A BRIEF HISTORY OF ROADSIDE SAFETY AT THE TEXAS A&M TRANSPORTATION INSTITUTE (TTI)

Focused on Saving Lives

The Federal-Aid Highway Safety Act of 1956 created the Interstate Highway System, at the time the largest public works project in American history. The new system was designed to enhance United States transcontinental traffic with new roads designed to uniform highway safety standards. However, by the mid-1960s, it had become apparent that there were serious roadside dangers for drivers who veered off the highway. An American Association of State Highway and Transportation Officials (AASHTO) study laid out a few of these hazards:

- guardrails and median barriers with dangerously exposed ends;
- massive sign supports set in concrete immediately adjacent to the road edge;
- "gore" areas, where highways split, or at off-ramps that had numerous fixed concrete obstacles; and
- culverts with large concrete headwalls close to the road.[1]

The Texas A&M Transportation Institute (TTI) and the Texas Highway Department (THD) understood early on that the highway engineering community needed to lessen the impact of run-off-road incidents. They were spurred on by observing motorists who ran off roads and died from striking highway signs and other fixed obstacles. The local media reported on these incidents, often showing the twisted metal wrecks on the evening news.

THD district engineers in several cities asked THD and TTI to explore the development of "forgiving" highway signs. TTI researchers adopted as a guiding principle that the "penalty for driver error should not be death" by providing a margin for error by making slight, but critical, changes in designs of roadside devices. The principle was expressed in TTI's commitment to developing a "Forgiving Roadside." Since the 1960s, TTI has led the safety movement on the Interstate Highway System by developing safer roadside hardware and performing crash tests on signs, guardrails, and crash cushions at its Proving Ground Research Facility in College Station, Texas.

Today, as the result of years of TTI's research and technological innovations, safety improvements can now be seen on virtually every mile of roadway in Texas and across the United States.

[1] American Association of State Highway Officials, *A Policy on Design Standards*, Interstate System (1967).

TTI Roadside Safety Innovations – 1960s

To determine whether ideas for making roadsides safer might actually work, thousands of crash tests have been performed at TTI’s Proving Ground Research Facility, which is ISO 17025 accredited by the American Association for Laboratory Accreditation. Today, the facility also includes the Center for Transportation Computational Mechanics, where analysts run computer simulations to evaluate potential roadside safety solutions and improvements to existing safety hardware before performing an actual crash test.

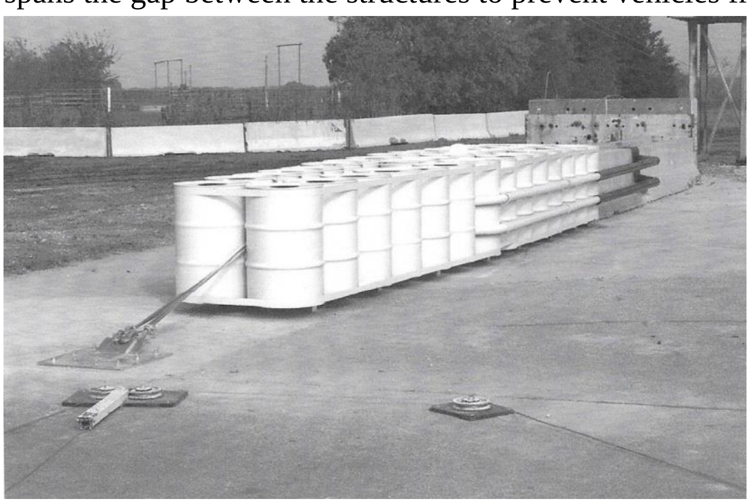
Here are several safety developments that were designed, tested and developed at TTI’s Proving Ground Research Facility:

