

Construction of the Narrow Connecticut Impact-Attenuation System at Five High-Hazard Locations

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In an ongoing effort to develop improved vehicular impact-attenuation devices, the Connecticut Department of Transportation has designed, tested, and installed in the field a new and unique crash cushion known as the Narrow Connecticut Impact-Attenuation System (NCIAS). NCIAS is the third and latest device to be introduced to the family of Connecticut impact attenuators. Like the first truck-mounted device (Connecticut Crash Cushion) and the second wide stationary device (Connecticut Impact-Attenuation System), steel cylinders of various wall thicknesses are used as the energy-absorbing medium in NCIAS. Unlike the first two devices, NCIAS incorporates eight steel cylinders that are arranged and connected in a single row to protect motorists from striking narrow and rigid roadside features, such as bridge piers and blunt ends of concrete longitudinal barriers. The completed system is 3-ft wide \times 24-ft long, which facilitates its use in width-restricted hazard areas. The shop fabrication of NCIAS units and their subsequent construction and installation at five high-hazard expressway locations in Connecticut are described in this paper, the fourth in a series of publications on NCIAS. NCIAS has been approved by FHWA for use as an experimental safety appurtenance on Federal-aid highway projects and has been installed at two locations in Tennessee in addition to the five locations described here. The operational and safety performance of these installations will be monitored for a 3-year field evaluation period.

In a continuing effort to improve the safety of the highway environment, research personnel from the Connecticut Department of Transportation (ConnDOT) have introduced a new and unique vehicular crash cushion, known as the Narrow Connecticut Impact-Attenuation System (NCIAS). NCIAS is the third in a series of cylindrical steel impact-attenuation devices designed by John F. Carney III and developed by ConnDOT in cooperation with FHWA. In the mid-1970s, a mobile, truck-mounted attenuator (TMA), using four steel cylinders as the energy absorbing medium, was crash tested and subsequently used in the field by ConnDOT. This TMA became known as the Connecticut Crash Cushion and is now in widespread use by ConnDOT and other highway agencies for protection of slow-moving and stationary maintenance and construction operations (1).

Using the crushable-steel-cylinder concept, Carney designed a stationary crash cushion consisting of 14 steel cylinders arranged in a wedge-shaped cluster. This design, which became known as the Connecticut Impact-Attenuation Sys-

tem (CIAS), passed a complete crash-test and field-evaluation program conducted by ConnDOT during a 5-year period (2). Because of the outstanding safety performance during the first 2 years of field service, CIAS was designated operational by FHWA in 1986. Since its initial installations in 1984, CIAS has been extremely successful in preventing injuries to occupants of impacting vehicles, regardless of the severity of the accident (3,4).

Because of these favorable results, work began on the development of a crash cushion for use at width-restricted locations (i.e., locations too narrow for installation of CIAS). Based on scale-model impact tests, Carney designed a system of eight steel cylinders arranged in a single row (5). This design was then built to size and subjected to a full-scale crash-test program under the guidelines of NCHRP Report 230 (6). After a few design changes during the test program, the system, NCIAS, successfully satisfied the performance requirements and was subsequently approved by FHWA for field deployment as an experimental crash cushion (7). Both CIAS and NCIAS are eligible for installation on Federal-aid highway projects. In addition, all three Connecticut systems are nonproprietary; any government agency or highway authority can fabricate and use them without restriction. Each has been patented by the state of Connecticut in cooperation with FHWA.

The shop fabrication and field installation of five NCIAS units at high-hazard sites in Connecticut are described here. The objective is to provide a guide to familiarize users with field construction and installation procedures. Because NCIAS is new and unique, state engineers may be hesitant to deploy the system because of the uncertainty of unforeseen construction difficulties. Issued as specific documentation of previously installed units, this paper is intended to encourage the use of NCIAS and to supplement the other development reports. In addition to the five Connecticut sites described herein, two units have also been installed in Tennessee (8). These locations will be closely monitored to evaluate the safety and operational performance of NCIAS under field conditions.

DESCRIPTION OF NCIAS

NCIAS consists of five basic groups of components. Figure 1 shows a plan-view schematic diagram of NCIAS; major components are labeled.

