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Reconstruction techniques for energy-absorbing guardrail end terminals

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Abstract

Steel beam longitudinal barriers protect errant vehicles from roadside hazards; when impacted, they safely redirect the impacting vehicle and minimize the probability of serious injury. Guardrail end terminals are devices placed on the ends of longitudinal barriers and are frequently hit by vehicles that leave the roadway. Crash reconstruction is the effort to determine how a vehicle crash has occurred. Reconstruction is performed by several groups, including designers and testers of roadside safety devices so that they design and test for real-world conditions, and also by departments of transportation in order to determine appropriate warrants, maximizing the benefit–cost ratio for limited resources. This paper focuses on two items: first, the numerous types of energy-absorbing guardrail end terminals are identified and delineated and second, a crash reconstruction technique for determining the initial velocity of a vehicle impacting a guardrail end terminal based upon conservation of momentum and conservation of energy is developed. By understanding the types of guardrail terminals and being able to reconstruct real-world crashes, highway planners, designers and maintenance people will have significant more information than is currently available to aid in the goal of mitigating roadside crashes.

Keywords: Highway safety; Accident reconstruction; Guardrails; End terminals

1. Introduction

Flexible steel beam longitudinal barriers protect errant vehicles from roadside hazards, redirecting the vehicles and minimizing the probability of serious injury. However, the introduction of these barriers onto the highway requires that the ends of the barriers be protected in an effective manner. Left untreated, the ends of the barrier are able to pierce into the occupant compartment, creating a dangerous roadside environment (Rys and Russell, 1997).

Longitudinal barrier impacts are the third most common fixed-object impact, after only trees and embankments (Sicking et al., 1994). In order to determine appropriate warrants for installing these barriers, it is critical to ascertain the distribution of real-world impact conditions (Mak and Sicking, 2003). Detailed reconstructions of actual crashes provide the best quantitative and qualitative information on the distribution of real-world vehicle trajectories (Solomon and Boyd, 1986).

Because of the frequency end terminals are involved in crashes, accurate reconstructions of these impacts are critical. Crash reconstruction is the effort to determine, from whatever information is available, how the crash occurred. Crash reconstruction includes utilizing engineering concepts, such as conservation of momentum and conservation of energy, to estimate initial vehicle conditions and how the vehicle progressed through the crash.

Currently, there is an absence of any reconstruction technique available for guardrail end terminals (Coon, 2003). While extensive testing on guardrail end terminals has been performed, the information required to be reported is not particularly useful for performing crash reconstructions (Ross et al., 1993). This paper offers a method of reconstructing guardrail end terminal impacts.

The importance of reconstructing guardrail end terminals impacts is manifold. First, designers and testers of these roadside safety devices must be certain they are designing and testing for real-world conditions (Mak and Sicking, 2002). Second, state departments of transportation must determine

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the impact severity of these impacts to determine appropriate warrants, maximizing the benefit–cost ratio for limited resources (Mak and Sicking, 2003). Additionally, reconstruction techniques provide a useful litigation tool, allowing sureties, insurers and litigators to estimate compliance with applicable laws; however, this last reason for conducting the research was not, by any means, the focus of the researchers.

Guardrail end terminals are separated into two categories: energy-absorbing terminals and non-energy-absorbing terminals. Energy-absorbing terminals attenuate energy to slow the impacting vehicle. Non-energy-absorbing terminals are designed to offer little resistance during end-on impacts so that vehicles can safely pass behind the system.

This paper focuses on the identification of the numerous types of energy-absorbing guardrail end terminals and develops a technique for determining the initial velocity for impacts with guardrail end terminals based upon full-scale test results. However, care must be taken when comparing full-scale crash tests, which occur on ideally installed end terminals under optimal conditions, to real-world crashes.

1.1. Crash reconstruction overview

In order to determine impact conditions, crash reconstructions must be performed. Vehicle mass, run-out trajectory and the resulting deformed geometry of the barrier can generally be measured after the impact. However, the impact velocity must be estimated through crash reconstruction techniques.

Energy-absorbing guardrail end terminals crash reconstruction is performed using conservation of momentum during the initial portion of the impact where the terminal impact head is accelerated by the impacting vehicle. After the impacting vehicle and terminal impact head have reached the same velocity, conservation of energy is used reconstruct the rest of the impact. This includes, vehicle crush energy and the energy dissipated by the terminal through kinking, bursting, crushing or extruding process, depending on the terminal type. Results from full-scale crash testing are used to estimate energy dissipations for many existing end terminals on the market today.

2. History of guardrail end treatments

Safe and economical methods of termination of strong-post W-beam guardrail have been a critical concern for more than three decades. Early W-beam barriers were constructed with an untreated blunt end that was capable of piercing through impacting vehicles and causing serious injuries and/or fatalities. In order to address this problem, guardrail turndowns were used, bending the guardrail into the earth or onto a concrete footing. Unfortunately, small vehicles impacting these turndowns have a tendency to roll over. Because of this, another method of addressing the guardrail end problem was desired.

Development of several new end treatments occurred in the 1980s. These included the Safety End Treatment (SENTRE), the Transition End Treatment (TREND), the Vehicle Attenuating Terminal (VAT) and its second generation (CAT), the Controlled Release Terminal (CRT), the Eccentric Loader Terminal (ELT), the Modified Eccentric Loader Breakaway Cable Terminal (MELT), as well as modifications to the turndown and Breakaway Cable Terminal (BCT).

With the adoption of NCHRP Report 230 and its update, Report 350, the Slotted Rail Terminal (SRT) and the Redirective Gating End Terminal (REGENT) were developed. While these terminals met increasingly stringent test criteria, they were considered non-energy-absorbing and simply protect the vehicle from intrusion of the guardrail and severe impacts from full line posts rather than attempting to attenuate significant amounts of energy.

The Guardrail Extruder Terminal (GET) was the first in a family of energy-absorbing terminals that deformed the W-beam guardrail itself rather than adding crash cushions or other implements to the guardrail system (Sicking et al., 1989). The energy-absorbing terminal concept consisted of a terminal head that dissipated energy through extruding the guardrail. New concepts, including kinking and cutting the W-beam, were then developed to safely attenuate the impact energy. These terminals were the Beam Eating Steel Terminal (BEST), the Sequential Kinking Terminal (SKT), and the Flared Energy Absorbing Terminal (FLEAT). End terminals for box-beam guardrail include the Wyoming Box-beam End Terminal (WY-BET) and the Box-beam bursting Energy Absorbing Terminal (BEAT).

Approximately, 19 guardrail end treatments are currently approved under NCHRP Report 350 for usage on the National Highway System (NHS). The similarity in appearance among end treatments can cause confusion in determining the appropriate methods and values to be used to reconstruct a crash.

3. Energy-absorbing terminal identification

Energy-absorbing end terminals rely on an impact head to kink, cut or extrude the guardrail; in the case of box-beam guardrail, the terminal either bursts the beam or crushes pultruded fiberglass/epoxy tubes within the beam. There are six unique designs of energy-absorbing end terminals: the BEAT family, the BEST, the ET-2000 family, the FLEAT family, the SKT and the WY-BET. These terminals have distinctly different force-deflection behaviors, as well as significantly different masses, which must be differentiated before performing a reconstruction.

Each of the energy-absorbing terminals is identified by its distinguishing characteristics. The appearance of the deformed guardrail section, which is unique to each end terminal, is also examined.

3.1. Box-beam bursting energy-absorbing terminal

Produced by Road Systems Inc., the BEAT is designed as an energy-absorbing end terminal for standard