Breakaway Sign Supports

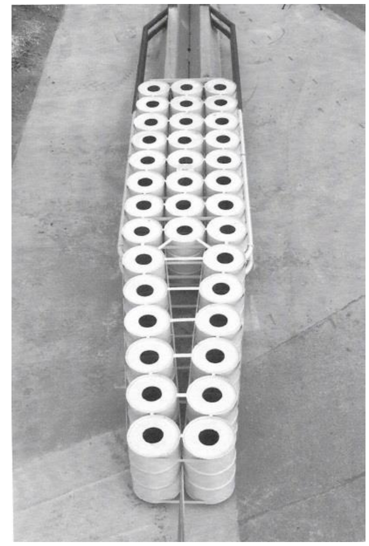
One of TTI’s initial contributions to the “forgiving roadside” concept came in 1965 when it pioneered the “breakaway” design for freeway sign supports, later applying the same principle to light poles, utility poles, sign bridges and mailbox supports. TTI researchers developed a sign support that had the strength to withstand heavy winds and other climatic conditions, but would yield to an errant motorist. After several experiments and crash tests, TTI researchers developed a design that reduced the rigidity of the sign by using a slip joint and a hinge joint that allowed it to breakaway when struck and did not leave anything obtrusive for the vehicle’s undercarriage to snag on. The design was adopted by state departments of transportation, as it could be easily applied to the standard unbraced sign supports used in Texas and across the United States. The results of the crash tests were so impressive that Francis Turner, head of the Federal Highway Administration (FHWA), had breakaway signs placed on interstate highways before the final reports had been written. Since the 1960s, this implemented concept has saved thousands of lives. Prior to the innovation and implementation of “breakaway” supports, the death rate of motorists who struck one of the old sign supports was extremely high.

Texas Crash Cushion

From September 1961 through June 1968, 27 fatalities occurred in Houston due to vehicles striking concrete abutments located in the gore of diverging lanes. A parapet, or retaining wall, spans the gap between the structures to prevent vehicles from driving off the side of the freeway



and falling to the lower level. Most accidents occurred when motorists traveling on the main freeway lane decided too late to turn right onto an off-ramp. Until 1968, parapets were marked with a 4- to 5-foot tall reflectorized “V” that warned oncoming motorists of the danger. Engineers also placed signs and lane markers to alert drivers. Despite these warnings, drivers still had a number of serious accidents. TTI research engineers believed that while these accidents were not totally preventable, they could be made less severe, so they set out to develop a method of safely decelerating a vehicle while minimizing the risk to the occupants of the vehicle. Additionally, since a solution to this problem was needed in hundreds of locations throughout the state, the solution and materials had to be relatively inexpensive.



After extensive research and crash-testing, the eventual standard crash cushion design consisted of 38 to 44 interlocked 55-gallon steel drums placed in the gore in front of the parapets. When an errant vehicle strikes the honeycomb array of barrels, much of its energy is absorbed by successive crushing of the barrels. The simplicity of design and the relative low cost of TTI's impact devices made them extremely popular with TDH district engineers, who also placed crash cushions around other immovable items such as bridge and overpass supports.[2]

TTI researchers did not have to wait long to see how the "Texas Crash Cushion" (as it became to be known) operated on the state's freeway system. Statistics showed that more than 100 vehicles struck various crash cushions in 2½ years in Houston, with just five people injured seriously enough to warrant a trip to the hospital and one fatality. Most drivers hit the barrels, backed out, and kept on going. The Texas Crash Cushion was a resounding success.

TTI Roadside Safety Innovations – 1970s & 1980s

Bridge and Guardrail Designs

During the 1970s, TTI researchers also studied carefully the performance of existing bridge rail and guardrail designs. Full-scale crash tests revealed shortcomings in many of these designs, either in geometrics or structural adequacy or both. Researchers modified existing designs to improve performance. This work resulted in development of data and better understanding of automobile and bridge rail dynamic behavior during impacts. This allowed researchers to formulate design requirements for bridge railings to safely contain vehicles ranging from 1,800-lb automobiles, larger automobiles, large trucks, school buses and intercity passenger buses to 80,000-lb tractor/semi-trailers. In the 1980s, TTI researchers were actively conducting bridge rail design and impact testing research. By 1986, TTI researchers had developed a bridge rail that would prevent subcompact cars from snagging on rail posts and redirect vehicles of up to 32,000 pounds traveling up to 60 miles per hour without causing rollover. This rail proved successful enough for FHWA to recommend to its regional offices for adoption. Additionally, TTI researchers developed a 90-inch tall bridge rail—the only bridge rail developed to date capable of redirecting up to an 80,000-lb tractor

