

**COMMONWEALTH OF KENTUCKY****CHARLES PRYOR, JR.**
COMMISSIONER OF HIGHWAYS**DEPARTMENT OF HIGHWAYS**
FRANKFORT, KENTUCKY 40601

March 15, 1973

ADDRESS REPLY TO:
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DIVISION OF RESEARCH
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H.2.64

MEMORANDUM TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee**SUBJECT:** Research Report No. 359; "Experimental Installations of Impact-Attenuating Devices;" Final Report on Study KYHPR-70-64; HPR-1(8), Part II.

My transmittal of a progress report on the subject study, dated May 5, 1971, is quoted verbatim:

Quite some time ago, interest mounted regarding a device (Tor-Shok) which was capable of arresting a fast-moving automobile in a survivable way. While plans for a trial installation were being drawn, several other developments emerged. The Fitch-type barrier offered convenience of installation, and the Rich-type could be fitted into minimal space situations. The FHWA invited experimental installations and evaluations. At first, they were limited to sites already constructed but were later extended to future construction. Six existing sites were programmed on an experimental basis -- under force account provisions. In mid-summer, 1969, the Assistant State Highway Engineer for Pre-Construction appointed a committee consisting of the Directors of Design, Bridges, Maintenance, Traffic, and Research to overview and coordinate all projects. Later, the FHWA dismissed the experimental status of the barriers but invited evaluation-and-performance reports. Meanwhile, the Research Division advanced a research proposal involving intensive surveillance of several installations. The FHWA approved that proposal July 28, 1970.

Early in 1970, the Committee charged the Research Division to survey the entire interstate system and to submit recommendations concerning safety revisions needed at gore sites. Only those portions opened to traffic were inspected then; some portions not then open to traffic were added in a subsequent report. Those sites not requiring a soft barrier but needing other corrective measures are being included in other safety projects.

The report submitted herewith was prepared to document programs toward the objectives of the research study and to provide a convenient reference for the Committee.

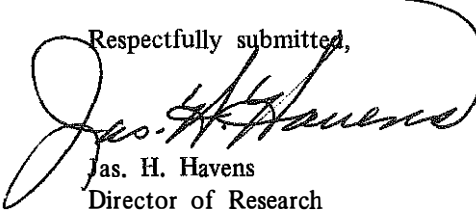
At a recent meeting, the Committee resolved to "design away" -- when possible -- any situation otherwise requiring a cushion-type barrier. Contour grading is appearing in current plans. On-structure splits are being designed to move the gore-wall more remote from the apex of the bifurcation; also the grade is being continued as far as possible to present a better view to the driver.

An informal report was made to the Research Committee, June 6, 1972. Films of a few crashes, many near-misses, and various activities in gore areas were shown at that time. The camera monitoring was discontinued during the latter part of August 1972. One site was monitored about two years. The Barrier Committee has continued active inasmuch as several sites remain pending in some way.

The report now submitted concludes the work planned and approved under Part II of the HPR program. Follow-up accident and cost surveillance will continue as long as the Committee desires. Camera monitoring may be renewed when a Steel (Drum) Crash Cushion is installed.

The Committee directed the research team to draw warrants enabling implementation of barriers, as needed, at the design stage or on existing facilities. Those contained in the report may need to be amended or stated more discretely. Inasmuch as the use of barriers will continue to be dependent upon engineering judgement, the Department recently elected to proceed independently from a program proposed by the FHWA (Ref. your letter, Division Engineer, December 15, 1972; re: IM 40-7-72, Use of Crash Cushions on Federal-Aid Highways).

Respectfully submitted,

A handwritten signature in cursive script, appearing to read "Jas. H. Havens", is written over the typed name and title. The signature is fluid and somewhat stylized, with a large loop at the end.

