TURNING THE WORLD’S ROADS INTO FORGIVING HIGHWAYS

THEME:	**ROAD SAFETY**
SUBTHEME:	**ROADSIDE SAFETY**

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1. INTRODUCTION

Imagine the worldwide alarm if a fully loaded Boeing 747 airplane was crashing everyday somewhere around the world. This would be the number one topic in every legislative body, at every dinner table and the lead story on every news channel. Countless amounts of money, energy and time would be spent to come up with some solution to this tragic situation that would threaten to shut down economies from the United States to Germany to Japan to South Africa to Australia to Chile. Finding an answer to stop these airplanes from crashing would be the single most important issue for all of mankind.

Statistically speaking, six to seven fully loaded Boeing 747 airplanes crash everyday…on the roads around the world. The World Health Organization estimates that over 1,300,000 people are killed every year on the roads around the world. Too often unless the person in the accident is someone close to us or someone famous, no one notices the death and the carnage continues with seemingly little concern by road authorities.

Unfortunately, it is impossible to completely eliminate all accidents around the world. As long as humans are driving the vehicles, accidents will happen on the roads. All humans make mistakes. When a driver makes a mistake with a steering wheel in his or her hand, the result can be a very serious traffic accident. While these accidents will never go away, it is possible to design highways to use today's technology to make these impacts less severe. In effect, this technology is forgiving motorists when they make a mistake, and not making the motorist pay for his or her mistake with capital punishment by giving up his or her life. When this is accomplished, the roads become known as "Forgiving Highways."

Highways are often called a country's arteries. It is a deserving description. Just as a body uses veins and arteries to circulate blood, highways are used to circulate people throughout a country. The challenge highway engineers in the Twenty-First Century and beyond is to utilize state of the art technology to provide kilometers of roads in very small areas near, or in cities around the world. This is where people want to live and this is where the roads are needed. One of the inevitable results of these new highway designs, through no fault of the designs themselves, just the lack of ideal geometries, will be black spots, or dangerous potential accident areas. These typically are areas where drivers need to make decisions. When making a decision, the driver can be either right or wrong.

Approximately thirty percent of those fatal accidents will be single vehicle, non-pedestrian (SVNP) accidents where a car will run off the road and impact a rigid roadside object. These rigid roadside hazards include bridge abutments, bridge piers in the median, median barrier terminals, bridge rail ends, sign supports, railroad crossing signal arms, or the barrier ends located in the aptly named "gore areas" at exits, to name just a few.

Locating a black spot is not difficult. Ask any traffic policeman where additional roadside hazard protection is needed, and he or she will quickly start to tell you when he or she last used the "Jaws of Life" to free a mangled body from a crashed vehicle. Ask an experienced highway design engineer to unfold new highway drawings, and he or she will undoubtedly be able to identify a location with poor geometries that could be

a problem. Ask a safety auditor in England or Australia to review an evaluated highway, and he or she will be aware of many roadside locations that could be made safer with improved crash protection.

Most qualified experts in the highway safety industry could travel any road in any country around the world and identify multiple dangerous roadside hazards that are not properly shielded. The experts may also identify stopped or slow moving trucks in work zones that can be extremely dangerous to motorists, even when these trucks are fitted with arrow boards, lights and variable message signs. They may also point out inadequate protection for workers and motorists due to the use of cones or barricades in these work zones.

Not correcting a dangerous condition on the highway can prove to be a much more costly option than treating the site with a properly designed and tested crash protection. Utilizing proper crash management is proving on a daily basis around the world that it is a highly economic tool that must be used to improve roadway safety.

2. BACKGROUND

In the 1950's and 1960's, the number of vehicles and the kilometers of roads grew around the world. As they grew, so did the number of fatalities on the roads. About one third of these fatalities were due to single vehicle, non-pedestrian (SVNP) collisions. Most of these accidents were motorists impacting rigid objects near the side of the road. Unfortunately, little was done in the 1950's and 1960's to prevent this carnage on the highways.