2 *Vehicle Impact Attenuators for Bifurcations*, Texas Highways, December 1968, pp. 4-7.

semi-tank trailer. The data developed and collected allowed researchers at TTI to formulate design provisions in Section 13 of the AASHTO Bridge Specifications.

Roadside Parallel Drainage Structures

Until the early 1980s, the ends of most highway drainage concrete culverts remained completely exposed, resulting in safety hazards to any vehicle that might leave the roadway. Highway drainage structures historically had been constructed without much thought given to the possibility that a car could leave the roadway and strike a culvert or a grate that projected up from the ground. Some culverts and grates had caused serious injuries and deaths by making wayward vehicles stop suddenly or veer out of control. TTI researchers believed that properly sloped culverts and grates could drain the same amount of water and protect the public at the same time. TTI researchers determined, using mathematical computer simulation techniques, the most effective slopes for constructing culverts and that the proper culvert construction guidelines should include end treatment openings that matched the driveway slope to eliminate collisions with the end treatments. This work was initiated in 1972 by FHWA and TTI researchers. These criteria, and findings from subsequent TTI studies, have remained the industry standard ever since and can be found in design guidance published by AASHTO.[3]

Breakaway Mailbox Supports

In 1980, TTI researchers authored an FHWA-commissioned report on the dangers of rural mailbox supports to vehicles that leave the road. After conducting a series of five full-scale crash tests, researchers determined that most devices used to support rural mailboxes could potentially cause serious injury or death to drivers and that wooden support posts posed especially hazardous conditions. In two crash tests conducted on posts supporting single mailboxes, it was found that both secured and unsecured mailboxes tore loose from the posts and struck the windshield. As a solution, TTI researchers developed a post similar in design to the breakaway sign posts with a breakable coupling at the base. In crash-tests, the coupling broke away on impact, the box remained connected to the post, and the car safely rode over both.

Hawkins Breakaway System

In 1983, TTI began a long research project for FHWA to develop a new type of roadside utility pole. With the advent of breakaway highway signs and impact attenuators, wooden utility and telephone poles became among the most dangerous roadside obstacles. By the late 1980s, about 2,000 people were killed annually when their vehicles smashed into or wrapped around utility poles. Led by TTI researchers, the Hawkins Breakaway System, which was based on the same principle as the breakaway highway signs, was developed. The researchers had to confront the concerns of utility companies, including the possibility of a domino effect on adjacent poles when one pole was struck, accelerated wood decay, and the increased failure of poles under

[3] Texas Transportation Researcher, July 1972, p. 2.

severe weather conditions. After several crash tests, the successful design featured poles that hinged about 15 feet above the base. When such a pole was hit, the bottom section slipped away from the base and swung upward, while pivoting at the hinge. This design not only minimized risk to the occupant but also allowed telephone or utility lines to remain intact.[4]

Work Zone Barriers

In the early 1980s, one increasing area of importance for transportation engineers concerned the safety of maintenance workers on the state's highways and freeways. As the Interstate Highway System was starting to show its age, and more of the highway system required maintenance and reconstruction, the numbers of deaths and injuries suffered by highway workers increased dramatically. In 1977, almost 8,000 accidents occurred in work zone areas in Texas, resulting in 73 deaths and almost 3,000 injuries. Eighty percent of these accidents occurred in urban areas, but according to research conducted by TTI investigators, rural work zone accidents accounted for over half of the reported fatalities. The rest of the country matched this surge in work zone deaths and injuries, causing FHWA to proclaim work zone traffic safety a national emphasis for research.

