simulated by DYNA3D

In the early 1990's, the Federal Highway Administration (FHWA) began exploring new technologies to be used for improvement of existing roadside safety facilities, such as guardrails, bridge rails, crash cushions etc. In the past, the roadside safety hardware was primarily designed using intuition and contemporary engineering experience with relatively limited participation of analytical methods during the design process. A primary tool used for verification of hardware prototypes has been a sequence of expensive full-scale tests, which represented expected worst case scenarios. Dramatic changes in the car market, especially increasing number of sold small and medium size cars, have indicated needs to retrofit many of existing facilities, which were designed and judged in the past as safe for full size sedans (Ray, Viner, 1987). Traditional retrofit of existing hardware would require a new, expensive series of crash test for each project. Analytical methods can substantially decrease the cost of proposed structural retrofits. In addition, full-scale crash tests cannot provide sufficient information about loads, accelerations, stresses and strains of barrier components to develop design based on the mechanical behavior of barrier components. Repetitive tests are expensive and are not well suited to parametric analysis. It is also known that two apparently identical full-scale crash tests do not necessarily yield two identical sets of data. It is impractical to test full range of vehicles that should be examined (Hendricks, Wekezer, 1996). It is not possible to examine the effects of a variety of test conditions like non-tracking pre-impact trajectories, side impacts, and driver braking and steering during impact. For these reasons, advanced analytical tools are needed (Ray, 1996).

RESEARCH INTERESTS OF FHWA

Suitability of DYNA3D in modeling of an impact encouraged the FHWA to initiate cooperative research programs with several universities to develop computational models of cars and roadside safety facilities for mechanical analysis of an impact as an alternative for full-scale crash tests. Recognizing that newly designed hardware systems tend to use many standard components, the Federal Highway Administration have been supporting the development of finite element models of several existing NCHRP Report 350 hardware system models (TRB, 1993). It included, among others: G2 Weak-Post W-Beam guardrail, the Modified Thrie-Beam Guardrail, the Modified Eccentric Loader Terminal (MELT), the Dual-Leg Triangular Slip-Base Sign Support, and the Frangible Transformer Base Luminaire Support System. The FHWA supported research efforts conducted at: FAMU-FSU College of Engineering, the University of Mississippi, the University of Iowa, University of Colorado, the Texas A&M University, and the University of Cincinnati. At present, several public domain vehicle FEM models are available for use in impact simulations. Among these are a 1991 Ford Festiva and a 1994 Chevy pickup truck. These vehicles are designated as the 82OC and 2000P, respectively in the NCHRP Report 350. Under development are finite element models for the 1996 Ford model F800 (8000 kg) truck and the 1996 Dodge Neon. Older finite element models include the 1991 Saturn (Wekezer et al., 1994), the 1983 Honda Civic, and the 1991 Ford Taurus.

Livermore Software Technology Corporation has been developing its LS-DYNA3D code to include features necessary in crash modeling, e.g. orthogonal friction to differentiate between wheel rolling and skidding, new types of contact between elements of an impact, seatbelt capabilities, models of airbags etc.

Figure 2 illustrates some graphical results of numerical modeling of a 2000P vehicle to G2 weak-post W-beam guardrail - the FEM analysis of NCHRP Report 350 Test Level 3: a 25 degrees impact with the velocity 100 km/h. The finite element model of a 1994 Chevrolet C-2500 pick-up truck, created at the FHWA/NHTSA National Crash Analysis Center, was developed specifically to address vehicle safety issues for roadside hardware design. It consists of 10,723 nodes, 8,721 shell elements, 34 beam elements, 337 hexahedron elements and 37 material models. Seven 3.81 meter spans of W-beam guardrail and six posts were modeled using the Belytschko-Tsay shell formulation with three integration points across the thickness. Posts were modeled using shell elements fixed at a point located 120 mm below the ground surface. This formulation allows for failure of the connection and separation of the guardrail from the post.

