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SUMMARY OF CRASH CUSHION EXPERIENCE
IN TEXAS--FOUR HUNDRED COLLISIONS IN SEVEN YEARS ON
ONE HUNDRED THIRTY-FIVE INSTALLATIONS

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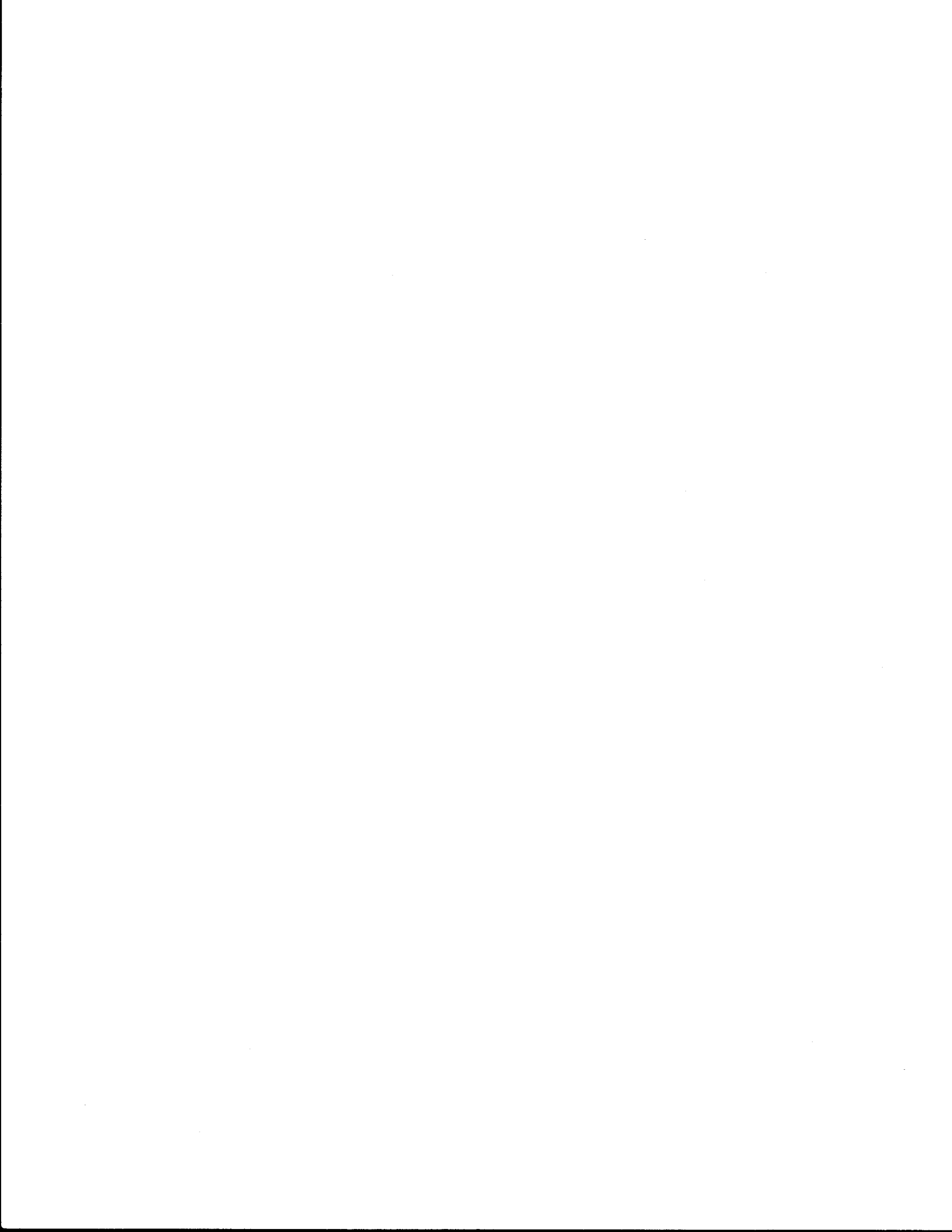
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Crash Tests and Evaluation of Precast Concrete Barrier
and Remedial Measures for Crash Cushions

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ABSTRACT

Steel drum crash cushions (both fixed and portable) and the sand inertia barrier have made and will continue to make important contributions to the safety of our state's and nation's highways. Texas first installed the steel drum crash cushion in October 1968. As of July 1, 1975, 147 crash cushions of all types were in use on Texas highways. These crash cushions have sustained over 400 vehicle impacts since the first installation more than seven years ago.

Researchers from TTI and the State Department of Highway and Public Transportation visited seven districts that had widely used the crash cushions to see if changes or improvements were needed. Discussions were held with traffic engineers, maintenance engineers, foremen and shop supervisors. As a result of these discussions and accident data gathered several changes or improvements were developed which should increase the safety and economy of the devices.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Crash Cushions, Vehicle Impact Attenuation, Highway Safety, Traffic Barriers.

ACKNOWLEDGEMENTS

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SUMMARY

Steel drum crash cushions (both fixed and portable) and the sand inertia barrier have made and will continue to make important contributions to the safety of our state's and nation's highways. Texas first installed the steel drum crash cushion in October 1968. As of July 1, 1975, 147 crash cushions of all types were in use on Texas highways. These crash cushions have sustained over 400 vehicle impacts since the first installation more than seven years ago.

Researchers from TTI and the State Department of Highways and Public Transportation visited seven districts that had widely used the crash cushions to see if changes or improvements were needed. Discussions were held with traffic engineers, maintenance engineers, foremen and shop supervisors. As a result of these discussions and accident data gathered several changes or improvements were developed which should increase the safety and economy of the devices.

1. Elimination of the redirection panels on crash cushions at sites with low probability of angular impacts with the back up system, would improve the safety and reduce the construction and maintenance cost of these devices by one half or more.

2. Elimination of the requirement for using new steel drums would reduce costs further. Salvage and reconditioned drums that do not meet DOT specifications for packaging hazardous materials are satisfactory for crash cushions and cost less than one half as much.

3. The Portable Crash Cushion made of 55-gallon steel drums needs to be redesigned to eliminate fatigue failures and to improve the maneuverability of the system. A modified design is included in the Appendix.

4. Inertia barriers need regular routine inspections to determine if vehicle brush hits, vandalism or deterioration by other forces has adversely affected the modules.

5. Other more detailed recommendations for fabrication, installation, and maintenance of crash cushions were developed which could further reduce the cost of these crash cushions.

IMPLEMENTATION STATEMENT

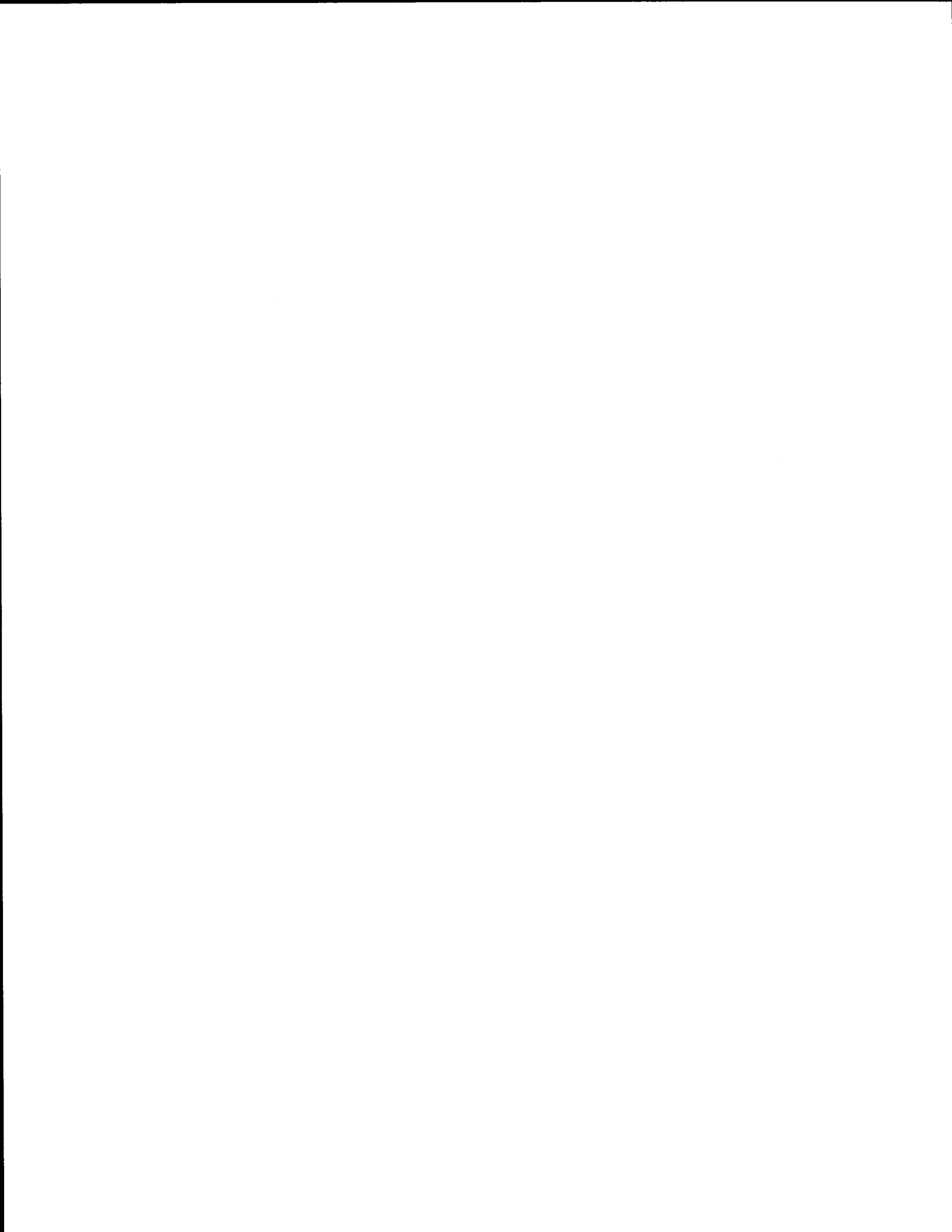
This survey and summary of crash cushion experience gained in Texas has resulted in several recommended changes concerning the design, construction, and maintenance of these devices. These recommended changes should result in increased safety and lower costs for the crash cushions.