The FHWA emphasis and this nationally recognized problem prompted TTI to search for new methods of protecting construction and maintenance workers. Knowing workers could not erect and remove conventional precast concrete barriers quickly enough in areas where work would be completed in only a few hours, TTI researchers developed several concepts that fulfilled three major desires: crashworthiness, portability and affordability. One of these designs included an extraordinarily portable system dubbed the "Car Train." The Car Train consisted of a line of five used automobiles connected together by three steel telescoping tube pipes. Researchers attached a standard three-beam guardrail to the sides of the vehicles to redirect errant motorists away from construction workers.

Researchers returned to the precast concrete barrier design to determine if they could customize it for portable work zones. Their resulting design effectively cut the old barrier in half. Not only could these barriers be transported from site to site more easily, but since the state made the 30-foot segments in its construction plant, the two new barriers could be cast in the department's existing forms.

Researchers also utilized the 1960s "Texas Crash Cushion" approach to shield the ends of these temporary barriers. Since the portable end-treatment had to react as a crash cushion if hit head-on, and as a longitudinal barrier if struck from the side, the design posed some special problems. The researchers connected a single row of 55-gallon steel barrels (some empty, some containing sand ballast) to a collapsing W-beam guardrail to construct the cushion. The single-file barrels worked on the same principle as the Texas Crash Cushion, helping to absorb the vehicle's kinetic energy. The W-beam guardrail attached to the side of the barrels acted as a redirecting barrier for vehicles that hit the side of the cushion. To help keep impact forces within tolerable levels during head-on collisions, the TTI researchers weakened the W-beam rail in several places.

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[4] Texas Transportation Institute, *Safer Timber Utility Poles*, U. S. Department of Transportation, Federal Highway Administration, 1985.

The portable barrier and end treatment proved successful and was widely accepted. Over the next decade, TTI researchers continued to modify and improve these types of temporary work zone barriers. For example:

Low Profile Barrier

TTI developed a low profile portable concrete barrier that is designed for use at intersections in construction zones. This concrete barrier, about12 inches shorter than the previous standard, allows drivers a greater field of vision. The barrier's shape is designed wider at the top to reduce the tendency for a vehicle to vault through the air on impact with the barrier.

Cross Bolt Barrier Connection

With TxDOT sponsorship, TTI developed a new, portable concrete barrier with an innovative connection that has the lowest deflection of any portable barrier in the country. And rather than waiting to schedule a crane to move standard, 30-foot barriers into place, the 10-foot lengths can be moved with a commonplace front-end loader—thus speeding up emergency responses and lessening the time it takes to deploy barriers on a job site. This development of a temporary concrete barrier connection with significantly reduced lateral deflection than those connections previously being used had national significance.

Single Slope Median Barrier

In the late 1980s, TTI researchers working with the State Department of Highways and Public Transportation (SDHPT) set out to develop a concrete barrier that would address some issues with the popular and successful New Jersey concrete barrier (CMB). The CMB had one big disadvantage; its profile varied with height above grade. This means that if the roadway is resurfaced, both the height and shape of the barrier will change with respect to how it presents itself to an impacting vehicle. TTI researchers developed the single slope median barrier to address up to several inches of additional asphalt overlays without affecting the crash performance of the barrier. Upon completing crash testing, FHWA accepted the Single Slope Median Barrier for use on the National Highway System (NHS) on February 11, 1992.

TTI Roadside Safety Innovations – 1990s & 2000s

ADIEM

In the early 1990s, the Advanced Dynamic Impact Extension Module (ADIEM) barrier made of a soft crushable concrete called Perlite, also developed by TTI researchers, answered the demand for a cost-effective, easy-to-install crash cushion for concrete barriers. When struck by a vehicle, an ADIEM module absorbs the kinetic energy of the impact by disintegrating and slowing the vehicle to help bring it to a safe, controlled stop. FHWA acceptance for use on the NHS was granted on March 3, 1997.