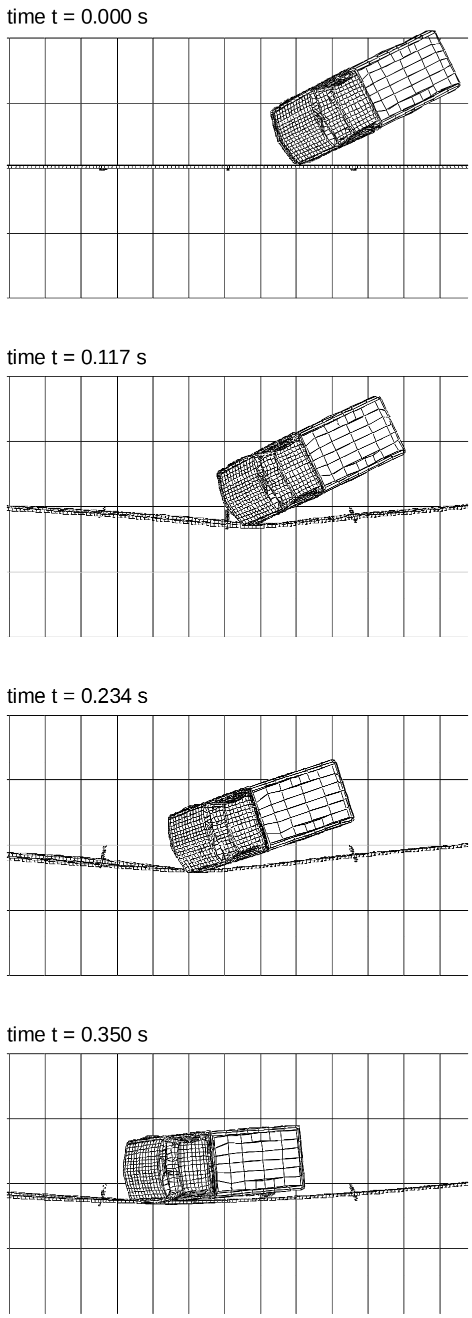

Fig. 2 Animation sequence of the 2000P and the G2 guardrail

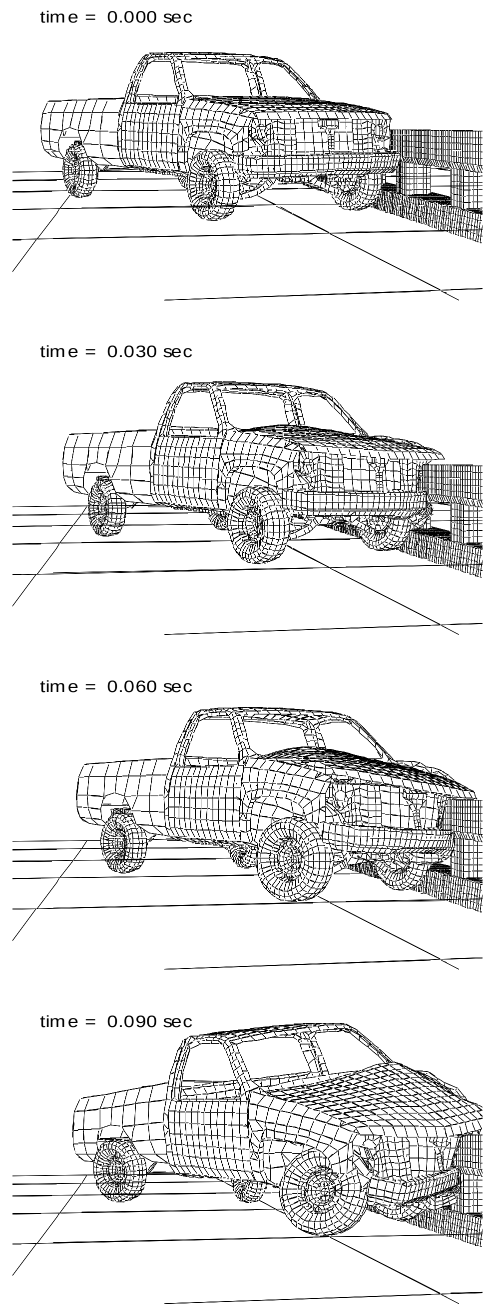

Fig. 3 Animation sequence of the 2000P and the Post and Beam bridge rail

RESEARCH INTERESTS OF THE FLORIDA DEPARTMENT OF TRANSPORTATION

The Florida Department of Transportation (FDOT) has recognized computational mechanics as a powerful tool for improving roadside and bridge barriers. The following two projects have been conducted thus far for the FDOT: “Conceptual Analysis of an Aesthetic Bridge Barrier” and “Structural Modifications of Existing BCT Terminals”. The primary subject of the first study was the FDOT Beam and Post bridge rail, a reinforced concrete structure originally developed in the early 1970s. Large number of installations throughout the State of Florida represents a sizable investment of the State. The barrier was constructed of a beam or rail running parallel to the ground connected by posts at 6 feet intervals.

Light trucks represented a large part in the current passenger vehicle market. Their sales have continued to climb over the past 20 years up to 40% in 1994 (Ross, 1996). As the most of “rail and post” barriers, the Florida Beam and Post barrier has shown poor performance during side impacts of light trucks (Mak, Menges, 1989). A typical problem with barriers is the “snagging” effect commonly observed between the post and the corner of the vehicle. Due to the large decelerations, the barrier often appeared to be fatal for drivers and passengers of these cars. Figure 3 