As a result of this study, the Federal Highway Administration has approved an SDHPT request to eliminate redirection panels on most of the steel drum crash cushions. In addition, the requirement for using new steel drums has been relaxed permitting the use of salvaged and reconditioned drums. These and other changes are now being incorporated into new state design standards. For more detailed information, contact the Planning and Research Division, State Department of Highways and Public Transportation, Austin, Texas, 78763.

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INTRODUCTION

Steel drum crash cushions (both fixed and portable) and the sand inertia attenuator have made and will continue to make important contributions to the safety of our state's and nation's highways. The steel drum and sand-tire crash cushions called vehicle impact attenuators (VIA's), were developed and implemented through close cooperation between TTI researchers and SDHPT highway engineers. Texas first installed the steel drum crash cushion in October, 1968. A total of 147 VIA's were in use on Texas highways as of July 1, 1975. These VIA's had sustained more than 400 vehicle impacts since the first installations 7 years ago. Both SDHPT engineers and TTI researchers felt that it was time to take a close look at the VIA's in Texas to see if changes or improvements were needed. Various aspects of the crash cushions were considered, such as:

1. Safety of the Motoring Public,
2. Safety to Highway Maintenance Personnel,
3. Initial Costs,
4. Maintenance and Repair Costs,
5. Durability, Reliability, etc; and
6. Overall Cost Effectiveness

Researchers from the State Department of Highways and Public Transportation and from the Texas Transportation Institute traveled to seven district offices of the Texas State Department of Highways and Public Transportation that had had wide experience in the use of VIA's. The researchers discussed these field experiences with traffic engineers, maintenance engineers, maintenance foremen and personnel,

and shop supervisors. As a direct result of these discussions, several improvements are recommended which should increase the safety and economy of the devices.

ACCIDENT EXPERIENCE WITH CRASH CUSHIONS

The first crash cushions in Texas were installed in October, 1968, on the Houston expressway system. According to White, Hirsch, and Ivey (1):

Three concrete abutment gore locations were the scene of eight fatal accidents reported during the period from September, 1965 through October, 1968. Modular Crash Cushions were installed at these three locations as well as at two other gore positions in late October, 1968. Records show there have been thirteen accidents involving these installations through October, 1969, with no serious injuries nor fatalities at any of these sites.

In-service experience with the Modular Crash Cushions at the five reported sites has indicated satisfactory performance. A good example was the most gratifying performance of the crash cushion during a head-on collision at an estimated speed of 70 mph. The vehicle came to a complete stop in approximately 17 feet with an average deceleration of about 9.5 g's. Even though the driver and passenger were not wearing seat belts, their injuries were minor (the driver received a broken nose and the passenger, a broken collarbone).

The in-depth study of the steel drum or Texas Crash Cushions installed in Houston continued until March 12, 1971, when the 50th accident was recorded. At that time, there had been seven crash cushions installed on the Houston urban system. (One of these protecting a T-mounted sign was removed with the removal of the sign.) According to White and Hirsch (2), there were no police records on 31 of the 50 accidents. There were six accidents in which injuries were reported. During this period, there was a single fatality. The lone occupant was driving a 1968 pickup without seat belts and had a blood alcohol content of 0.348 percent immediately after the accident. The fatal impact was a classical head-on at the center of the vehicle and crash cushion. The fatality was not due to any malfunction of the steel drum crash cushion.

On August 31, 1975, District 12 (Houston Urban) had 60 Texas Crash Cushion installations. There had been a total of 306 known impacts in Houston alone with these VIA's since October, 1968. There were injuries in approximately 12% of these accidents and only the one death in 1971. One hundred-seventeen accidents occurred during the year starting September 1, 1974. It is interesting to note that only three of the sixty Texas Crash Cushions or 5% in the Houston area were installed with fish scales or redirection panels along the sides. One of these was impacted in 1974 and the maintenance crews removed the fish scales when it was repaired.

The use of Vehicle Impact Attenuators (VIA's) has increased, so that there were a total of 135 installations throughout the state of Texas at the end of 1974. There were 117 Steel Drum Crash Cushions with the remainder being sand inertia-type barriers. By July, 1975, that number had increased to 147 with forty-nine steel drum type under contract and several inertia systems on order.

A summary of state-wide accident data involving VIA's during the calendar year 1974, is shown in the accompanying Table 1. During this period, there were a total of 180 impacts with 135 VIA's installed. Ten percent or 18 of these occurred in District 2 at ID-35N (NB) and IH-30 (WB). Of this group, there were 73 known impacts on the noses of the attenuators and two known impacts on the side into the fish scales or redirection panels. Of the two known side impacts on fish scales, one resulted in the only fatality of a vehicle occupant in 1974 and only the second VIA fatality since 1968. The single death in 1974 occurred in District 2 at the intersection mentioned above. In the second side

TABLE 1. SUMMARY OF ACCIDENT DATA WITH
VEHICLE IMPACT ATTENUATORS IN TEXAS.* 1974

	<u>Number of Installations</u>	<u>Impacts</u>	<u>Fatalities</u>	<u>Reported Injuries</u>	<u>Reported Property Damages</u>
Texas Crash Cushion Steel Drums	117 (60 in Houston)	160 (81 in Houston)	1**	25 (10 in Houston)	96
Fitch Inertia Barrier	14	13	0	7	4
Sand Tire Inertia Barrier	4	1	0	0	1
Totals	<u>135</u>	<u>180</u>	<u>1</u>	<u>32</u>	<u>103</u>

*Courtesy of the State Department of Highways and
Public Transportation, File D-18.

**Fatality resulted from angle impact into side of
steel barrel VIA with redirection panels. Vehicle
was redirected and struck concrete parapet wall on
both sides of the highway then overturned.

angle impact there was more than \$2000 damage done to the vehicle. Both of the passengers were injured but were treated and released from the local hospital. Of the more than 400 impacts since the installation of the first VIA in 1968, there have been 151 known impacts on the noses of VIA's and 16 impacts into the side.

The Department of Public Safety accident reports are not immediately available and the impact areas of the remaining impacts are in question.

The one death in 1974 was the second death in VIA history in Texas. The accident occurred in downtown Fort Worth on the IH30-IH35 interchange. The vehicle involved approached a 30 mph (48kph) exit ramp on an elevated gore at a high rate of speed. The driver impacted the side of the Texas Crash Cushion near the nose on the redirection panels. The vehicle was redirected into the parapet rail on the sharp curve in a severe secondary impact; the vehicle then ricocheted across the roadway and hit the opposite parapet rail where the vehicle overturned. The driver was dead at the scene.

These data indicate that there are few, if any, severe angle impacts at the rear of the crash cushions. In Houston, where over 95% of the steel drum crash cushions do not have redirection panels, there have been no severe impacts into the rear corner in over 306 collisions.

The addition of redirection panels apparently increases the severity of all vehicle collisions with crash cushions. In Houston, where 95% of the crash cushions do not have redirection panels, the injury rate per accident is 12%. In the rest of the state where approximately 33% of the crash cushions have redirection panels, the injury rate is 19%. This conclusion is not surprising in view of the fundamental mechanics involved. The addition of fish scales to the steel drum crash cushion increases the mass and stiffness of the barrier, both of which will cause higher deceleration forces on an impacting vehicle.

The purpose of redirection panels was to prevent the serious or fatal injury anticipated by angular vehicle impacts near the rear of the crash cushion and into the hard back up system. The accident experience just cited has indicated that the frequency of this type impact is very low on most installations. Since redirection panels can possibly inhibit attenuator performance, it is recommended that they be used only at locations where a high frequency of angular impacts with the back up system is likely to occur.

TEXAS CRASH CUSHION (STEEL DRUM)

Design Types

Currently two basic types of steel barrel crash cushions are used in Texas, i.e. those without redirection panels and those with redirection panels. The first steel drum systems without redirection panels were fabricated and installed in October 1968 by highway maintenance forces. Excluding site preparation costs, these units were installed for about \$500 to \$600 each. In recent years the steel drum crash cushion design was modified to include redirection panels and they have been included as an item of construction in highway improvement projects. In 1974 and 1975 contract costs for these assemblies have averaged \$5,600. The huge increase in costs is attributed to use of new materials in construction, the addition of redirection panels, and inflation.

Current Construction Procedures

Currently, with special permission, three contractual arrangements can be utilized to fabricate and install the Texas Crash Cushion. They may be fabricated and installed by a general contractor as part of a larger contract; they may be fabricated and installed by a speciality contractor dealing directly with the district; or they may be fabricated and installed by district SDHPT personnel. Units installed by the contracting sector are fabricated from new 55-gallon (208-liter) 20 gage tighthead steel drums. Holes, as specified by the plans and specifications, are cut into the tops and bottoms prior to the application of a protective coating. The steel drums are welded together in their locations and fish scales, if required, are attached. The assembled crash cushion is then hauled to the site and installed. This is normally accomplished prior to opening the section of roadway containing the crash cushion to traffic.