Single vehicle, non-pedestrian accident

Many road administrators at that time argued that the SVNP accidents were often the result of excess speed or alcohol consumption. They contended that drivers involved in these SVNP accidents were "authors of their own misfortunes". In some countries, imprecise reporting made it difficult to identify the hazard that was the cause of the accident. Therefore, the dangers posed by a particular site were not clear.

Most road administrators in the 1950's and 1960's believed that alert and competent drivers could achieve satisfactory levels of roadway safety if they stayed on the highways that were designed using conventional engineering. By the mid 1960's, it was obvious that this logic was no longer valid. Between 1956 and 1966 the number of motor vehicles on the American roads alone had grown 47% to over 96 million. In 1966, the number of deaths on the United States roads alone had reached 53,000 and more than 2,000,000 people were subjected to disabling injuries. Many countries around the world

had similar fatality levels and vehicle growth figures. Something needed to be done to make the roads safer.

In the late 1960's, concentrated efforts to create a "Forgiving Highway", or safe road that would not make driver error a capital offense, were initiated in many parts of the world. The United States Department of Transportation Federal Highway Administration (FHWA) was at the forefront of the efforts to develop the "Forgiving Highway" concept. During the 1970's and into the 1980's, many countries evaluated the success of the United States Department of Transportation Federal Highway Administration programs and incorporated some of the American ideas, along with remedial actions that were more appropriate to the needs of the motorists in their countries. In every case, the goal was to create a "Forgiving Highway."

Ideally, the road design for a "Forgiving Highway" should incorporate the clear zone concept by removing hazards that are near the road. This is not always practical, especially in high volume urban roads that are surrounded by a variety of complex highway structures, traffic signs or lighting columns.

If removing the hazard is not practical, road authorities should move the hazard further away from the road to reduce the possibility of impacts. Long masted luminaire supports would be good examples of this solution.

Removing or moving the hazard is definitely the most effective and desirable actions to correct a dangerous roadside situation. However, if designing out or removing the hazard is not possible, then the next option is to design these hazards that are near the road so they will "breakaway" when impacted. This will lessen the severity of the impact for the occupants of the vehicles.

If a breakaway feature is not feasible, the hazard should be shielded using a crash barrier (e.g., steel guardrail or concrete barrier) or a crash cushion. The remainder of this paper will concentrate on the last option; shielding the hazard using a crash barrier or a crash cushion.

3. TYPICAL ROADSIDE HAZARDS

Most high-risk sites on a highway occur at a point when the driver must make a decision. If an unprotected rigid object is in the driver's decision area, and if the driver makes the wrong decision, the results can be disastrous. The hazards that cannot be removed, moved, or made breakaway, and therefore must be shielded from errant vehicles, are similar in all countries.

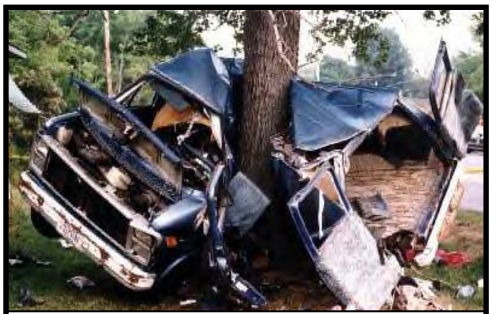
Table 2 illustrates the similarities between the most frequently impacted hazards involved in SVNP fatal accidents in the United States and Great Britain. Successful concepts used to design a "Forgiving Highway" can be translated between countries. While these statistics are not current, the items being impacted today would be similar to those impacted in the 1990's.

