Development and Simulation of an Energy Absorbing Guardrail Terminal

by

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GRADUATE COLLEGE
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DEVELOPMENT AND SIMULATION OF AN
ENERGY ABSORBING GUARDRAIL TERMINAL

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Advisors: Dean L. Sicking and John D. Reid

Through this research an energy absorbing guardrail terminal was developed which is capable of bringing errant vehicles to a safe and controlled stop. This terminal incorporates a mechanism which cuts standard W-beam guardrail into strips, thereby producing a force which absorbs the kinetic energy of an impacting vehicle. A nonlinear finite element code, LS-DYNA3D, was used to simulate the cutting phenomenon. The model consisted of fully integrated solid elements in conjunction with an elastic-plastic material model with strain based failure. A very fine mesh with multiple elements through the thickness of the material being cut was used to capture the highly localized cutting phenomenon. The results of this computer simulation effort have implications in not only the safety community, but in industrial applications where an accurate model can be used to develop more effective and economical shearing procedures.

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Introduction

Guardrail systems are installed along roadways to protect the traveling public from hazards such as trees, bridge piers, and steep embankments. Careful consideration is given to each location to ensure that an impact with the guardrail system will be less severe than an impact with the hazard which it is placed there to shield. Impacts which occur along the length of the guardrail usually result in the vehicle being redirected to the roadway, but problems arise when impacts occur at the end of an installation. If the end of the system is left untreated, the guardrail can spear through an impacting vehicle, resulting in a very deadly accident. A number of guardrail terminals have been developed to decrease the severity of end-on impacts, but none of them have met with much success.

One of the earliest guardrail terminals was made by twisting the end section of W-beam 90 degrees and anchoring it to the ground. This 'Turned-down' terminal eliminated the spearing problem associated with the stand-up end, but led to rollover problems with small vehicles (1,2). A flared guardrail terminal known as the 'Breakaway Cable Terminal' (BCT) was developed in the early 1970's (3). This terminal was designed to buckle out of the way and allow impacting vehicles to pass through. However, major problems have been encountered with small car impacts on this system, as a large amount of yaw is induced in the vehicle, causing it to spin back into the system and impact the buckled portion of the guardrail with the side of the vehicle. Several other disadvantages are inherent to the BCT system, as it is very

sensitive to the flare rate at which it is installed, and much dirt work is required to obtain a level surface on which to place the flare.

The accident statistics on these older terminal types reflect the problems discussed above. These statistics show that 17% of accidents on turned-down terminals result in serious injury or death. The BCT system shows little improvement, with 14% of accidents resulting in serious injury or death.

Based on this information it is evident that there is a need for a new, more effective guardrail terminal which is not subject to these disadvantages. An energy absorbing guardrail terminal has many advantages over conventional systems. This type of terminal could be placed tangent to the roadway, thereby eliminating the need for extra fill and dirt work. An energy absorbing terminal will bring the impacting vehicle to a safe and controlled stop, rather than allowing it to pass through and possibly impact the obstacle which the system was placed there to protect. This system would be required to meet nationally accepted safety standards, and be relatively cheap and easy to install. This study was undertaken to develop such a system.

This dissertation involves the analysis of the original concept, the static and dynamic component testing, and the full-scale developmental crash-testing which was performed throughout the development of this new guardrail terminal. Computer simulation of the cutting mechanism was also performed with LS-DYNA3D (4), a 3-dimensional non-linear finite element package developed at Livermore Software Technology Corporation (LSTC). This simulation was conducted in order to gain a

better understanding of the cutting action, as well as to provide a useful tool for future research involving the shearing of materials.

Chapter One: Literature Review

The Evolution of the Guardrail Terminal

As the vehicle population grew throughout the 1930's and 40's, it began to become apparent to highway engineers that it was necessary to develop a means of protecting the traveling public from roadside hazards such as steep embankments, utility poles, and trees. In response to this need, a number of different types of steel guardrails were introduced and installed along the highways of the United States. By the early 1950's, a shape known as the 'W-beam' had become the standard for guardrails throughout most of the nation. This 12 gauge steel rail worked well for redirecting errant vehicles which impacted the guardrail along its length, but accidents occurring at the ends of the systems proved to be very deadly.