Crash cushions are also installed on active roadways to protect elevated gores, T-mount signs, area light standards and other fixed hazards. At these installations, site modifications are frequently necessary and usually expensive. The required modifications may include the deletion of curbs, the modification of bridge parapets to provide adequate area for the crash cushion or the provision of a back-up structure to list a few.

State personnel are sometimes utilized by the State of Texas to fabricate and install crash cushions at new sites. State personnel, from the SDHPT District involved, are almost always utilized to repair or replace damaged crash cushions at existing sites. District personnel have the option of using new or used materials. These options are in conjunction with the steel drums and fish scales.

New Steel Drums. The new drums are 55 gallon (208 liter) 20 gage tighthead drums with the specified holes cut in the tops and bottoms by the manufacturer prior to the first application of the protective coating. The holes, according to the "Highway Design Division Operations and Procedures Manual" (3), are 7 in. in diameter and located in the center of the top and bottom of the drum. These new drums are now costing about \$11.87 each.

Used Steel Drums. Used steel drums are those which contained paint, solvent or other liquids purchased in quantity by the SDHPT. They are also 55-gallon capacity (208 liter) and usually conform to either TCC Spec 17E tighthead drums or 17H drums with a removable cover. These drums are then modified according to "Administrative

Circular No. 131-170" (4). The required holes are cut in the tops and bottoms with acetylene torches, commercial reciprocating metal shears or special cutting tools. (See Appendix for Research Reporter No. 18-75" of the Texas State Department of Highways and Public Transportation.) The cost of these drums has been included in the cost of the original material purchased and their use does not represent a cash flow to the Districts. Such salvaged drums can be modified for VIA use for about \$1.00 each. Commercially available reconditioned drums can be purchased for about \$5.50 each.

Redirection Panels. The so-called "fish scales" or side redirection panels may be fabricated from old sign boards or new plywood sheets. The panels are cut to size and installed with or without a steel sheet metal covering. The metal covering is constructed of 26 gage steel sheets precoated with enamel or galvanized. Galvanized sheets are usually painted prior to final installation.

Fabrication and Installation. Prior to the initial installation of a Texas Crash Cushion, the site must be investigated and if necessary, modified. Modifications may include the removal of small obstructions such as curbs or guard posts, the addition of a back-up structure, rebuilding a gore structure to provide adequate room for the installation of cable anchors at the nose and paving to provide a hard surface at the site. For existing sites, the preparation may be extensive even requiring major structural modifications. In these instances the site modification costs may be more than the remaining costs associated with the crash cushion fabrication and installation.

The components such as steel drums, fish scales, cables, etc., are usually stockpiled and used as needed. Prefabrication may include a complete crash cushion for a new installation or replacement; or it may include only a smaller module or cluster for partial replacement or for easier handling. There may be as much or as little prefabrication as may be required by design requirements or site conditions.

Commercial fabricators and SDHPT district shop personnel alike will normally prefabricate a complete unit for a new installation. Highway personnel will usually prefabricate a complete unit when it is necessary to replace the entire crash cushion. These complete units are then loaded on a float or low-boy and hauled to the site.

District 14 (Austin) threads the cables in the crash cushion during prefabrication. Turnbuckles are installed at the rear of the crash cushion. The distance from the cable attachment on the back-up wall to the attachment to the deck are predetermined or known and the cables are precut to length so that they may be readily attached in the field. They are tightened by the turnbuckles. The turnbuckle also allows for field adjustments required periodically due to seasonal temperature changes or creep in the materials. All nine units in District 14 are of the same design and field installations vary only slightly making the quick attachment turnbuckle concept very practical. The district also stockpiles complete prefabricated crash cushions and replaces the entire crash cushion rather than portions regardless of the severity of damage to the crash cushion after an impact.

Maintenance and Repair. Districts 2 and 12 repair their crash cushions by replacing only those drums which have been damaged. This process usually entails prefabricating a replacement section, transporting it to the

site, removing the damaged section from the crash cushion and replacing it with new drums or the prefabricated section. The cables would then be tightened, any desired cosmetic treatment would be applied and the site cleaned up. One minor disadvantage of this process is, that the interior bottom welds are omitted between prefabricated sections or around individual drums when they are attached to the undamaged section.

Fewer drums are needed which, in the case of District 12, will mean a lower cash outlay since they use only new drums. In addition, the maintenance crews do not have a trailer and hoist which would accommodate the weight of a complete unit without requiring additional lane blockage.

Repairing a damaged unit can take more time and be more hazardous than replacing an entire crash cushion. For this reason, District 14 will replace the entire crash cushion rather than repair it. The damaged unit is scalped for reuseable parts such as cables, clamps, turnbuckles, nuts and bolts and the drums sold for scrap. It should be noted that this district uses only salvaged paint drums. It has nine Texas Crash Cushions installed and reported two impacts in 1974. The paint drums do not require a cash outlay. The drums may be modified and a spare crash cushion fabricated during slack periods.

The first step in replacing a whole Crash Cushion is of course traffic rerouting and then to remove the damaged or destroyed unit. After this has been done, the procedure is the same as a new installation after the site has been modified. The crash cushion is loaded on a flatbed truck and hauled to the site; the crash cushion is set in place by a crane or other

lifting device; the cables are fastened to the back-up structure and nose anchors and tightened; and the damaged crash cushion is loaded on the float and hauled to the junkyard.

Traffic Control During Installation or Repair. Construction crews and their equipment while installing, replacing or repairing a Texas Crash Cushion or other vehicle impact attenuation device, will occupy the space of the crash cushion and probably one or more traffic lanes of the travel-way. Precautions must be taken to protect the construction crews, equipment, and traveling public. A portable crash cushion is an excellent means for providing such protection. The extent of the precautions will depend on such variables as the travel-way geometry, the time of day, the weather and the traffic. Crash cushions are placed at locations where the Average Daily Traffic (ADT) may be as low as 5,000 and at locations where the ADT approaches 200,000.

District 12 has several crash cushions at locations where the ADT is in excess of 100,000 and a few where the ADT on selective days is over 200,000. They repair the crash cushions between the hours of 9 AM and 3 PM on weekdays. The average time spent repairing an installation is 6 hours. Three hours of that are spent in rerouting traffic with equal times required to close down a lane and reopen the lane.

District 15 (San Antonio) repairs expressway installations during the early morning hours between midnight and 6:00 AM. Their personnel feel that repairs of all kinds are made quicker, safer and therefore less expensive. They point out that it is necessary to have a full week's work for a crew which is going to be put on the "graveyard shift". One reason for the savings in time and the safety of early morning work is

that the traffic is noticeably reduced or even non-existent when compared to the other 18 hours of the day.

Recommended Construction Procedures.

All of the techniques being utilized by the districts represent sound construction practices. There are several areas in which some improvements and economy can be obtained. These areas are discussed in the following paragraphs.

Steel Drums. The 55-gallon (208 liter steel drum with 20 gage body and top and bottom was initially developed as a standard for crash cushions. Its continued use is still recommended. However, there are available reconditioned 55-gallon (208 liter) steel drums constructed of 16, 18 and 20 gage steel in various combinations depending on intended usage. There are stockpiles of these steel drums in certain areas of the state which have been rejected by DOT as containers. These drums however would be acceptable for use in crash cushions. The rejected 55-gallon (208 liter) steel drums constructed to specifications 17E and 17H with 18 gage tops and bottoms could be used in lieu of the standard 20 gage steel drums provided the holes in the tops and bottoms are sized properly (2, 3, 11, 12). Reconditioned reject drums of this type are presently priced at about \$55.50 each compared to about \$11.57 each for new 20 gage drums. When "non-standard" drums are used, care should be taken to assure that drums of equivalent stiffness and energy absorbing capability are used.

The continued use of salvaged steel drums which formerly contained paint, etc. used by the district should be encouraged to use waste materials and to reduce costs. The required modifications such as

cutting holes in the tops and bottoms should be done by flameless techniques such as with the "nibbler" (an electric hand held metal shear) or by a cutting tool similar to the one developed by District 18 shop personnel (both previously discussed).

Redirection Panels. Redirection panels have proven to be expensive and can inhibit attenuator performance under head-on impacts. They are expensive to fabricate generally costing more than the steel drums and all other materials used in the attenuators. Their use requires heavier anchor cables, strong floating steel support posts, considerable amounts of fasteners, and more complex and costly installation procedures. An average Texas Crash Cushion as currently designed requires 28 panels (2 ft x 4 ft) with 112 bolts. All of these and other extra parts are expensive to purchase and to install. In addition, the exposure time of construction and maintenance crews is increased by the use of redirection panels. A Houston fabricator (13) who fabricated and installed 49 units recently on Loop 635 in Dallas County stated that, based on his cost accounting records, his costs would be reduced by approximately one-half if redirection panels were deleted. His average cost per crash cushion was about \$5,600 each.

Experience has shown that redirection panels have no effect on reducing fatal injuries and that side hits for which they were designed are less frequent than nose hits. Also, a greater number of sites can be protected with attenuators with funds available if redirection panels are kept to a minimum. Therefore, it is recommended that redirection panels be used only at locations where a high frequency of angular impacts with the back-up system is likely to occur.