Jas. H. Havens
Director of Research

JHH:dw

cc's: Research Committee

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Experimental Installations of Impact-Attenuating Devices				5. Report Date March 1973	
				6. Performing Organization Code	
7. Author(s) J. G. Pigman, W. M. Seymour, D. L. Cornette				8. Performing Organization Report No. 359	
9. Performing Organization Name and Address Division of Research Kentucky Department of Highways 533 South Limestone Lexington, Kentucky 40508				10. Work Unit No.	
				11. Contract or Grant No. KYHPR- 70-64	
12. Sponsoring Agency Name and Address				13. Type of Report and Period Covered Final	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the US Department of Transportation, Federal Highway Administration Study Title: Experimental Installations of Impact Attenuating Devices					
16. Abstract From a survey of the interstate system in Kentucky, 26 gore sites were found to be eligible for safety improvements. Energy absorbing barriers have been installed at five. Barriers are planned at 11 sites; seven sites have been contour graded; and three sites have been dismissed from consideration. HI-DRO Cushions and Fitch Inertial Barriers were found to be effective crash cushions. HI-DRO Cushion maintenance costs per impact were less than those for Fitch Inertial Barriers; however, initial costs of materials and installation were higher. The HI-DRO Cushion is generally more adaptable to narrow and relatively short areas than either the Fitch Inertial Barrier or the Steel Crash Cushion. Desirability of redirection capabilities is dependent upon site geometrics, traffic volumes, and speeds. If there is no feasible alternative, installation of an impact attenuating device is advocated in terms of warrants.					
17. Key Words Impact Attenuating Devices Energy Absorbing Barriers Gore Area Accidents Vehicular-Occupant Safety Barrier Selection Criteria				18. Distribution Statement	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price

Research Report
359

**EXPERIMENTAL INSTALLATIONS OF
IMPACT-ATTENUATING DEVICES**

Final Report
KYHPR-70-64, HPR-1(8), Part II

by

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DEPARTMENT OF HIGHWAYS
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in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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 Department of Highways or the Federal Highway Administration. This report does not regulate a standard, specification, or regulation.

March 1973



INTRODUCTION

An ironic consequence of modern highways has been the emergence of a new pattern of accidents. Recent investigations (1) have shown that "running off the road" may be the largest, single cause of fatalities on limited access, multilane roads. According to the 1967 Report of the Special AASHO Traffic Safety Committee ("Yellow Book") (2), the rate of accidents in gore areas is approximately four times that of ran-off-the-road accidents at other locations. Gore areas which are not or cannot be modified to provide favorable terrain and unobstructed recovery zones have been recognized as misfits in the environs of the highway. Crash cushions are only an expedient alternative.

In March 1969, the Division of Research was assigned the design and evaluation of two barrier installations. In mid-summer 1969, a committee representing the Divisions of Bridges, Maintenance, Traffic, Design and Research was assigned continuing responsibilities for the program. A survey (3) of the interstate system disclosed 26 gore sites which were adjudged eligible for some type of safety improvement. Barriers have been installed at five sites; eleven more barriers are planned; seven sites have been contour graded; and three sites have been dismissed from consideration.

Emergent objectives become: 1) to design away the need for barriers, crash-cushions, etc. wherever possible; 2) to modify existing sites, to remove obstructions, and to provide recovery zones; and 3) to install arresting barriers where the obstructions cannot feasibly be avoided. Although this report relates experiences with barrier installations, the higher ideals, mentioned previously, will surely prevail -- and be on-going. Development of barrier systems has been relegated to others. The performance histories cover two types of barriers: the HI-DRO- and the FIBCO-types.

In attempting to determine which of several types to utilize, a state-of-the-art review by the Division of Research in 1969 (4) led to the selection of HI-DRO Cushion Cells, Energy Absorption Systems, Inc. of Sacramento, California; and Fitch Inertial Barriers, FIBCO Inc. of Hartford, Connecticut. Later, it was decided to install a third type when the opportunity arose; this was the Steel Crash Cushion, Syro Steel, Girard, Ohio. Details of these types of barriers are in the manufacturers' literature (5, 6, 7).

Movie cameras were installed at three barrier installations. The cameras were triggered by air tubes pinned to the pavement or ground encompassing the gore area. Various types of encroachments were filmed. Some near misses and a few crashes were recorded. At

one site, camera monitoring covered a period of two years.