W-beam guardrails were first installed with an untreated stand-up end. After many horrendous accidents it was realized that this configuration was extremely dangerous, as the guardrail had a tendency to pierce through the vehicle and cause very serious injury or death to the occupants. The first attempts at resolving this spearing problem involved twisting the W-beam 90 degrees, and fastening it to a ground anchor. Although this system, called a turned-down terminal, effectively prevented spearing, it had a tendency to cause vehicles impacting the end of the rail to roll over (1,2). In an effort to alleviate this problem, the post to guardrail connections near the turned-down ends were weakened in order to allow the guardrail to drop to the ground during end-on impacts. Although this "floppy-end turned-down terminal" reduced the magnitude of the rollover problem, it still had a number of flaws. First of all, this

terminal was found to create maintenance problems when the rail fell down due to road vibrations, temperature changes, and minor impacts with roadside mowers. Further, as the vehicle fleet downsized during the 1970's and 1980's, the floppy end terminal was found to represent a significant rollover problem for many impacting vehicles. Several attempts were made to overcome the safety problems associated with the floppy end terminals (5,6,7,8), but none of the new systems were able to resolve the rollover problem.

The Breakaway Cable Terminal (BCT) was developed with funding from the National Cooperative Highway Research Program (NCHRP) in the early 1970's (3). The concept behind this terminal system is that when impacted from the end, the W-beam will buckle and allow the vehicle to pass behind the installation. Unfortunately, this system was found to be very sensitive to the flare configuration and field experience has shown that these systems are frequently installed improperly (9). Additionally, the BCT has been found to impart unacceptably high deceleration forces on small vehicles, even when installed correctly (10), and the FHWA has recently prohibited its use on high speed, high volume roads on the National Highway System.

Improved BCT designs, the Eccentric Loader Terminal (ELT) (11) and Modified Eccentric Loader Terminal (MELT) (12), have been developed and successfully crash-tested with mini-size vehicles. These systems utilize improved buffer mechanisms, and optimized post locations, to reduce the forces required to collapse the terminal. Although these systems should offer improved safety performance over the standard BCT, the flared barrier end remains a critical component of the design. Further, the

ELT and MELT have several other important design details which may adversely affect end-treatment performance if not installed correctly. Problems with the ELT system stopped it from being installed shortly after it began to be implemented. Although the MELT is beginning to be used widely, its field performance has not been monitored closely enough to be adequately evaluated.

Another modification to the BCT system is the Slotted Rail Breakaway Cable Terminal (SRBCT) (13). This system utilizes longitudinal slots in the W-beam to lower the dynamic buckling load. The concept behind this system is that thin slots along the peaks and valley of the W-beam will greatly reduce the section modulus with only a small reduction in the tensile capacity of the rail. Although compliance testing of this system indicates that it should perform well, few accidents involving this system have been recorded.

The Sentre (14) and Crash Cushion Attenuating Terminal (CAT) (15) end treatments are proprietary guardrail terminals which are marketed nationwide. The Sentre is an energy absorbing terminal consisting of sand boxes and telescoping side panels. The CAT relies on the energy absorbing force developed from bolts tearing through perforated lines in thrie-beam panels. Although both systems appear to have acceptable safety performance, the complexity of these designs increases the cost to an unacceptable level. As a result, deployment of these systems has been limited to sites where the probability of impact is extremely high or special geometric constraints eliminate the possibility of using less expensive systems.

The ET2000 is another proprietary end treatment for W-beam guardrail (16).

This system attenuates head-on impacts by flattening the W-beam guardrail and curling it out of the path of the vehicle. The most attractive features of this terminal are that it can be installed tangent to the roadway and that it is generally less expensive than other proprietary systems. Although this system has exhibited very good field performance, it is still a more expensive alternative than the commonly used non-proprietary terminals.

Due to the high cost and complexity of available end treatments that meet current safety standards, highway agencies continue to use BCT type terminals for a majority of W-beam guardrail applications.

Investigation of Energy Absorbing Alternatives

As stated previously, one of the criteria for the new guardrail terminal was that it be capable of being installed tangent to the travelway. There are a number of advantages to this type of terminal, the first being ease of installation. As discussed previously, flared terminals are frequently installed at the wrong flare rate, and extensive dirt work is often required to provide a level surface on which to install the flare. Both of these problems are eliminated with a tangent terminal. Ideally a terminal can be designed to bring impacting vehicles to a controlled stop, instead of allowing them to pass through the terminal and impact hazards which the guardrail was meant to protect them from. In order to achieve this goal a terminal must absorb the vehicles kinetic energy. With these goals in mind, a literature search was conducted to