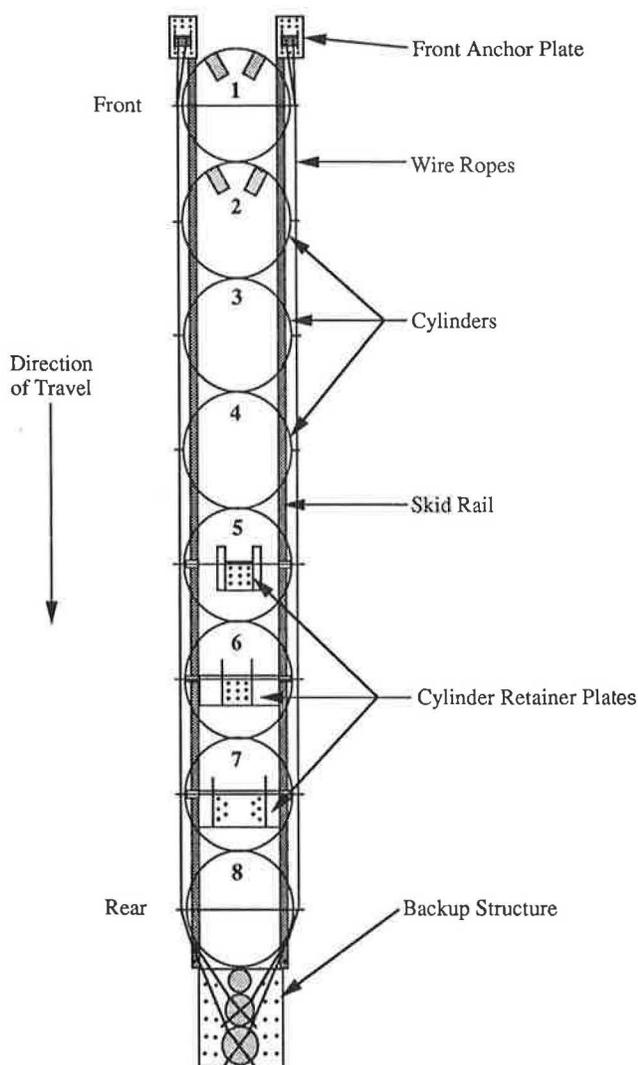


FIGURE 1 NCIAS plan-view schematic.

Concrete Base Pad and Barrier Curb End Treatment

NCIAS must be securely anchored to a sound concrete pad to ensure proper performance. The pad used by ConnDOT is 30 ft long, 10 ft wide, and designed to resist heavy uplifting and overturning loads, which may be incurred during severe side impacts. The pad design used by Tennessee DOT incorporates a concrete block, deadweight approach, which is used with other commercially available crash cushions (8). The design selected for a specific location should be based on the existing site characteristics.

A tapered nose piece (barrier curb end treatment) was constructed to provide a smooth redirecting transition from NCIAS to the protected object. The nose piece is designed to be attached to a standard, single, 24- × 32-in. concrete barrier curb section, but can be connected to other structures, such as bridge piers and parapets. The end treatment can be precast or cast-in-place, depending on site conditions.

Anchored Components

These parts are semipermanently bolted to the base pad with $\frac{7}{8}$ -in. chemically anchored studs and are intended to remain undamaged during a system impact. The following parts are included in this group.

The free-standing backup structure is anchored at the rear of the system and consists of three concrete-filled pipes. It serves as the rear anchorage for the wire ropes and provides a smooth transition between NCIAS and the tapered end treatment.

Two skid rails are positioned parallel to the longitudinal centerline of the system and anchored at each end. They allow the energy-absorbing cylinders to slide freely during the collapsing process.

Three cylinder retainer plates are anchored along the longitudinal centerline of NCIAS; they are positioned in Cylinders 5–7, as shown in Figure 1. They provide lateral stiffness to NCIAS during side impacts, but do not restrict the system's collapse during head-on impacts.

Finally, two front anchor plates, located in the front of the system, serve as the front anchorage for the wire ropes.

Cylinders

Eight steel cylinders are used as the energy-absorbing material in NCIAS. All cylinders are 3 ft in diameter and 4 ft high; they have wall thicknesses ranging from $\frac{1}{8}$ to $\frac{3}{8}$ in. Cylinders 1 and 2 contain box-beam members, which force the cylinders to wrap around and capture the hood of an impacting vehicle. Cylinders 5, 6, and 7 have retainer clips welded to their inside walls; these clips engage with the retainer plates during side impacts. Other internal cylinder components include stiffening pipes inside Cylinders 5, 6, and 7. These pipes also provide lateral rigidity to the system during side impacts, but do not hinder the collapse during a head-on impact. Cylinder 8 contains a combination tension/compression pipe, which provides stiffness to NCIAS under all impact conditions. The cylinders weigh between 200 and 600 lb, and each is numbered on the inside wall with its position in the array. They are connected to each other with two $\frac{7}{8}$ - × 2-in. bolts, and the rear cylinder (Cylinder 8) is attached to the backup structure with four $\frac{7}{8}$ -in. nuts.