shows the animation sequence of the computer simulated crash between the truck and the barrier. A preliminary evaluation of crash tests suggests the problem may be caused by: (1) the inertial and stability properties of the truck, (2) particular aspects of the suspension design that promote failure in barrier collisions, and (3) the short overhang distance between the front bumper and front wheel. While improvement in the performance of roadside hardware devices can probably be achieved for other specific impact conditions, this class of vehicles appears to have serious problems in barrier impacts. These problems might only be solved by improving the design of the barrier, or the vehicle, or at least through a better understanding of the interaction between vehicle and barrier. Computer crash modeling utilizing finite element methods was leading an effort to retrofit these barriers. Crash performances of the original barrier and of its four analyzed modifications (Fig. 4) were examined through computer impact analysis (Wekezer et al., 1997).

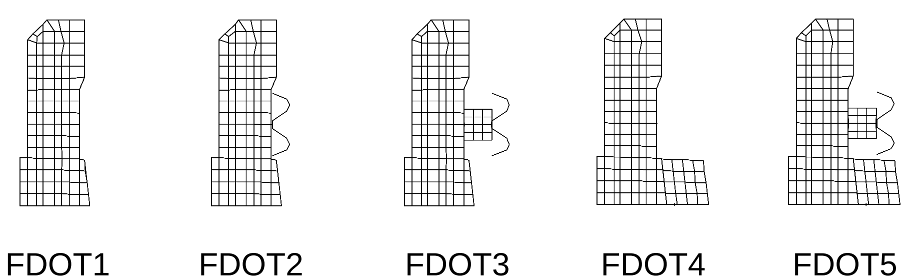

Fig. 4 Analyzed FEM models of the Florida Beam-and-Post Barrier

The FEM model of one, nine meters long section of the analyzed barrier (post space 1.83 m) was constructed with approximately 12,000 solid elements. The steel W-beam guardrail used in the three modified barriers was modeled as an elastic-plastic shell. The strain rate effect was included for both: steel and concrete. A simplified model of a bolt connection accounted for combined tension/shear failure.