Design. At locations where it has been determined that redirection panels can be deleted, additional changes can be made in the design of a crash cushion. Cable sizes and hardware may be reduced, the requirement for straight sides is relaxed and the necessity for strong support legs or posts is eliminated. Several new designs have been developed and are detailed in Appendix B. These designs are based on a 12 g's average deceleration for a 2250 lb (1020 kgf) vehicle impacting the nose of the VIA at 60 mph (96.5 km/hr) (5) and they are designed in modules. That is, sections may be prefabricated in advance of need and stockpiled. Then, as needed, modules can be drawn from the storage area and used to replace damaged portions of an impacted VIA.

Fabrication. Most items previously discussed under "Current Construction Procedures" are sound and economical. The researchers are of the opinion that most districts are using ineffective procedures for cutting the holes in the tops and bottoms of the drums. A central cutting shop in each District using a cutting tool similar to the one developed by District 18 would be more effective, economical, and safer.

The jig concept for laying out standardized attenuator designs developed by District 2 should be extended by making the included angle between the sides adjustable. An adjustable jig would call for the accurate location of any drum in any VIA in a district provided that the VIA had straight sides. For complicated drum arrangements, the outline could be painted on a hardboard backing or chalk lined on a concrete floor.

Traffic Control During Installation or Repair. Safety is of prime concern during all work particularly adjacent to an active highway system. In order to insure the safest working conditions an adequate warning system is essential. Before starting to install, replace or repair a VIA, warning devices should be set up well in advance of the work and continue to and beyond the work site. Closing one or more traffic lanes and/or gore exits may take considerable time. The warning system used should employ the latest technology. The system should include some device such as a lighted arrow, flashing lights, sequential lights, or portable crash cushion or a combination of these items set up, up-stream from the repair site. These special devices should be in addition to the usual traffic cones, and arrows or other temporary delineation objects.

Timing should be an important consideration. The prevalent time is after the early morning rush hours and before the "five o'clock rush". District 15 in San Antonio likes to repair their crash cushions after midnight and before 5 AM. At this time traffic is the lightest. One should keep in mind, however, that many of our high speed impacts with attenuators and fixed objects near the freeway frequently occur during the early morning hours.

PORTABLE CRASH CUSHION

The original portable crash cushion, called the Texas Crash Cushion Trailer, used in the state of Texas was developed by TTI researchers under the Cooperative Research Program with the State Department of Highways and Public Transportation. It was a part of Research Study No. 2-8-68-146 and the testing, design and details were reported in Research Report 146-6 (6). Thirteen Texas Crash Cushion Trailers have been fabricated for use by ten of the SDHPT Districts. Some of the Districts use their trailer regularly, particularly on interstate maintenance and repair work. Other Districts used their trailer until the welds at the tops of the steel drums broke due to fatigue and then they parked or abandoned the unit.

There have been three accidents reported involving the crash cushion trailer in the state. In each of these, the device was credited with saving the lives of some or all of the maintenance crew being protected. A District 17 maintenance crew from Huntsville area was repairing a portion of I-45. The lane was closed and delineated with a long row of plastic cones, direction arrows and signs. A truck went through the cone delineators, impacted the crash cushion trailer, was slowed and deflected to the left. The maintenance crew and the District Engineer credit the crash cushion trailer with saving the lives of one or more of the crew.

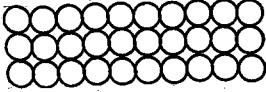
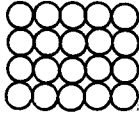
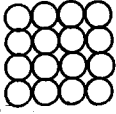
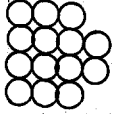
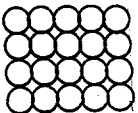
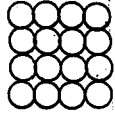
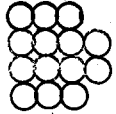
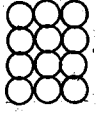
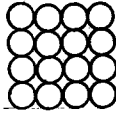
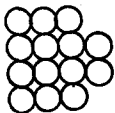
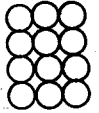

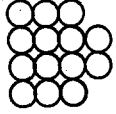
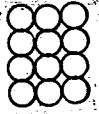


Most of the personnel agree that the portable crash cushion is basically a good idea and that it will save lives. Also, most of the personnel of the SDHPT interviewed feel that there is room for improvement. A primary concern is that it is too long and consequently offers a much larger target than necessary. As designed, it will effectively lengthen

a dump truck or other towing vehicle approximately 23 ft (7.0 m). Adding a 23 ft (7.0 m) trailer to a vehicle makes the units very difficult to maneuver. When the connection to the towing vehicle is made rigid, maneuvering difficulties are compounded. Most of the SDHPT personnel interviewed felt that a portable crash cushion should be more compact and be easier to attach and detach from the towing vehicle. Also they felt that a portable crash cushion should be adaptable for use on several different trucks or vehicles of the 10,000 lb (4536 kg) class.

A Portable Crash Cushion (PCC) needs to be effective under many traffic conditions. On an open rural section of the interstate system, a substantial number of vehicles may be traveling at a speed of 60 mph (96.5 km/h). On the urban sections with more traffic congestion and maneuvering, the traffic will be more nearly traveling at or below the national speed limit of 55 mph (88.4 km/h), particularly in the vicinity of maintenance operations. The traffic in some areas may be slowed to 45 mph (77.4 km/h) or less. Next, the portable crash cushion may be stationary, such as would be required when protecting crews repairing a fixed object; or it may be protecting a moveable object such as a pavement stripping machine or a street sweeper. The portable crash cushion would then be traveling at the speed of the object being protected. These travel speeds range up to 15 mph (24.1 km/h). Portable crash cushion configurations have been developed for combinations of vehicle speeds varying from 45 mph (72.4 km/h) to 60 mph (96.5 km/h) in 5 mph (8.0 km/h) increments and for truck speeds varying from zero to 15 mph (24.1 km/h) in 5 mph (8.0 km/h) increments. Design methods presented in Research Report 146-6 (6) were used to develop the configurations. White and Hirsch (2) demonstrated that steel drums with an average 6,000 lb (4380 kg) static crush strength could be compressed 21 in. A dynamic

load factor of 1.5 and the 21 in. crush distance per drum means that each drum will absorb 15,750 ft-lb (21,354 N m) per drum. This value is used to determine the number of steel drums required for each condition. Figure D1 in Appendix D indicates that the dynamic load factor which compares the dynamic energy absorbed by a steel drum to the static energy absorbed is still approximately 1.5 at 21 in. of crush. The truck was assumed to weigh 10,000 lb (4536 kg) in each calculation. Suggested configurations with the average deceleration forces for each condition are shown in Table 2. Fifteen of the 16 configurations are considerably more compact than the original trailer. The 16th suggested configuration for a vehicle impacting a truck at 60 mph (96.5 km/h) remains the same as the original design. The designs show a reduction of a minimum 10 ft (3.05 m) based on the length of the drums. The towing and trailer attachment for the original design took approximately 3 ft (0.91 m). A design that will hook on the tailgate of a dump truck and then attach to the frame in two places similar to a "three point" tractor hook-up is developed in Appendix C. The hooks are first adjusted to the height that will raise the portable crash cushion a predetermined distance off the ground, e.g., 6 in. (15.24 cm). The truck bed is raised to "dump position", the truck backed up to the uprights and the truck bed lowered. (Note, raising the truck bed to dump will lower the tailgate sufficiently to clear under the hooks.) The two ball joints are attached to the truck frame to studs welded to the main structural member. The arms are then adjusted to level the portable crash cushion. This design is a maximum of 10 ft (3.05 m) long or only 43% as long as the trailer. For impact velocities less than 55 mph (88.5 km/h), the length may be reduced even more.

TABLE 2
PORTABLE CRASH CUSHION
CONFIGURATIONS

	Truck Velocity mph (kph) ←	Impacting Automobile Velocity V_o (mph ←)			
		60 (96.5)	55 (88.4)	50 (80.5)	45 (72.4)
No. bbl's req'd. Suggested Configuration Avg. G's 4500#(2040 kg)Veh 2250#(1020 kg)Veh	Stationary	30  6 12	20  8 16	16  8 16	14  7 14
No. bbl's req'd. Suggested Configuration Avg. G's 4500#(2040 kg)Veh 2250#(1020 kg)Veh	5 (8.0)	20  7.2 14.3	16  7.1 14.2	14  6.2 12.4	12  7.0 14.1
No. bbl's req'd. Suggested Configuration Avg. G's 4500#(2040 kg)Veh 2250#(1020 kg)Veh	10 (16.0)	16  6.4 12.8	14  5.5 11.0	12  6.3 12.7	8  4.5 9.0
No. bbl's req'd. Suggested Configuration Avg. G's 4500#(2040 kg)Veh 2250#(1020 kg)Veh	15 (24.1)	14  5.0 10.0	12  5.5 11.0	8  5.6 11.0	6  3.8 7.0

INERTIA BARRIERS

There are three basic types of inertia barriers in use in the state. They are the tire-sand inertia barriers, the Fitch inertia barrier and the Energite inertia barrier. The tire-sand barrier is constructed from readily available scrap materials, primarily salvaged automobile tires, plywood and fence wire. The Fitch and Energite barriers are proprietary and are manufactured from polyethylene and polystyrene. All use sand for mass to slow impacting vehicles. Specific comments from field personnel about these are found in Appendix A. Most district representatives interviewed feel that there is a definite place for the inertia barrier in the state system. For instance, inertia barriers are very useful in the protection of T-mount signs in surface gores, median barrier ends and rigid sign supports in medians. There is also a general feeling that the inertia barrier is an excellent device for temporary installations during construction. The primary complaint about the systems concerns vandalism. Several Fitch units have been slashed by knives and several sand-tire units have been turned over. A secondary complaint concerns the debris that is scattered over a sizeable area. The debris scatter makes the inertia systems unsuitable for use on elevated structures crossing over traffic areas below.