To the extent possible, each accident was investigated. Damages to the barrier and vehicle were assessed. In some instances, the driver was interviewed. Cost of repairing the barriers together with the cost of the installation provides the economic history of each site.

One of the most recent and probably the most comprehensive investigations of barrier systems was made by the Texas Transportation Institute in cooperation with the FHWA's Structural Systems in Support of Safety Program (8). There, three general classes of barrier systems were tested and evaluated as follows: 1) Impact attenuation barriers without redirection capability, 2) Impact attenuation barriers with redirection capability, and 3) Longitudinal redirection barriers such as guardrails, bridge rails, and median barriers. Perhaps the most useful information generated from that study was the summary of desirable characteristics for each of the three barrier classes. Inherent advantages and disadvantages were found to be peculiar to individual barrier types. It was concluded that a final selection must therefore be based on site inspection and engineering judgement.

Viner (9) evaluated the performance of impact attenuating devices by investigating accident experience. Data on 129 accidents involving a barrier impact were collected through April 15, 1971, by the Federal Highway Administration. Attenuator types included in the summary were steel drums, Fitch barrels, Tor-shok, HI-DRO Cushions, and Dragnet devices. In 30 instances judged likely to have produced fatalities or hospitalizing injuries had an attenuator not been present, it was found that only three hospitalizing injuries and one fatality occurred. As a consequence of the decrease in available recovery area in front of existing parapet noses and gore areas, it was found that the number of accidents at attenuator sites increased. At 28 sites under study, frequency of occurrence was 4.4 accidents per year of exposure.

A recent innovation in the development of impact attenuators has resulted in a hybrid system consisting of a steel drum crash cushion which smoothly transitions to a concrete median barrier (10). The system is narrow enough to allow installation in relatively restricted median areas under highway overpasses. This new system was tested with three impacts (two angled and one head-on) and appears to be a satisfactory means of minimizing impact with bridge piers which are exposed and frequently involved in fixed-object collisions.

PRESENT STATUS OF EACH SITE

Location 1. Campbell County; I 471 - 5th Street Interchange

A Fitch Inertial Barrier has been designed (Figure 1) and incorporated into the construction plans for this interchange. At the present time, no information is available on the scheduled start of construction.

Locations 2(a), 2(b), 2(c); Jefferson County; I 64 - 9th Street Interchange

- (a) Gore at Ramp 3
- (b) Gore at Ramp 4
- (c) Gore between Ramps 1 and 2A

Fitch systems are planned for Locations (a) and (b). These locations are in the design stage, and the barriers will be installed prior to opening to traffic. Following the original designs of these Fitch barriers, it was decided to allow more space between individual modules. Figures 2 and 3 show revised plan views of

the designs for Ramps 3 and 4, respectively.

A HI-DRO Cushion System was selected for use at the gore between Ramps 1 and 2A. The gore area and the planned standard, eight-bay unit are depicted in Figure 4. Design of the system at this location has not been finalized.

Locations 3(a), 3(b), 3(c), 3(d); Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65):

- (a) Gore between Ramps 4 and 8
- (b) Gore between Ramps 3 and 6
- (c) Mainline exit northbound
- (d) Mainline exit southbound

HI-DRO Cushions have been installed at Locations (a) and (b); a Fitch Inertial Barrier has been installed at Location (c). These locations and the experience to date with each barrier will be discussed in detail in the next section of this report. Installations at Locations 3(a), 3(b), and 3(c) are shown in Figures 5, 6, and 7,