Wire Ropes

To control lateral deflection of NCIAS and provide a smooth redirecting response under side-impact conditions, two 1-in.-diameter wire ropes are placed along each side of the system. Each wire rope passes through eyebolts on the sides of Cylinders 1 and 8 and through U-bolts on the sides of Cylinders 2–7. At the front of the assembly, each wire-rope end has a closed-swage-socket fitting for attachment to the front anchor plates, and each end at the rear has a threaded stud fitting for attachment to the backup structure.

Cover

To prevent the buildup of snow, ice, and debris inside the cylinders, a vinyl-coated polyester cover is attached to the top

of the cylinder array. The cover has sewn-on straps, which fold down and attach to the cylinders by means of chrome-plated steel clips and aluminum pop rivets. NCIAS units in snow-free areas need not have a cover, provided that they are checked periodically to ensure that no debris collects in the cylinders.

All fabricated parts are made from standard carbon grade steel in readily available shapes. Current prices for the individual parts are presented in the section on costs.

NCIAS SITE SELECTION

NCIAS is suitable for placement in front of a variety of narrow rigid roadside hazards, such as bridge piers, parapets, and exposed ends of longitudinal concrete barriers. Since NCIAS includes a stand-alone backup structure, it does not rely on other objects for anchorage. The situation ideally suited for deployment of NCIAS is a highway bifurcation divided by a concrete, Jersey-shaped barrier. Tests have shown that when these barrier ends are vertically sloped, the result is an extremely dangerous ramping response when impacted. For this reason, crash cushions are the best protection for these locations. A maximum hazard width of 2 ft is permitted at NCIAS installation sites. If longitudinal space is available, wider hazards can be tapered down to a single 24- × 32-in. barrier curb section. All site appurtenances and their orientation to adjacent travel lanes must conform to AASHTO guides (9,10).

To date, NCIAS has been installed at five hazardous expressway locations in Connecticut. These areas were selected on the basis of their physical suitability for NCIAS and the accident histories of previous crash cushions at these locations. All five sites are in gore areas formed by exit ramps

and mainline expressways where exposed bridge-parapet ends present the rigid hazard. Data for each site are presented in Table 1.

INSTALLATION

Site Preparation

The first step in the NCIAS installation process is to set up a safe and proper work zone around the hazard location. At the five sites discussed here, temporary concrete barriers were placed in a V-shaped array, which enclosed and protected the entire pad excavation area. Pointing toward oncoming traffic, the vertex of the barrier arrangement was shielded with an array of sand modules. These modules were the same ones that previously existed at the sites, except at Site 2, where new ones were required. At Site 2, a Hi-Dro Sandwich System was removed and salvaged for spare parts. In addition to the shielding of personnel in the work area, it is imperative that construction-zone hazards are not introduced to the motoring public.

Pad Construction

Once the sites were prepared for installation, the NCIAS pad location at each was established by first constructing a centerline coinciding with the center of the fixed hazard. The centerline extended upstream from the fixed hazard toward the vertex of the gore area and was equidistant from the two travelway edges. The 10- × 30-ft pad was then placed axi-symmetrically about the centerline with the rear edge oriented toward the hazard end treatment. Once established, the

TABLE 1 Site Information

Site Number	Route and Direction	Milepost	Average Daily Traffic	Exit Number and Direction	Exit Destination	Town	Type of Attenuator Replaced
1	2 Eastbound	5.15	55,800	7 Left	Route 17 Southbound	Glastonbury	Sand Module Barrier
2	I-91 Southbound	0.14	84,900	1 Right	Route 34 Westbound	New Haven	Hi-Dro ® Sandwich System
3	8 Northbound	26.30	43,800	28 Right	Union Street	Naugatuck	Sand Module Barrier
4	I-84 Eastbound	31.85	80,300	19 Right	Route 8 Southbound	Waterbury	Sand Module Barrier
5	I-84 Eastbound	31.92	77,300	20 Left	Route 8 Northbound	Waterbury	Sand Module Barrier

boundaries of the pad were sawn and its area excavated to the proper depth. After the excavation was cleared out and properly compacted, the reinforcing steel cage was placed in conformance with the project plans. The position of the rebars in the top mat was adjusted to be clear of the anticipated locations of the anchor bolt holes. This was done to avoid hitting the steel when drilling the anchor bolt holes in the finished concrete. It was only marginally successful because of difficulty in holding the locations of the rebar to such close tolerances while people were walking on the cage during concrete placement. At Sites 2–4, the mainline and ramp are at different elevations, which created the need for a sloped pad. Because a level surface is desired under crash cushions, these three pads were constructed level under NCIAS and tapered down to the lower elevation on the appropriate side. Once the rebars were placed and positioned correctly, concrete was poured in each excavation, vibrated, and leveled to the surrounding elevations. The pad concrete was then allowed to cure for at least 7 days before it was drilled.