The various components of the proprietary systems are fabricated from polymerized hydrocarbon plastics. The components exposed to weather are predominantly polyethylene although polypropylene has also been considered (7). Both of these materials are adversely affected by sunlight or ultraviolet rays (8). Sunlight will after a time cause a general weakening of the material eventually causing the component to separate. This process may take a few months or it may take two or three years depending on the exposure

and pressure of sand in the unit. There are methods available to increase the life of these polymers such as adding carbon black in the plastic as a filler or even using a neutral coating. Field experience in both Districts 12 and 18 indicate that these module containers tend to split or fail prematurely and brush hits can render an instant and hazardous reduction in attenuation capacity.

The tire-sand barrier is the least expensive of all of the vehicle impact attenuators. The testing program (9, 10) results indicate that this system is equally as effective as the other inertia systems provided that a proper base is used. The preferred base is made from 1 in. x 2 in. 14 gage galvanized steel wire fence as detailed in the Highway Design Division Operations and Procedures Manual (3).

CONCLUSIONS

These conclusions and recommendations are based on the results of the interviews with SDHPT personnel and the data heretofore presented and discussed. Safety is a prime criterion for all recommendations. The cost factor, while important, is secondary. All of the personnel interviewed agreed that VIA's have made and will continue to make important contributions to the safety of our state's and nation's highways. The predominate VIA's in use in Texas were found to be the Barrel or Texas Crash Cushion, the Portable (trailer) Crash Cushion and the sand inertia impact attenuator.

The Texas Crash Cushion. The major recommendation of the field personnel and the researchers is to eliminate the strict requirement for redirection panels. The available data indicate that these panels can inhibit the performance of the crash cushion in head-on impacts. Secondly, the panels are very expensive comprising approximately half of the total cost of a Barrel Crash Cushion. Deleting the redirection panel requirement at most locations where accident data indicates low probability of angular impacts will result in a safer and less expensive installation.

The other recommendations involve maintaining the same safety at a somewhat reduced cost. They are:

- (1) Allow the use of steel drums which have been rejected for use as containers for hazardous materials by DOT and
- (2) Allow the use of salvage steel drums such as paint containers which are common in all SDHPT Districts.

The Portable Crash Cushion. All personnel interviewed felt that the Portable Crash Cushion should be redesigned so that it could be more maneuverable and easier to attach to the truck being protected. The designs shown in Table 2 and Appendix C should accomplish these recommendations.

Inertia Barrier. The personnel interviewed believe that the inertia barrier is useful in selected locations. These recommendations do not include areas such as elevated structures where flying debris would disrupt the traffic on a lower level.

The exterior covering of the two proprietary sand inertia barriers is molded from polyethylene. This and many other polymerized hydrocarbon synthetics deteriorate in direct sunlight making regular inspections of installation necessary.

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13. George W Combs. President and Owner of Combs Industrial Company, Inc., Houston, Texas. Discussion with, June 1975.

APPENDIX A

NOTES ON THE USE OF
VARIOUS VEHICLE IMPACT ATTENUATORS
IN SELECTED DISTRICTS IN
THE SDHPT OF TEXAS

SUBJECT: Project 2-10-75-223 - Field Experience and Evaluation of Attenuator Systems and Portable Crash Cushions Utilized by the Department.

GENERAL:

As an objective of the above research project, Dr. T. J. Hirsch, Dr. Eugene Marquis, Dave Hustace and John Nixon visited District 12, Houston Urban Office and Combs Industrial Company (prefabricator of barrel crash cushions), Houston, Texas. Excluding Dr. T. J. Hirsch, the three also visited District 14, District 15, District 9, District 2 and District 18. The purpose of these visits was to obtain firsthand experience from the field in the usage of the various attenuation devices, problems, suggestions and evaluation such that revised plans could be formulated to make such systems more economical, practical, safe, efficient and easy to maintain.

Information was secured from the Districts on each of the devices as follows:

1. TEXAS CRASH CUSHION TRAILER

District 12 - Have used system for about six months behind sweepers but jiggle bars caused welds to fail. They have abandoned its usage after several repairs - might be useful if it were more maneuverable and was more substantial.

District 14 - District has a trailer but have not used it to date. Objections to its use are: they can't turn it around, length is prohibitive, requires a storage area when not in use and may not be practical in urban areas. They have had three instances in past where people have run into back of trucks used for various purposes. They do have

a truck protecting workmen on maintenance, striping and sweeping. They suggested different designs for different purposes. However, on striping of two-lane highways, head-on collisions are also possible and no protection is provided by a crash cushion trailer. They did think it might be useful to study where the crash cushion trailer would be advantageous and where it wouldn't.

District 15 - They work on downtown sections at night with maintenance forces. Because of lack of maneuverability of crash cushion trailer, they have never acquired one. They have had three or four instances in which equipment has been hit in the rear. They have considered using Hi-dro cushions attached to rear of trucks. The crash cushion is too big, too hard to see as they do striping at night and move 10-15 mph. They prefer the use of sequential lights mounted on trailer as standard procedure. They had one truck hit and truck bed slid into cab injuring driver. They desired a 4' to 6' Hydrocell device. Sequential lights are considered very good and accidents have been virtually eliminated through their use. They do not want a dump truck to be tied up entirely for the purpose of hauling a portable crash cushion.

District 9 - Do not have a crash cushion trailer. Traffic volume is not great enough. They barricade off their work areas and flag traffic. The striping machine has been

hit several times in the rear. They have had a herbicide truck hit two or three times. Sign trailers are provided on which they haul all signs. They might consider a trailer if it could be used as a combination vehicle, also for heavier volume traffic behind sweeper, center stripe, etc. They thought it should be designed for a lower speed as braking could occur and traffic should not be this fast in urban areas.

District 2 - Don't have one because of maneuverability problems. They use sequential arrows costing \$4800 each which have virtually eliminated rear end collisions. They might use an improved version of a trailer for sweeper, striping and combined usage.

District 18 - Don't have a crash cushion trailer as it is too bulky for heavy traffic. They feel that sequential arrows work best.

2. TEXAS BARREL CRASH CUSHION

District 12 - A. It is preferred to weld all barrels together but have considered using clips costing \$1.00 each in lieu of welds when welder is busy. When field repair is performed, barrels are welded together on all tops and only the outside bottoms as they can't get to all the interior spots.

B. They cut the crushed attenuator apart with a torch and pull apart when repairing.

C. They utilize clusters of 12-15 barrels, so four or five people can lift by hand to eliminate need for a

hoist on job.

- D. Sometimes they haul the complete attenuator to the site on a low bed trailer.
- E. They have trouble getting the 1" cable out of crushed attenuator sometimes.
- F. The repair generally takes six hours. Three hours is required to detour traffic.
- G. They do not use Styrofoam behind cables anymore.
- H. They have 1,000 barrels in stock now for replacement. By using rejected barrels not meeting specifications for fuel shipping, they received a bid of \$5.50 each.
- I. The average repair cost runs \$650 - \$800.
- J. The earlier costs for barrel installations including breaking back walls and filling in bridge decks was \$3,400.
- K. Present installations cost about \$1,000 each.
- L. They use old paint barrels for OMB markers.
- M. They use two-strap banding to hold units together in modules.
- N. Their collection rate for damaged crash cushions from known drivers is about 15%.

They recommend:

1. Use of smaller cables.
2. Standardization of barrel geometry to enable pre-fabrication.
3. End treatment that will require no maintenance.

4. Suggest eliminating jiggle bars since tire tracks indicate that vehicles lose traction which would cause skidding.
5. They are not sure of clips as they can be dislodged when hit with hammer.
6. May have rusting problem with barrels.
7. Do not use paint barrels because of fumes, smoking when cutting with torch. High price salvage barrels makes new ones more economical.
8. They like barrel attenuators as repair is not required immediately.
9. Fish scales are too difficult to repair although they have little experience with replacement. When this type attenuator needs significant repairs, they are replacing it without the redirection panels.
 - (a) They recommend elimination of fish scales as they are more costly, exposure time to repair is increased, too costly to maintain and may not want redirected vehicle back into traffic stream. Past accidents do not indicate fish scales are needed. Contractors do not like fish scales. Also, we design a soft cushion and then put scales on it making it harder and redirecting vehicles into the stream of adjacent traffic. They prefer to catch the vehicle in a soft cushion.
 - (b) Several smaller cables - 5/8" are preferable to large 1" cable.

Houston Urban

- (c) Aluminum skin is considered unnecessary.
- (d) Noses are painted black and yellow on aluminum sheeting. Elimination of single nose barrel eases installation of sheeting.
- (e) Trouble areas should be conspicuous by flood lighting, marking, etc.
- (f) Rusting may be a problem at SH-225 and IH-610.

Combs Industrial Company - Houston

- (a) Floating posts are expensive and troublesome.
- (b) Panels have too many bolts and handwork, and specifications are too strict. Had to repaint after shipping to site.
- (c) They weld as whole assembly.
- (d) Galvanized cables are used, two on each side.
- (e) Aluminum nose is used.
- (f) Chairs are welded to rebar.
- (g) Attenuator costs twice as much with panels.
- (h) Recommends alternate gage drums with different size holes.

District 14

Suggest simple design, no frills - wrap with aluminum foil for appearance at \$35, 0.020" x 36" x 100' 3003 corrugated aluminum cross crimp sheeting, mill finish, annealed, without moisture barrier, Allied Metal, Inc., Houston, Texas, (713) 923-9491. Dan Walker, June 26, 1975, \$103.50/roll, FOB Houston. Also Thorp Products Company, Houston - cheaper than painting. They pop-rivet at top and bottom and then band. They weld together as standard.