TABLE 1 SINGLE VEHICLE NON-PEDESTRIAN FATALITIES BASED ON FIRST HARMFUL EVENT				
	UNITED STATES (1994)		GREAT BRITAIN (1988)	
OBJECT	**NUMBER**	**PERCENTAGE**	**NUMBER**	**PERCENTAGE**
NONE	1141	10.2	153	19.1
TREES	3014	27.1	186	23.2
POLE/POST	1465	13.2	144	18.0
GUARDRAIL/ BARRIER	1126	10.1	35	4.4
CULVERT/ CURB/DITCH	1629	14.6	55	6.8
OTHER	2760	24.8	228	28.5
TOTAL	11135	100	801	100

Source: RAGB,1988 ARHSIP, 1994

TREES

Trees are the most frequently impacted objects in both countries. Roads were initially built between trees to provide shade for the horses pulling carriages. Trees also provided a guide to allow motorists to know where a road was located in areas that experienced significant levels of snow. Neither of these reasons for planting trees near a road exists today. Unfortunately, it continues to be common practice to beautify roads by planting trees too close to the traveled way. The general public and government officials often remain reluctant to remove existing trees despite the fact that motor vehicle impacts into trees resulted in over 27% of the SVNP deaths in the United States in 1994 and over 23% of the SVNP deaths in Great Britain in 1988.



Trees are the number 1 roadside killer

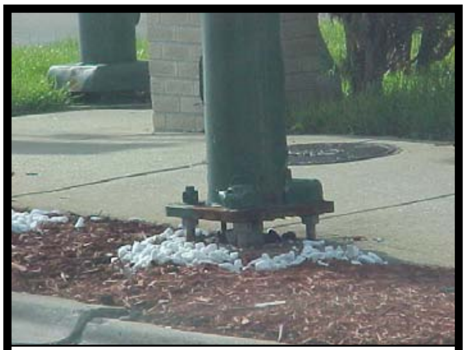
Indiscriminate removal of all trees from the adjacent roadside is not the answer because it is not cost-effective. Rather, a firm policy could be followed to remove trees that were either frequently impacted or considered, by experience, to be potentially dangerous. Should it be decided not to remove a hazardous tree, then shielding may be the last resort to provide safety to occupants of errant vehicles that collide with the tree. This can be accomplished through the use of guardrail (crash barrier) or crash cushions or a combination of both.

POLES

It has been estimated that in the United States alone about 130 million utility poles, sometimes referred to as telegraph or telephone poles, exist. Millions more luminaire supports also are installed in the United States. More than 100 million of these posts are installed in close proximity to the traveled way of highways, roads, and streets. Of these, more than 50 million can be considered hazardous roadside objects. About 2,100 lives are lost each year by vehicle impacts with poles and posts in the United States, and 140 more in Great Britain.

One product that could make these poles and sign posts safer is a breakaway device. A variety of breakaway devices are available. The Transportation Research Laboratory (TRL) in Great Britain invented one of the first devices in the early 1960's.

Breakaway poles sever when impacted and allow the vehicle to pass through with a minimum change in velocity. Although the breakaway pole and signpost concept was invented in Great Britain, they are not extensively being used in Great Britain, but are being used in other countries.



Slip base design breakaway post

Breakaway timber utility pole

One breakaway concept, the breakaway timber utility pole, is becoming more popular in the United States. This pole, designed to break away upon vehicle impact, is intended for use in situations where a rigid pole is known to be in a potentially hazardous location and its removal or relocation is not possible or practical.

The pole features a steel slip base at ground level that works along with a steel strap hinge located about 4.5 meters up on a typical 12-meter (40 foot) utility pole. The slip base absorbs the force of impact, and breaks away from its foundation. The hinge mechanism absorbs the bending moment created in the pole by the vehicle impact forces, so that the upper section of the pole (and all of the attached utility cables) are or not affected by the forces of the collision. It is the isolation from impact forces that enables the breakaway timber utility pole to prevent the interruption of utility service even when the pole is hit.

These poles were field tested in nineteen roadside installations in Massachusetts over a two- year period. It is noteworthy that in five hits, no serious injuries were reported to vehicle occupants, at no time has utility service been interrupted, and no litigation was filed against any of the participants in the evaluation.

Guy wires are required for certain utility pole applications. These guy wires can be very dangerous to motorists. New concepts are being developed to allow these guy wires to break away when impacted to prevent vehicles from being vaulted or rolling over.