Results of computer impact simulations for the original barrier (model FDOT1) confirmed earlier concerns regarding snagging with estimated occupants peak accelerations reaching –45g (Fig. 5). Application of the W-beam bolted to the posts (model FDOT2) resulted with substantial reduction of peak accelerations to –22g. Surprisingly, results for model FDOT3, where timber blockouts were used

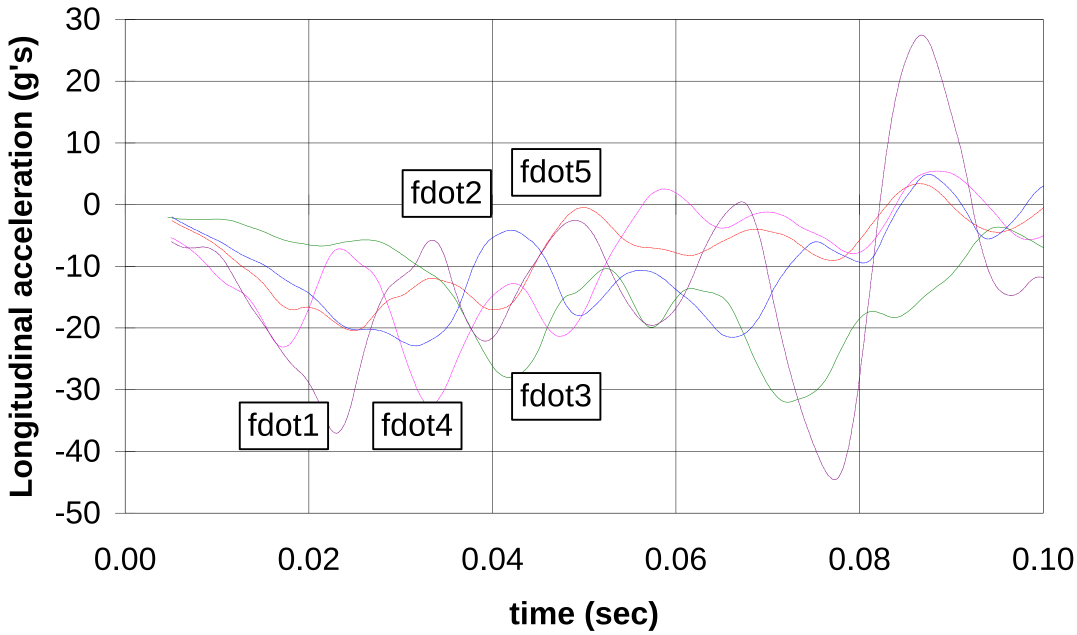

Fig. 5 Occupant's accelerations estimated in computer simulation for five retrofit models of the Florida Beam-and-Post bridge barrier.

between the W-beam and the concrete post, did not confirm expected further reduction of acceleration peaks. An initial 30 ms period of the collision, characterized by small accelerations (below 10g), was subsequently followed by increased decelerations with a peak value of 31g at 70 ms. It appears, that a relatively weak connection between the timber blockout and the concrete post used in the FEM model possibly contributed to this response. In the FDOT4 model, the original barrier was retrofitted with an external curb in an effort to avoid snagging between the wheel and the post. Unfortunately, the curb did not prevent the bumper from snagging with the post, exhibited by the highest deceleration of -32 g at 37 ms. The most desirable deceleration profile was obtained for the last model examined, the FDOT5. This variant, a simple combination of two preceding models: FDOT3 and FDOT4, provided the smallest peak deceleration of 20 g at 22 ms.

"Structural Retrofit of Existing BCT Terminals" is another project currently supported by the FDOT. The Breakaway Cable Terminal (BCT) was introduced in 1960's as an end treatment for a steel W-beam guardrail. Due to its low costs and relatively good performance in accidents with a full size sedan, it became very popular. In 1982 there were estimated more than 100,000 BCT installations nationwide. Unfortunately, the BCT designed and verified as safe for cars dominating in 1960's and 1970's appeared to be fatally stiff when impacted by small cars, which participation in the market dramatically increased during 1980's and 1990's. Preliminary results of the study seem to indicate a need to weaken the BCT structure in longitudinal direction. This task will not be easy since lateral stiffness of the BCT can not be compromised during the retrofit process. It appears again, that computational mechanics is the most effective tool, which can substantially aid in the design process used to improve the impact performance of BCT terminals.