Cash outflow for materials is about \$150 for one attenuator. Other labor costs must be paid for anyway. They use standard float and haul to site and unload with hoist. They believe in a straight line on sides for appearance. The need for fillers in spaces may be eliminated by use of strap spacers. Front marking was not considered important. The less conspicuous the better. They use 4-5/8" eye cables supported by eye bolts threaded down center. They use paint barrels only and by using electric shear, modify barrels for \$1 each. No painting is done except for tops as aluminum foil is used on outside. It costs them \$1000 to construct including back-up and \$650 for complete repair. They recommend concrete slab be used when attenuator is placed on ground. They sell damaged attenuators for scrap and replace the whole unit.

District 15

They do not have time to make own barrels. They sold old paint barrels for \$4.50 each. They would consider buying modules. Welding bottom is not possible at site. Suggested use of corrugated pipe to make sides in a straight line. They like the straight side for performance and appearance.

District 9

Like barrels. Use paint barrels but sold last paint barrels for \$3.49. They keep enough for one unit. They estimate cost of barrels with fish scales at \$5000. They presently burn out paint in their barrels so that cutting with torch will not smoke or burn.

District 2

Used HMAC to level up ahead of barrel installation. All five installations are of same design and have a jig made of steel framing set up and can be used for repair by noting damaged modules and welding together before carrying to site. Like fish scales as many replacements have been made unnecessary by their use. They used old sign material for fish scales. They don't have to paint as hidden by scales. They don't usually block traffic to repair. Those constructed by contractor went for \$12,000. Could probably be done for \$2500 each if they construct. They have had trouble drilling for cable anchor and like the epoxy and plate used by Dallas. They think the attenuator needs much delineation and even lighting.

District 18

Use bouncing ball lights to call attention to attenuator. The shop foreman built a big can-opener for cutting out bottoms and tops of barrels. They do not use anything but used paint barrels. Cost for this and painting is 75 cents. They are not using fish scales except for some on IH-635 under construction. Scared of repair, ordinarily their hits are head-on or on the sides. Repair costs average about \$300. For repair they fix clusters and haul to site. When cushions are hit, they bill the victim if he is known and collect on a large percent for damages. They haven't used clips and use welds at all points. Like soft nose, 18" D hole in lead barrels. Do not clean barrels as special cutter or can-opener cuts barrel holes without smoke or fire hazard. When driver of impact vehicle is known he pays for damage to attenuator.

3. SAND TIRE ATTENUATOR

District 12 - Prefer barrels to any other system. Don't want anything requiring scattered debris clean up which is immediately required.

Houston Urban - Doesn't look good and very subject to vandalism.

District 14 - Have nine installations - one hit - cost \$900. Baskets cost \$9 each to construct. Concrete pad was necessary for support. Have had some vandalism. Shoved all down once at a site and ruined wire cage supports. Can't salvage sand - Painted tires look best. Plywood disks may deteriorate and plan to put plastic under top tire. Prefer steel drums.

District 15 - Use wire cage but had difficulty getting wire. They did straighten wire baskets out and reuse after one collision. Covers are a problem. They are harder to construct and take longer to repair than Fitch system. It is hard to stuff tires with sand.

District 9 - They paint white using traffic paint with two coats, the last coat they bead. Full coverage not achieved and therefore recommend three coats. They place plywood disks on top to eliminate water but have trouble attaching. They place a 4" unreinforced slab beneath at a cost of about \$200. Bags are not recommended. Besides short life, vandals cut up. Roofing material has been used but isn't too satisfactory. Linoleum won't work. Prefer white paint but a nose delineation is needed and some method to attach

same. A wire cage costs approximately \$3.00 and takes ½ hour to construct. Barrel bases cost about \$2.50 to \$3.00 to construct. Sand tires are considered a temporary expedient until the obstruction is removed. Otherwise they have had no problems except one installation caused sight distance problems at an entrance ramp. They recommend reducing cost of site preparation and compromising on design speed. One installation was slightly damaged during our visit.

District 2 - None planned.

District 18 - Plan to construct one at IH-35E north of river bridge to try.

4. FITCH SAND BARRELS

District 12 - Don't want anything where debris must be cleaned up immediately. Vandalism is bad. Turn over to see what's inside or get Styrofoam. Barrels have split caused by age. Discolored after 18 months.

Houston Urban - Barrels preferred. Good for temporary use at construction sites. Don't like debris. Expensive.

District 14 - Barrels preferred - too expensive.

District 15 - Simple. Can't buy parts immediately and then whole assembly. Sits on grass. \$1700 labor and materials for 11 barrel units. On incline some turned over. Three hours to place. Can be placed with common labor needing little or no supervision.

District 9 - Not interested - too costly.

District 2 - Temporary use only. Easy to install. Little site preparation. Have had some splitting barrels.

District 18 - O.K. Easy to install. Several installations had barrels splitting. Installations on concrete appear neater and less susceptible to fatigue.

Attached is an updated listing of the number of attenuators in various Districts of the State and a telephone survey of evaluation for "Extent of the Use of Portable Crash Cushions in Texas."

TABLE A-1. Listing of Vehicle Impact Attenuators
By District as of July 1, 1975.

<u>District</u>	<u>Steel Barrel</u>	<u>Fitch Barrel</u>	<u>Sand Tire</u>	<u>Total</u>
2	5	2 <u>Temporary</u> <u>One Spare</u>	0	7
3	0	1	0	1
4	2	0	0	2
5	0	2	0	2
6	1	0	0	1
9	5	0	8	13
11	4	0	0	4
12	60	0	0	60
14	9	0	9	18
15	4	3	0	7
16	1	0	0	1
18	15	3	(one under const.)	18
19	4	0	0	4
20	2	0	0	2
24	<u>7</u>	<u>0</u>	<u>0</u>	<u>7</u>
	119	11	17	147

Districts 1, 7, 8, 10, 13, 17, 21, 22, 23 and 25 have none.

SUBJECT: Extent of the Use of Portable Crash Cushions in Texas.

A telephone survey of all districts was made to determine which districts are using portable crash cushions and to what extent they are being used. This survey was made at the request of T. R. Kennedy and for the primary purpose of informing the FHWA. Districts 13 and 17 comments have been expanded to include the information based on personal contact with district personnel.

The following comments are from the districts which have one or more portable crash cushions. Districts which are not listed reported that they do not have a crash cushion at this time.

District 1, Thomas Hagood: They have four crash cushion trailers. One was sideswiped last year; therefore, it does not function as an attenuator. Hopkins County maintenance personnel reported that they had used their crash cushion trailer on IH-30 but that the welds fatigued. They also reported that the trailer was just too much trouble to use. Franklin County personnel have never really used their crash cushion trailer. They feel that it is too hazardous. Hunt County maintenance personnel use their crash cushion trailer when they have to close one or more lanes; but they feel that it's actually too much trouble to use. Grayson County maintenance personnel reported that they have used their crash cushion trailer 35-40 hours (on US 75); but they don't like to use it...they feel that it's too much trouble.

District 3, Frank Ragland: They have one trailer, and it has never been hit. The welds fatigued and they repaired it with the low tension cables. Mr. Ragland reports that they are satisfied with its use... it's a real good tool.

District 12, Hunter Garrison: They have had a crash cushion trailer for about 18 months, but they haven't used it for about a year. They tried to use it behind the sweepers on interstate, but they ran over too many jiggle bars...they rewelded it several times. Mr. Garrison said that he and John Lipscomb had discussed repairing with the cables, but so far, they haven't done anything. They also report trouble turning the trailer. If they could (1) repair it where it would hold together and (2) redesign it to where it would be easier to turn, they would like to use it. They like the idea but it just needs to have the bugs worked out.

District 13, Vernon F. Matusek, Bob Kaiser and Alfred Holik: They have one crash cushion trailer which the center stripe crew uses on IH-10 and US-59. They also use it while performing maintenance operations on these highways. They feel that it is a good safety device but a lot of trouble and hard to maneuver.

District 14, Damon Naumann and Ruben Wallendorf: They have one trailer which they've tried a little. It was so difficult to maneuver that they never actually used it, even on interstate. It's just sitting idle.

District 17, W. J. Byford and Raymond Kurtz: They have one crash cushion trailer which is being used primarily in Walker County on IH-45 where they are tearing out old concrete movement. It was moved to Madison County and they used it every day for about six months. They feel that it's definitely worth the trouble and effort. There has been one instance in which a transport struck the trailer, was slowed and deflected. The maintenance crew involved as well as all supervisors and engineers including Mr. Joe Hanover, the DE, felt that the trailer was instrumental in saving the lives of several of the crew members. No maintenance was

allowed on IH-45 until the trailer was repaired.