NCIAS Layout on Pad

The anchored components of NCIAS must be properly positioned on the pad to ensure that no gaps are created between the end treatment of the barrier curb and NCIAS. To begin, the backup structure was placed on the pad flush with the end treatment and centered. Using the actual base plate of the backup structure as a template, the 20 anchor-bolt holes were marked on the pad. The locations of the remaining anchored components could then be measured off the pad centerline and the backup structure. The actual components were used as templates for marking the hole locations. For the first installations, the cylinders were placed on the skid rails to ensure that the retainer plates and front anchor plates were in their proper positions relative to the cylinders. The retainer clips that are welded to the inside of Cylinders 5, 6, and 7 must align properly with their respective retainer plates. The front anchor plates must also be positioned properly. Once all anchor-bolt-hole locations were marked out on the pad, all components were removed so the holes could be drilled.

Anchoring of Base Components

The base components of NCIAS are anchored to the pad with $\frac{7}{8}$ -in.-diameter chemically anchored bolts, available from several manufacturers. With the locations marked on the pad, the bolt holes were drilled to the proper depth. The ASTM A325 anchor bolts used at the sites are 12 in. long, so the holes were drilled $9\frac{1}{2}$ to 10 in. deep. An air-powered rotary-impact hammer drill with a 1-in.-diameter bit was used for the holes to provide the best adhesion surface for the anchor resin. Conventional rotary drills are not recommended because concrete powder becomes embedded in the walls of the holes; air-impact drills blow the powder out. When reinforcing steel was encountered during drilling, an impregnated diamond or carbide core bit of the same diameter was required to penetrate through the bar. These water-cooled bits worked well, but required much more drilling time than holes in which

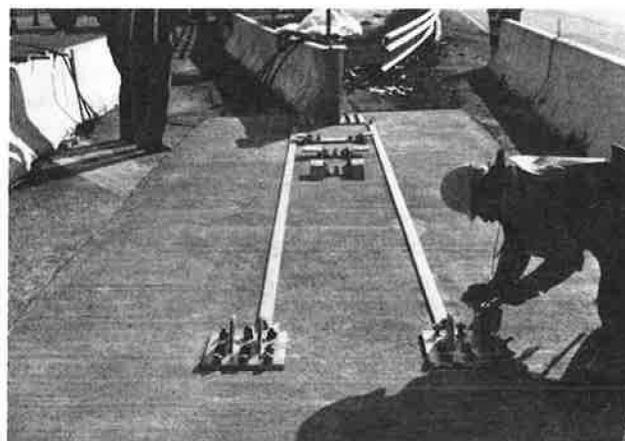


FIGURE 2 Anchored components.

no steel was encountered. For this reason, the rebars should be moved clear of the bolt locations before the concrete pad is poured. On the average for the five sites, steel rebars were struck in about 10 percent of the holes.

Once the holes were drilled to the proper depth, they were blown out with compressed air to remove all dust and debris. The anchor bolt resin was then mixed and poured into the holes in strict conformance with the manufacturer's instructions. The anchored components were left in place to hold the anchor bolts while the resin cured. Most common anchor resins set rapidly, so care must be taken to ensure that each bolt is in its proper position. The resin was allowed to cure overnight; the anchor bolts were then tightened with the anchored components in place. All nuts, with washers, were loaded to a minimum torque of 75 lbf-ft, and 1 of every 10 was proof-loaded to 125 lbf-ft to ensure solid anchorage of the bolts. As with the lugs of car tires, the nuts were tightened in a crisscross pattern to obtain uniform contact pressure between the plates and the pad. The finished pad with all anchored components securely fastened is shown in Figure 2. NCIAS is designed such that the cylinders sustain all the damage to the system when it is struck by a vehicle. The anchored components are intended to remain undamaged through many impacts, depending on the individual site conditions. Because the anchored components are key to the system's performance, they must be thoroughly inspected for damage and loose anchorage after each impact.