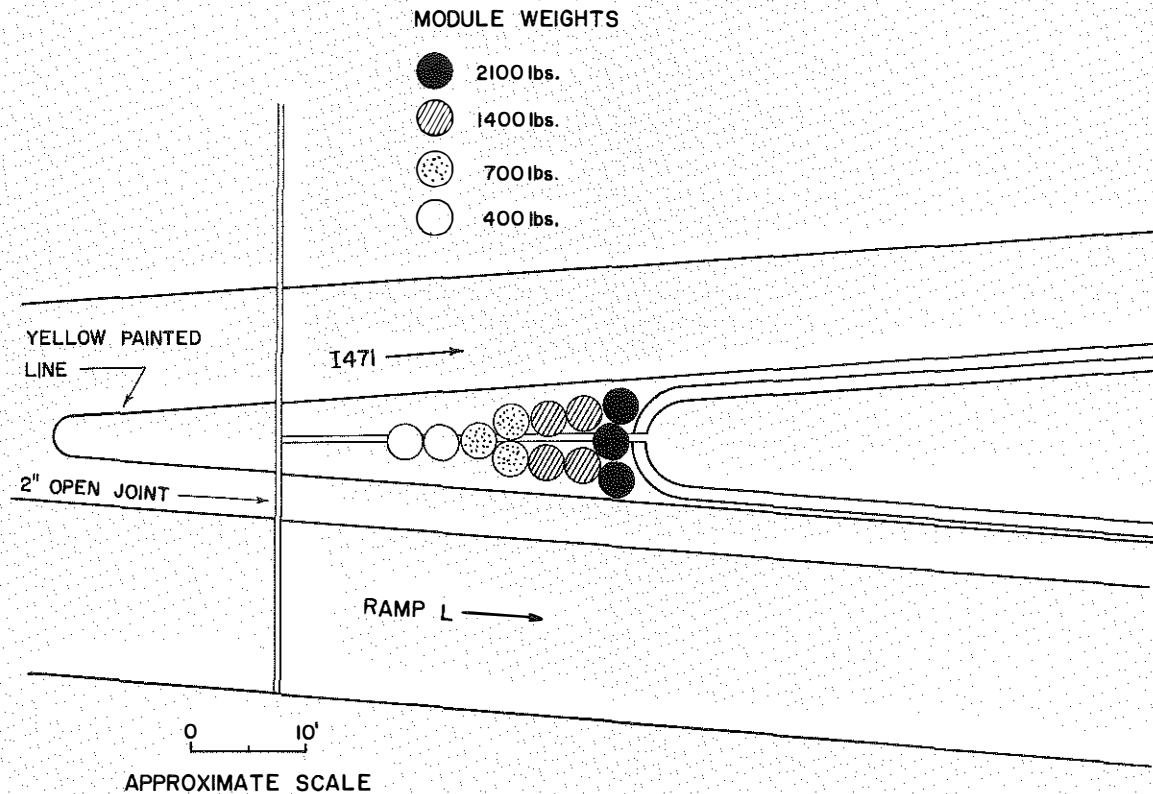
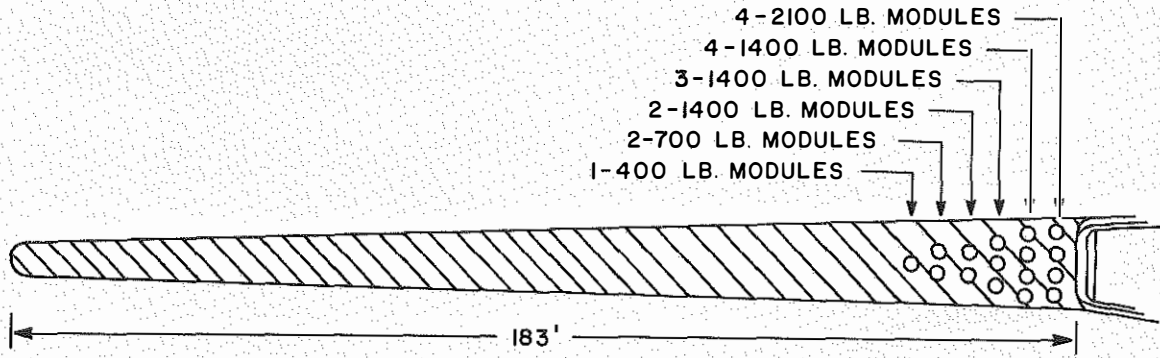