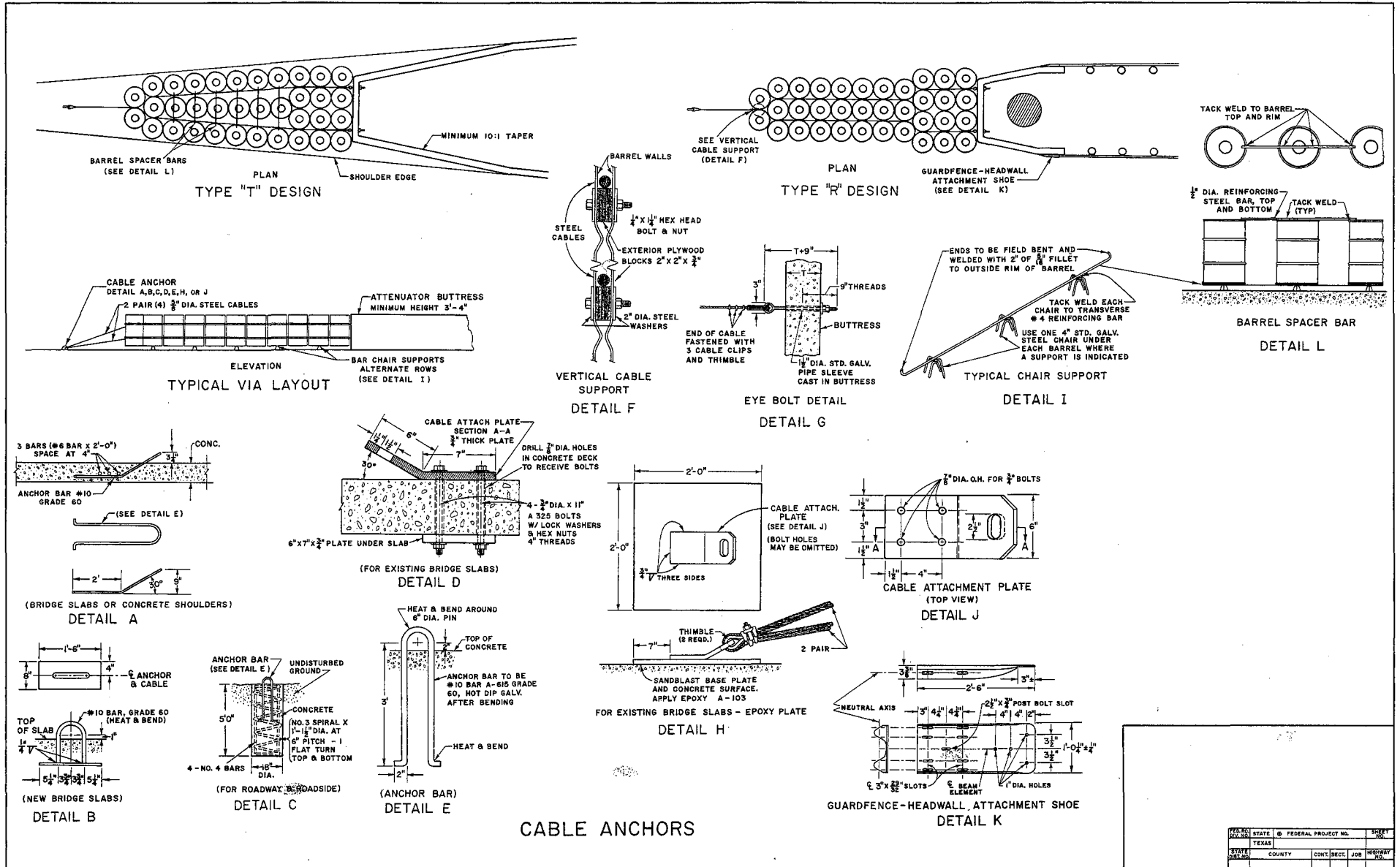
District 20, Thomas McNamara: They built their own crash cushion trailer, but when the welds broke they quit using it. They felt that it was just too much trouble.

District 21, Sam Cox: They have one crash cushion trailer and have ordered two more. They use their trailer all the time with the striping crew. They plan to leave one trailer in the upper part of the district rather than move it back to the main District warehouse after every job, in order to increase the stability of their unit, they load the dump truck, thus increasing the mass of the whole rig. Mr. Cox said they had had one of their men run over (totaled a pickup and sign trailer) before they started using the attenuator trailer. Since the accident, they have felt that it's no trouble at all to tow the crash cushion along...it's also used in dynaflect work, coring work, or any slow moving maintenance operation. Mr. Cox reports that they are very much in favor of using the crash cushion trailer.

District 24, James Lawrence: They built a crash cushion trailer a year to 18 months ago, but didn't use it much until they had an accident - a rear end collision. Now they are using it frequently on interstate. Lawrence himself is not really in favor of using the portable crash cushion because it is so large that it is an obstacle itself. After the accident one of his foremen requested that he be allowed to use the portable crash cushion.

APPENDIX B

TEXAS REVISED
CRASH CUSHION DESIGNS



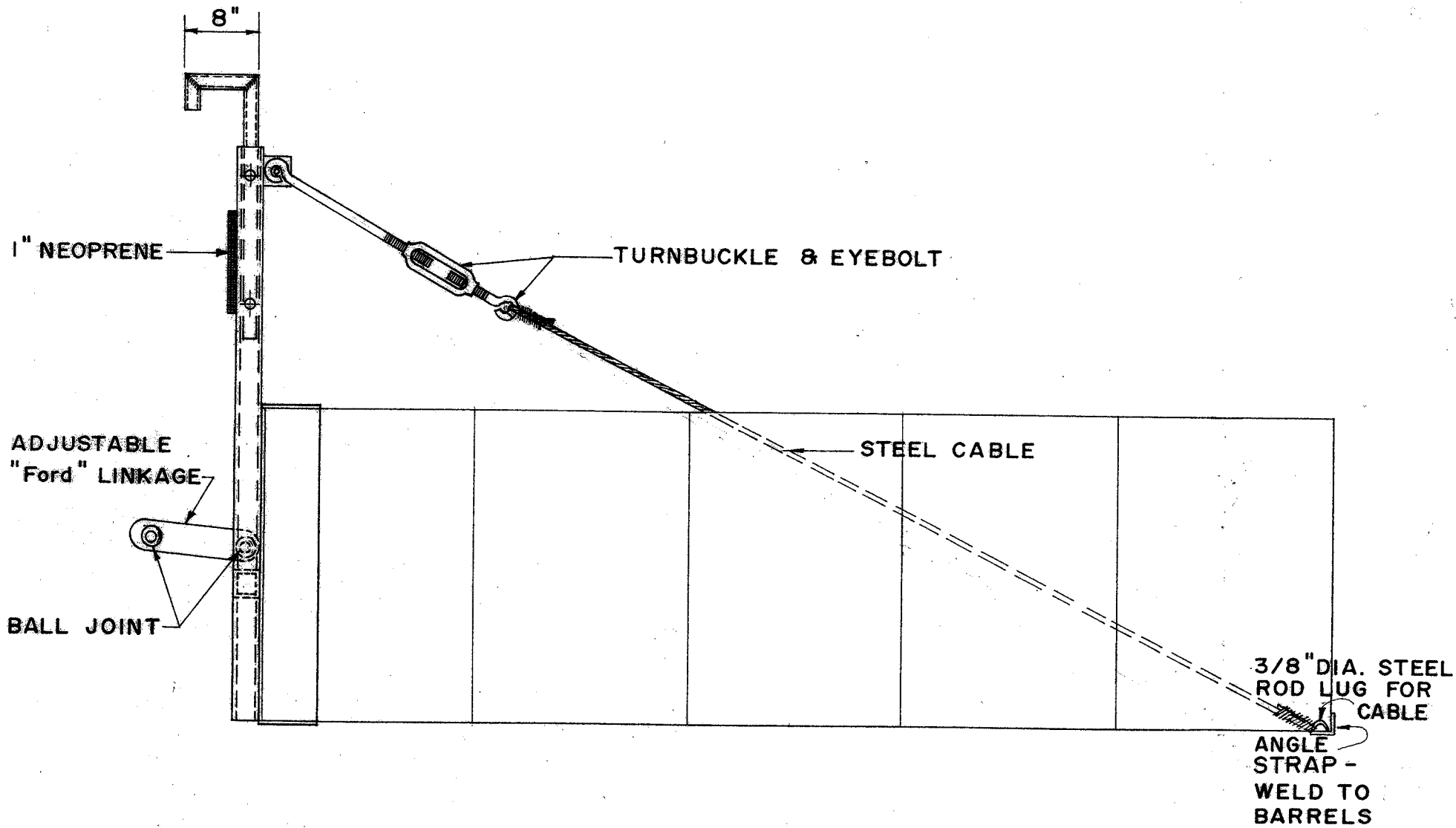
4.4

FIGURE B-I - SUGGESTED CONFIGURATIONS AND DETAILS OF TEXAS CRASH CUSHION

FED. PROJ. NO.	STATE	FEDERAL PROJECT NO.	SHEET NO.
	TEXAS		
STATE DIST. NO.	COUNTY	CONTR. SECT.	JOB HIGHWAY NO.