HEART

In the early 2000s, TTI researchers developed a crash cushion that can be reset and reused after being impacted. The goal was to develop a high performance crash cushion that had the potential to reduce maintenance costs to the states by potentially being re-useable after an impact. The result was a crash cushion fabricated from high-density-high molecular weight polyethylene (HDPE) plastic. Upon impact the flat HDPE side panels fold at predetermined hinge points and allow the crash cushion to collapse in a telescoping manner. After an impact at less than the ultimate design capacity of the system, the cushion is reset by pulling the nose back into its original position. The FHWA accepted HEART for use on the NHS for use on March 17, 2005.

Guardrail End-Terminals

<u>ET-2000 & ET Plus®</u>

TTI researchers believed guardrail safety needed improvement and focused their attention on the end of the guardrail, or more specifically on “turned-down” guardrails. THD officials originally designed the turned-down guardrail, or the “Texas Twist,” in the 1960s as replacements for blunt-end rails. The blunt-end rails caused hundreds of fatalities and injuries due to their ability to spear and penetrate through a car body, which could severely injure or kill passengers. The improved Texas Twist curved to terminate at ground level and successfully eliminated the spearing hazard. However, an unforeseen problem occurred with the innovation. Small vehicles could potentially roll over in certain types of impacts.

Once again, the cooperation between SDHPT and TTI found an answer. TTI researchers developed a guardrail end-terminal that could absorb a head-on impact and reduce the risk of causing serious injuries to the passengers. In 1988, TTI researchers filed for and later received a patent for a new guardrail end-terminal—the ET-2000. The impact head on the ET-2000, which was designed to meet federal crash testing criteria, includes an extruder throat, an impact plate and “guide channels.” In end-on impacts, the flattening and bending of the guardrail section away from the vehicle (a process called “rail extrusion”) helps to slow the vehicle after impact. The guide channels help keep the impact head aligned with the guardrail during an end-on impact to enable the rail extrusion process to take place, if it is impacted within federal guidelines.

The ET-2000 was further designed to accommodate end-on impacts at an angle through a process known as “gating.” Gating occurs when the impacting vehicle pushes the impact head out of alignment with the guardrail. The guardrail bends and forms a hinge about which the impact head rotates and swings away from the vehicle.

The design proved successful in its first documented in-service impact when a motorist struck an ET-2000 on IH 35 near Buda, Texas in March 1991 and walked away without injury. Similar results throughout the country occurred and the developers of the ET-2000 were recognized for their efforts with the 1991 Federal Highway Administrator’s Biennial Safety Award.

TTI researchers continued to explore opportunities to improve the extruder-terminal technology, as they do with many other highway technologies. Seeking to improve the technology for end-terminal systems, TTI research engineers developed the ET Plus® end-terminal system. The ET Plus® retained the same extrusion throat mechanism of the ET-2000, but incorporated several significant design improvements to enhance safety. The ET Plus® end-terminal system was accepted by FHWA for use on the National Highway System (NHS) on January 18, 2000.

Wire Rope Terminal

Despite designers providing wide medians between opposing traffic and improved high-speed roadway geometrics, motorists continue to cross over and have head-on collisions. The TTI researchers who were involved in crash testing both the low-tension and new generations of high-tension wire rope cable barriers identified the need for a better performing terminal for high-tension longitudinal cable barriers.

TTI researchers set out to develop a wire rope terminal that performed well when impacted in either direction, was cost-effective and had multiple anchors built in. The TTI cable terminal system has three anchor posts and continues to provide some anchorage of the barrier if one of the cables is released in a low-speed impact, such as mowers or vehicles at low speeds. The TTI wire rope end-terminal system was accepted by FHWA for use on the National Highway System (NHS) on August 29, 2002.

Summary

TTI researchers continue to actively and vigorously pursue one of the most important missions at the Institute: research that leads to saving lives on our highways. In support of this mission, TTI researchers have developed numerous other highway safety devices that have not been presented here. They will continue to improve existing roadside safety hardware, develop new hardware, and search for materials and methods to save lives and reduce the severity of run-off-road accidents into the future.