In the late 1980's the collapsible pole was introduced in Sweden. The pole is designed to capture an impacting vehicle and slowly decelerate it. The pole has been successful in the Scandinavian countries and highway agencies in other countries are currently evaluating this concept.

Another method used to provide motorist protection from a utility pole installed near a multi-road intersection is to install a wrap-around crash cushion of small diameter collapsible high-density polyethylene tubes. When the tubes are impacted, the tubes crush and the vehicle is slowly decelerated to a stop. These systems are recommended when anticipated vehicle impact speeds of 70 kilometers per hour (43 moles per hour) or less are envisaged. A variety of other crash cushions are also available to provide head-on and angle protection for motorists from roadside posts.

4. CRASH BARRIERS

Nearly all countries throughout the world are using guardrail, also called crash barriers, to shield hazards. Many different types of roadside barrier systems, also known as guardrails, guide rails, longitudinal barriers or crash barriers, are being used around the world. Most steel barriers are considered semi-rigid or semi-yielding barriers because they are designed to have limited deflection when hit on an angle by an errant vehicle. This deflection will typically provide for a less severe impact for the motorists in the vehicle. Care must be taken to ensure that these steel barriers have a proper, flat clear zone directly behind them when they are installed to allow for the anticipated deflection. The post spacing can have a significant effect on the amount of deflection of the steel barriers.

Some steel barriers use several strands of wire rope fastened to steel posts. Others use a steel box beam or a double corrugated steel railing or triple corrugated steel railing as its longitudinal member fastened to steel or wood posts.

Concrete barriers that utilize various designs of safety shapes also are being used where no deflection of the barrier is acceptable. Concrete barriers are very popular in medians due to their limited, if non-existent deflection characteristics.

Errant vehicles colliding with barriers accounted for over 1,100 fatalities in the United States in 1990 and 35 reported lives in Great Britain in 1988. The number of annual fatalities have been reduced greatly in recent years by improvements such as the use of safety shape design, crash cushions to protect the rigid ends, block-outs, shorter spacing of guardrail posts, proper installation and the use of the triple corrugated railing (thrie beam).

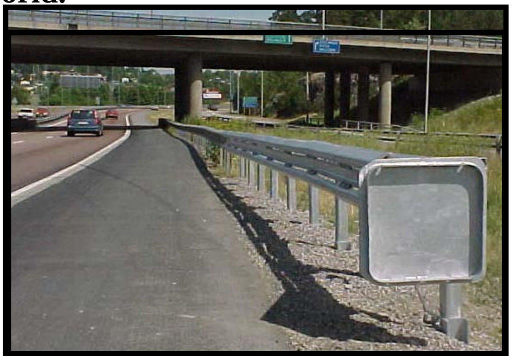
Many of these crash barriers have extremely dangerous ends. A variety of efforts have been made to treat the ends, including breakaway cable terminals (BCT), and turned down ends. Neither of these solutions is totally acceptable today.

The small car that became prevalent on European and American roads in the 1970's creates a real problem for the breakaway cable end terminal. Guardrail ends using the breakaway cable terminal have been known to penetrate or spear smaller cars during an impact causing motorist injuries and deaths. In 1993, the FHWA in the United States outlawed the use of the BCT for new roads. The performance is fatally unacceptable.

Typical turned down end installation

The turned down or ramped end also has proven itself to be extremely dangerous by causing the vehicle to ramp and the driver to lose control. In June of 1990, the United States recognized this danger and outlawed the use of ramped ends on high speed, high volume roads. In 1998 these turned down ends were prohibited for use on the upstream end of any barriers on the National Highway System in the United States. Disastrous experiences with turned down ends in Europe have many road authorities looking for options to improve their barrier terminals.

A variety of crashworthy terminals and crash cushions that do not spear, roll or vault an impacting vehicle are commercially available. Their use has been increasing in the United States in recent years and the trend is being followed in Europe and other countries around the world.