APPENDIX C

PORTABLE CRASH
CUSHION DETAILS



SIDE ELEVATION

FIGURE C-1 ELEVATION OF PORTABLE CRASH CUSHION

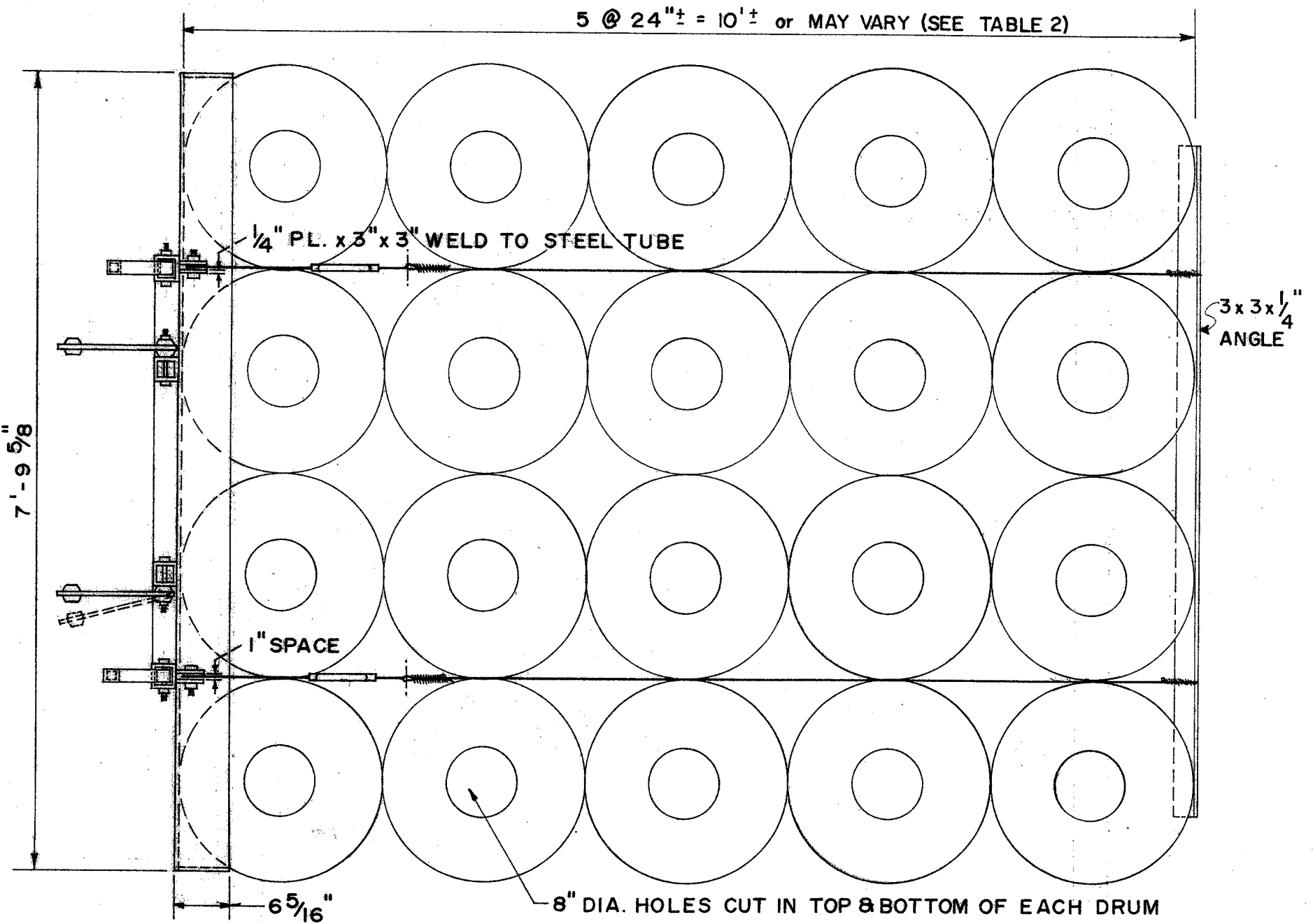
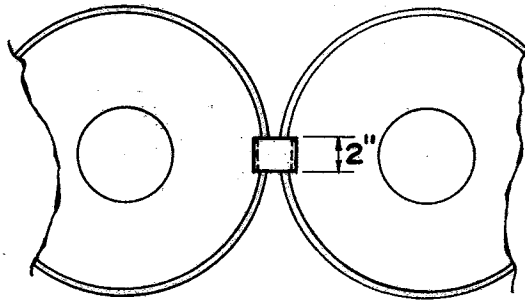
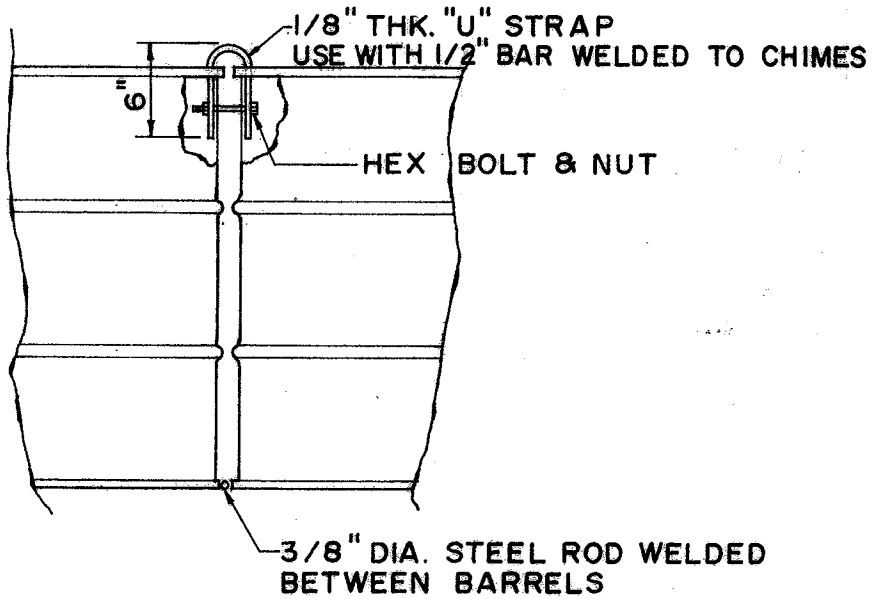


FIGURE C-2 PLAN VIEW OF PORTABLE CRASH CUSHION



PLAN



ELEVATION

FIGURE C-4 - BARREL ATTACHMENT DETAIL.
PORTABLE CRASH CUSHION

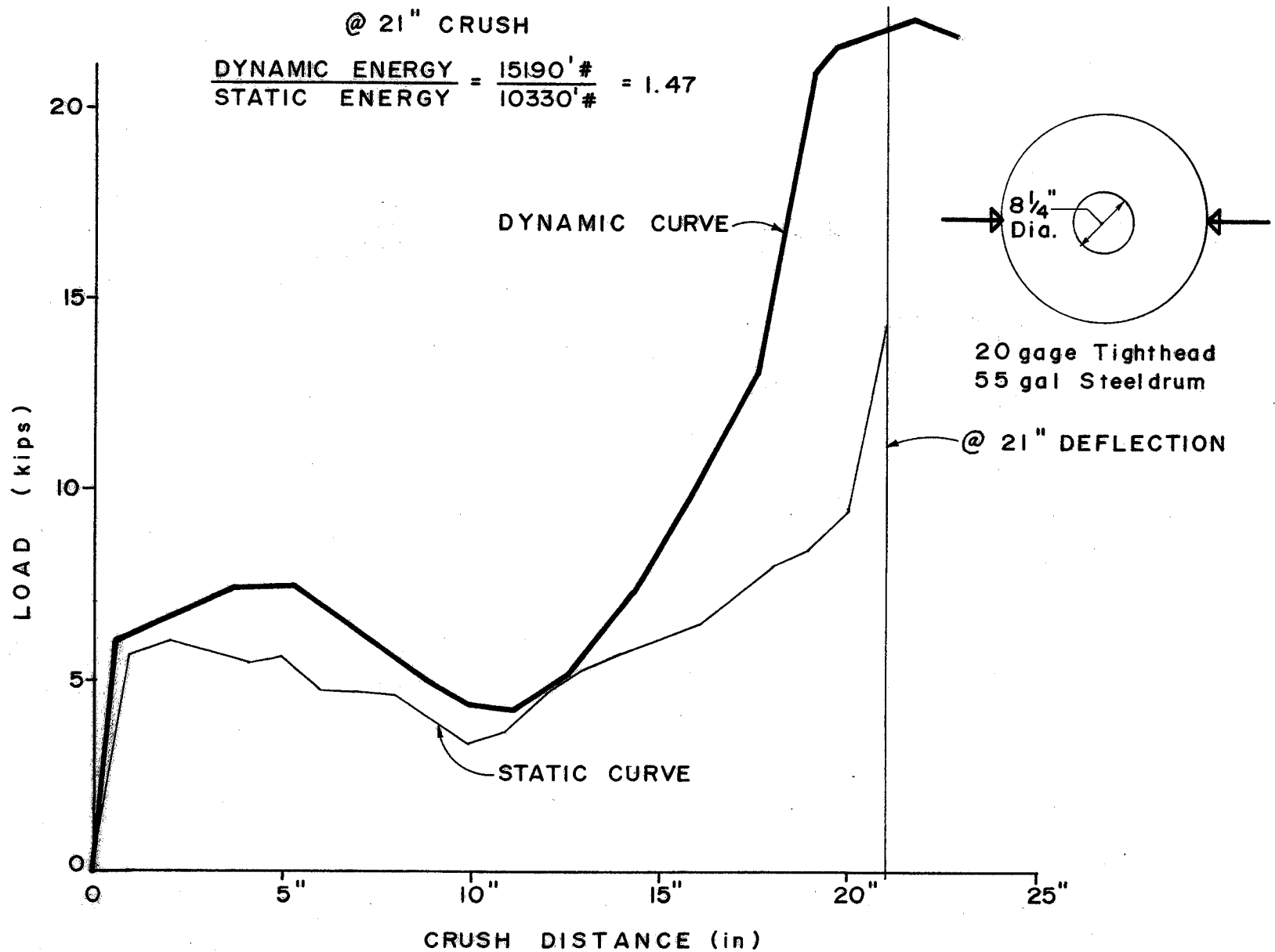


FIGURE D-1. COMPARISON OF DYNAMIC TO STATIC FORCE vs. DEFORMATION DATA FOR STEEL DRUM. Dynamic data determined by 2000 lb pendulum impacting at 20 mph.