MILITARY APPLICATIONS

The DYNA3D high performance computer code was initially developed to solve specific military applications. Although the range of problems being solved by the code was substantially expanded to include transportation applications and roadside safety structures, there is still a need to continue military research using high performance computing needs. Some of these topics identified by the Army include:

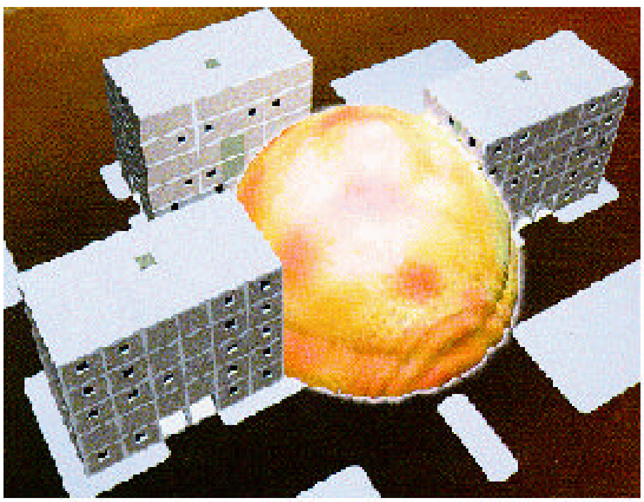

Fig. 5. Explosion among military barracks

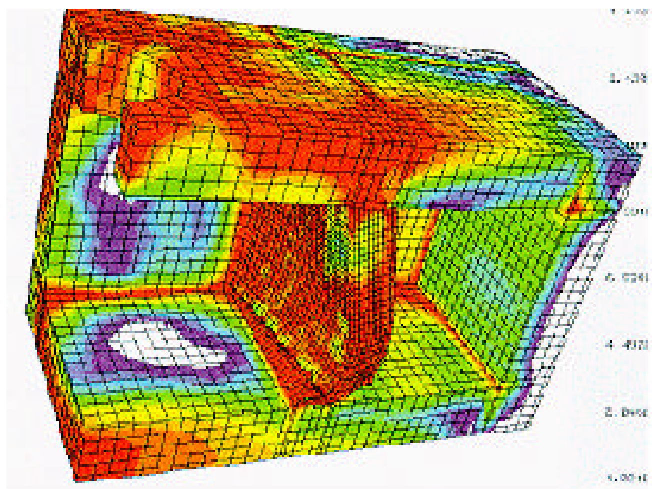

Fig. 6. Effect of explosion on a partition wall

- Response of above-ground and shallow-buried structures to loads either from nuclear or conventional weapons,
- Development of innovative design of structural components, such as windows and doors, subject to high-explosive loads,
- Development of analytical methods for predicting the effects of forced entry devices on structural components,

- Development of innovative designs using lightweight materials for expedient protection of troops, weapons systems, and equipment from the effects of blast and fragmentation,

and many others. These issues should be efficiently addressed through a shift from expensive, experimental research to more efficient use of high performance computing methods.

The development of DYNA3D and its subsequent release to the public provides a new tool for investigating a complex mechanics inherent in designing roadside safety hardware and in evaluating their effectiveness. Certain types of impacts require a better understanding of the nonlinear dynamics of impacts. To address this issue, nonlinear finite element codes are being incorporated into the development and evaluation of roadside safety hardware. There is a need to develop finite element codes and finite element analysis techniques to the point where they can be used with confidence. The full potential of DYNA3D for simulating impacts with roadside safety features is not expected to be reached for a number of years, but even today simulations can contribute to improved designs.

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