The ABC Terminal

Approximately 750,000 terminals, some crashworthy, some not crashworthy are currently installed on the approach ends of crash barriers in the United States. About 15,000 of these terminals are impacted every year resulting in about 100 fatalities and about 5000 injuries. Not using crashworthy end treatments to shield the ends of the crash barriers cannot be professionally justified.

One reason often given for not undertaking a program to replace dangerous turned down ends or breakaway cable terminals with crashworthy terminals and crash cushions relates to liability. Road authorities are concerned that if they admit that one

turned down end is dangerous. and they replace it with a crashworthy terminal, and then an errant vehicle hits another turned down end, the highway agency will be subjected to serious liability issues for allowing this admittedly dangerous turned down end condition to exist.

Legal authorities agree that road authorities do not need to correct every similar hazard once they correct one hazard. This is financially unrealistic. Legal precedent in certain countries has shown that if a highway agency has a written plan that is realistic and based on financial restraints and time parameters, the courts will rule that the agency is doing everything in its power to correct the problem. The important issue is that the agency recognizes the problem and implements a realistic action plan.

5. INTRODUCTION TO CRASH CUSHIONS

Crash cushions, also called impact attenuators, are passive restraint systems that are designed to reduce the severity of an impact. A crash cushion reduces the consequences of an accident by slowly decelerating an errant vehicle before it impacts the rigid hazard. It is a means for "extending the time of the crash event", or simply decreasing the severity of the impact by reducing the rate of deceleration.

Crash cushions function in many ways like a parachute for your car. A person jumping from an airplane at 1,000 meters (3,300 feet) with no parachute will impact the ground at a very high speed. All of his or her bones will be broken and his or her internal organs will be destroyed due to the extremely high deceleration level he-mill experience. However, if this same person employs a parachute during his jump, he or she will slowly descend and softly land on the earth. His or her body will experience very low deceleration levels and he or she will walk away after hitting the ground.

A car traveling at 100 km/hour (62.5 mph) that impacts a rigid roadside object will come to a sudden violent stop. The passengers in the vehicle, who for a brief millisecond will still be traveling at 100 km/hour (62.5 mph), will then be thrown forward into some part of the car, the windshield, the steering wheel or hopefully a seat belt. Finally, all of the passenger's internal organs will impact his or her chest wall, causing internal bleeding and internal injuries. The deceleration levels will be incredible and the person will probably die.

However, if this same car traveling at the same speed impacts a properly designed crash cushion instead of the rigid object, the results will be much different. The vehicle will be brought to a controlled, safe stop as the impact is extended over time. Just as the parachute extended the time of the fall, the crash cushion extends the time of a crash. The vehicle still goes from 100 km/h (62.5 mph) to zero. What is different is the time used to go from 100 km/h (62.5 mph) to zero. By extending the time of the event, the deceleration forces on the people in the vehicle are reduced. The passengers will experience far lower deceleration rates, and they will probably walk away from the accident.

6. HISTORY OF CRASH CUSHIONS

The first crash cushions were developed in the 1960's in the United States. They consisted of empty oil drums that were systematically arranged in front of a roadside object. When impacted, these drums crushed, transferring the energy from the vehicle into the drums and extending the time of the event. The passengers experienced lower deceleration levels than they would have if they impacted the roadside hazard.

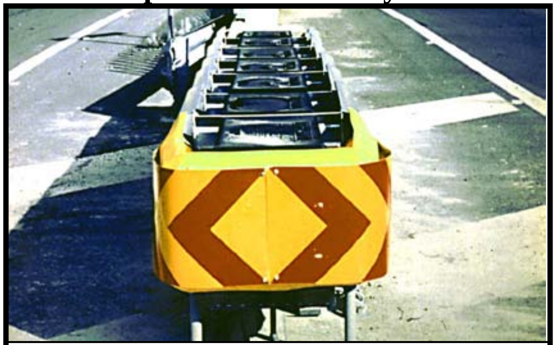
Modifications to this basic concept were made over the years. Instead of empty steel barrels, plastic drums filled with varying weights of sand were employed. The sand in these inertial barriers was elevated to provide the same center of gravity for impacting vehicles. This constant center of gravity ensured that the car stayed on the ground during the event.