System Assembly

The next step in the construction of NCIAS is placement of the energy-absorbing cylinders on the skid rails. The cylinders may be placed individually, in small clusters, or as one cluster. Each cylinder has two lifting rings welded to its inside wall for use with a chain and shackles. For the installations discussed here, all eight cylinders were connected together and placed on the skid rails as a single unit. Once on the skid rails, Cylinders 6 and 7 required maneuvering in order to position their retainer clips properly under the flanges of their respective retainer plates. It is very important that these parts engage correctly for NCIAS to function as intended. Once

the cylinders were in position, all connections were securely tightened, and Cylinder 8 was connected to the bolts on the backup structure and secured there with washers and nuts.

Four high-strength wire ropes are placed along the sides of NCIAS. The wire ropes have fittings on both ends and are made in two different lengths. The longer wire ropes are connected to the inside positions of the front anchor plates, passed through the top set of cylinder eyebolts and U-bolts, and attached to the rear-most pipe of the backup structure. The shorter wire ropes are connected to the outside positions of the front anchor plates, passed through the lower set of cylinder eyebolts and U-bolts, and attached to the middle pipe of the backup structure. The front wire-rope fittings are closed swage sockets for connection to a solid 2-in.-diameter pin supplied with the front anchor plates. The rear fittings are threaded studs, which pass through cross pipes in the backup structure and are tightened with nuts on the back. The wire ropes must be as tight as possible, but the eyebolts on Cylinders 1 and 8 must not be bent.

A cover should be placed on top of NCIAS installations in northern regions where snow and ice may collect in the cylinders. The cover is made of a tough polyester-reinforced vinyl fabric with straps sewn to it. The end of each strap has a steel clip, which is fastened to the cylinders with aluminum pop rivets. These rivets shear under impact, leaving the cover undamaged. The three rear-most cover clips are bolted to Cylinder 8 to prevent the cover from flying away in the event that all rivets are sheared during a severe impact. A detailed, step-by-step assembly procedure that includes the cover attachment and other maintenance requirements is contained in the NCIAS Maintenance Manual (11). Photographs of the completed installations are shown in Figures 3-7.

Exit Signs

The Connecticut NCIAS installations are at exit gore areas, which require exit signs. The standard Connecticut exit sign is supported by two 3-lb/ft U-channel posts. At Sites 3 and 4, the sign posts were embedded into the pavement, straddling a single concrete barrier curb section at the rear of the system

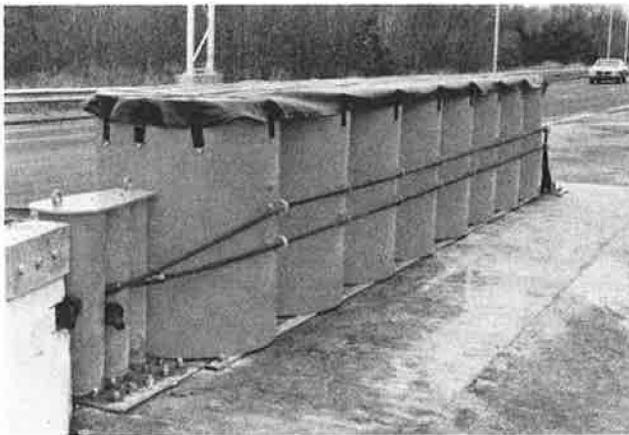


FIGURE 3 Site 1.



FIGURE 4 Site 2.



FIGURE 5 Site 3.



FIGURE 6 Site 4.

(see Figures 5 and 6). Although these posts comply with breakaway standards, it was decided to change the sign supports at these sites in order to prevent them from interfering with the safety performance of NCIAS and the concrete barrier curb. The new configuration uses a narrower exit sign on a single post support that is mounted atop the backup struc-



FIGURE 7 Site 5.

ture with four bolts. In addition to improving safety, the new sign mount may reduce repair efforts because it is less likely to be damaged in the raised position.

COSTS

A major goal of the Connecticut attenuator program is to provide alternative, safety-compliant crash cushions at reduced costs. Because NCIAS and CIAS are nonproprietary and fabricated from readily available materials, they offer the safety performance of modern devices with lower unit costs. For these five installations, the shop fabrication of NCIAS and their installation were completed under separate contracts with ConnDOT. A breakdown of the latest contract prices for fabrication of each complete NCIAS unit and for spare parts is presented in Table 2. The pad construction and NCIAS installation were included as a single bid item in the construction contract.