Inertial barrier arrays

Hi-Dro crash cushions

Crash cushions that used water as the energy-absorbing element followed the sand barrels, or inertial barriers. These "Hi-Dro" Systems provided redirection by guiding errant vehicles impacting at an angle back safely into the original traffic flow. While these "Hi-Dro" Systems worked well for larger vehicles, they did not always provide safe deceleration levels for occupants of a small vehicle during head-on impacts.

In the late 1970's, small cars became more prevalent on the world's roads, and a new energy-absorbing element was needed. In 1981, a revolutionary new concept, which used foam to decelerate the vehicle, was introduced. Boxes filled with this "Hex Foam" were placed between sliding fender panels to safely decelerate vehicles weighing between 820 kg and 2040 kg (1800 to 4500 pounds) traveling at speeds up to 113 km/h (70 mph). This concept can be used to shield hazards as narrow as 60 cm (24 inches) (G-R-E-A-T System) and as wide as 5 meters (16.5 feet) (Hex Foam Sandwich System). Approximately 60% of the components in these systems could typically be reused after a design impact.

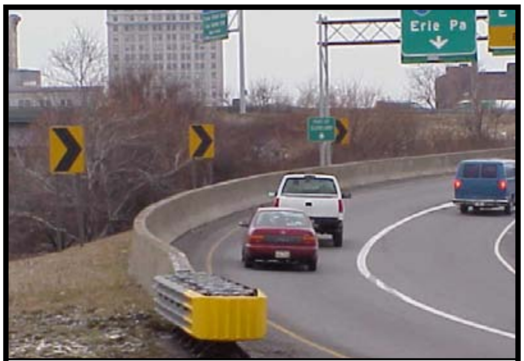


G-R-E-A-T Crash Cushion

One of the most innovative crash cushions is the QuadGuard System Family. The QuadGuard System was developed to meet the United States Federal Highway Administration performance requirements for crash cushions as prescribed in NCHRP 350. This document updated previous testing criteria to reflect current United States vehicle mix, and reflect increased knowledge about crash cushions and road safety.

The QuadGuard CEN System has been successfully completely tested to the European EN-1317-3 criteria for crash cushions for widths from 61 cm (24inches) to 2.3 meters (90 inches) for speeds from 80 km/h to 110 km/h. The test vehicles weighed between 900 kgs. (1,985 pounds) to 1500 kgs. (3,300 pounds).

The QuadGuard System replaces both the G-R-E-A-T System and Hex Foam Sandwich System by providing a single system ranging in width from 61 cm (24inches) to 2.3 meters (90 inches). The range of widths in the QuadGuard greatly reduces the spare parts inventory requirements for road maintenance authorities. The combination of Quad Beam and the monorail base make the QuadGuard System 30% stronger than any previous crash cushion.



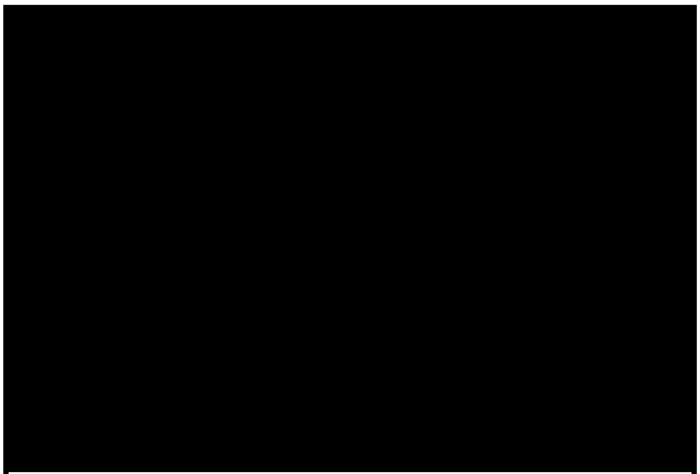
QuadGuard System for narrow hazards

QuadGuard System for wide hazards

The QuadGuard System uses a staged cartridge design to safely decelerate 820-kg (1,800 pounds) cars up to 2,000-kg (4,500 pounds) pickup trucks at speeds up to 113 km/h (70 mph). Sixty to sixty-five percent of the QuadGuard System can typically be reused after a design impact. Repair is simple and typically can be completed on site in less than two hours by a two-man crew.