When compared with other commercially available crash cushions, NCIAS is competitive in a cost-versus-safety analysis. For many years, the sand-module attenuators have offered a convenient, inexpensive method of protecting highway hazards. However, the sand systems do not provide the same level of safety performance as the newer mechanical devices, including NCIAS. In fact, many safety-improvement projects involve replacing sand attenuators with more modern crash cushions. Recent ConnDOT records show that average contractor bid prices for the supply and installation of other high-speed crash cushions have ranged from \$25,000 to \$38,000. Of course, each installation is unique and has different site-preparation requirements. Using the data presented in Table 2, highway agencies can compare the cost of NCIAS with those of other modern devices.

CONCLUSION

By describing the first five NCIAS installations, this paper familiarizes potential users with the methodology required to

TABLE 2 NCIAS Cost Breakdown

Complete NCIAS Unit	\$ 7,280.00
Pad Construction and NCIAS Installation	\$ 10,000.00
Total Installed Cost	\$ 17,280.00
Spare Parts	
Cylinder 1	\$ 610.00
Cylinder 2	\$ 590.00
Cylinder 3	\$ 600.00
Cylinder 4	\$ 600.00
Cylinder 5	\$ 660.00
Cylinder 6	\$ 700.00
Cylinder 7	\$ 730.00
Cylinder 8	\$ 640.00
Retainer Plate for Cylinder 5	\$ 242.00
Retainer Plate for Cylinder 6	\$ 242.00
Retainer Plate for Cylinder 7	\$ 242.00
Front Anchor Plate with Pin	\$ 70.00
Skid Rails	\$ 250.00
Backup Structure	\$ 1,110.00
Wire Rope with End Fittings	\$ 195.00

construct the device to perform as designed. It is extremely important that NCIAS and all roadside safety features be field constructed such that their safety performance at least equals that of the controlled crash tests. This paper is also intended to encourage highway agencies to install NCIAS for the collection of field performance data. As outlined in NCHRP Report 230 (6), field evaluation of experimental safety features is an integral part of the overall development and approval of these devices. On the basis of the installation of the NCIAS units described here, it is concluded that savings in material costs have been realized. Because it is nonproprietary, NCIAS can be purchased through competitive bids for less than other modern devices. Since no major construction problems were encountered, the installation costs for NCIAS are considered to be approximately equal to those of most present-day crash cushions. As the field evaluation progresses, cost figures for the repair of damaged systems, as well as safety-performance benefits, will be included to complete a cost analysis of NCIAS.

RECOMMENDATIONS

NCIAS is currently designated as experimental by the Geometric and Roadside Design Branch of FHWA. All sites are

being closely monitored for a 3-year field evaluation of safety performance, durability, and operational characteristics. To date, none of the installations in Connecticut or Tennessee have been impacted by an errant vehicle. When such an accident occurs, data on occupant injury, vehicle damage, replacement part costs, and required repair labor will be quantified and compared with those of other widely used systems. It is anticipated that NCIAS will achieve operational status when enough field performance data are collected and evaluated. It is recommended that transportation agencies consider using NCIAS at appropriate locations as opportunities arise. Many federally funded, safety improvement projects require the installation of crash cushions for the shielding of unremovable roadside hazards. With its stand-alone backup structure, NCIAS can be anchored in front of many types of narrow expressway gore areas in which a concrete barrier separates the mainline from the exit ramp. Other applications include the shielding of bridge piers in median areas, large-sign supports, median terminals, and bridge abutments. Many of these locations may currently be underprotected and in need of a crash cushion. As use of NCIAS increases, more field performance data can be obtained to complement the research efforts completed to date.

It is also recommended that research continue on the development of additional impact-attenuation devices for protection of hazards not suitable for CIAS or NCIAS. Many exit gore areas contain hazards that are too wide for use of NCIAS and too narrow for use of the CIAS. Work has begun on testing of a family of CIAS designs called the Generalized CIAS. With the use of a computerized design program, a hazard width and design speed can be entered to obtain a suitable cylinder arrangement to accommodate the site conditions (12,13). The extreme designs resulting from the program (small and large length/width ratios) are undergoing full-scale crash tests. If successful, a large variety of CIAS-type crash cushions will be available for use at almost all hazardous gore areas. Since the current safety performance guidelines of NCHRP Report 230 will soon be updated, development of new systems and upgrading of existing ones will be needed to keep pace with increasing safety requirements.

ACKNOWLEDGMENTS

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