The QuadGuard System has been tested using the NCHRP 350 criteria at speeds including 70 km/h (43 mph) (TL-2), 100 km/h (62.5 mph) (TL-3) and 113 km/h (70 mph). These tests consist of head-on impacts with lightweight vehicles and pick-up trucks as well as redirective impacts. The fact that the QuadGuard System successfully passed all of the NCHRP 350 tests at 113 km/h (70 mph) is extremely impressive. The innovative monorail provided outstanding redirective capability. The QuadGuard System did not allow vehicles to pass behind the unit when hit on an angle at the nose. This performance is referred to a non-gating. This non-gating capability makes the QuadGuard System ideal for medians, gore areas and roadsides.

Some crash cushion sites are very dangerous for maintenance crews or the crash cushions are hit very often. In these cases, road authorities are looking for crash cushions with greater than 60% + reusability. They are willing to spend more money up front because the crash cushion life cycle cost will justify the additional expense. In the long run, this will prove to be the best use of the taxpayers' money.



REACT 350 reusable crash cushion

A variety of these reusable systems are available including the QuadGuard LMC (Low Maintenance Cartridge) System, QuadGuard ELITE System and the REACT 350 System. Up to ninety-nine percent of these systems can be reused after a design impact. After most, but not all design impacts, these systems partially restore themselves to provide protection during the next impact. Maintenance departments appreciate the long-term value of these reusable crash cushions.

Unfortunately, design engineers and maintenance engineers have separate budgets. The design engineers typically want the cheapest system that meets the standards. The maintenance engineers want systems that will be easy and inexpensive to repair. Both engineering groups must take into consideration site specific information to be sure the crash cushion with the lowest possible life cost is used.

6. CRASH CUSHIONS TODAY

Crash cushions have become a common site on roads in the United States, with over 50,000 systems currently installed. Road authorities require these appurtenances to be tested to meet NCHRP or CEN criteria before they are allowed on the roads. Their insistence on the use of tested and proven crash cushions has resulted in over 30,000 lives being saved and hundreds of thousands of serious injuries prevented on American roads alone since 1969.

Crash cushions are also saving lives on roads in Europe, Asia, South America, the Middle East, Australia and Africa. These crash cushions are performing very well in these countries. One report from England noted that during a 26-month evaluation only one minor injury was experienced at sites where crash cushions had been installed. At these same sites during the seven years before crash cushions were installed, five people had been killed, four people had been subjected to serious injury and seven others had experienced minor injuries due to impacts with these rigid roadside obstacles.

The Annual Report on Highway Safety Improvement Programs published by the FHWA indicates that crash cushions have an 8.0 Benefit-Cost Ratio. These life saving devices not only are effective, they are cost effective.

8. CONCLUSION

Highways will always be dangerous. As long as humans are driving cars, accidents will happen. Since accidents cannot be eliminated, efforts must be made to design the highway so the ultimate results of the accidents are less severe. This would create Forgiving Highways that forgive the driver when he or she makes a mistake while driving.

Crash cushions, crashworthy terminals, crash barriers and breakaway devices are cost effective passive restraint devices that will not stop accidents, but they will reduce the severity of these accidents.

Today most countries with sophisticated highway systems and a desire for safer roads are incorporating these passive restraint devices into their highway design. Their goals continue to be a cost effective means to create "Forgiving Highways." These products are tools that can be, and must be used to reach their goals.

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