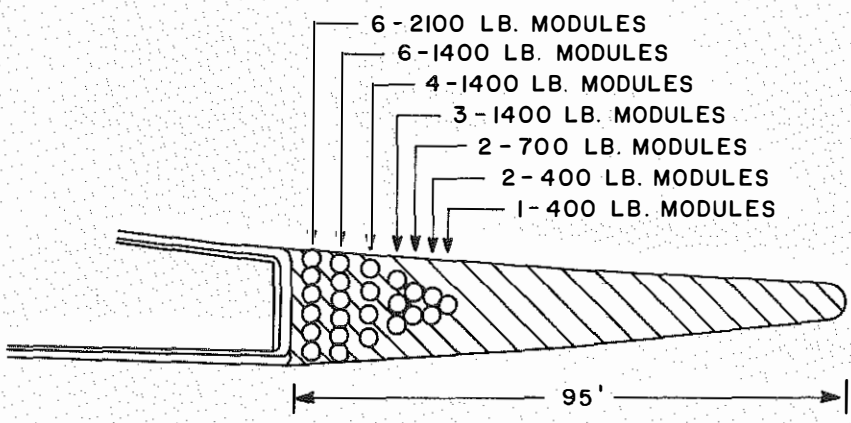
Figure 1. Plan View of Fitch Design for Location 1.



BARRIER LENGTH = 30'

NOTE : GAPS BETWEEN ROWS OF MODULES = 2'

Figure 2. Plan View of Fitch Design for Location 2(a).



BARRIER LENGTH = 28'

NOTE : GAPS BETWEEN ROWS OF MODULES = 2'

Figure 3. Plan View of Fitch Design for Location 2(b).

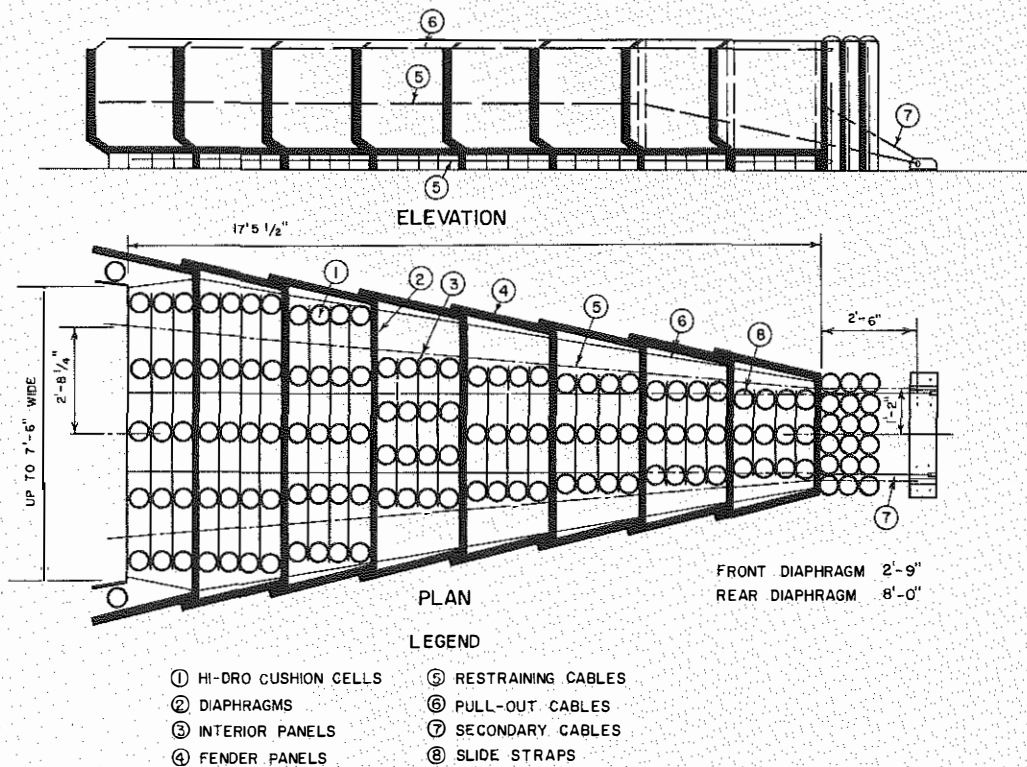
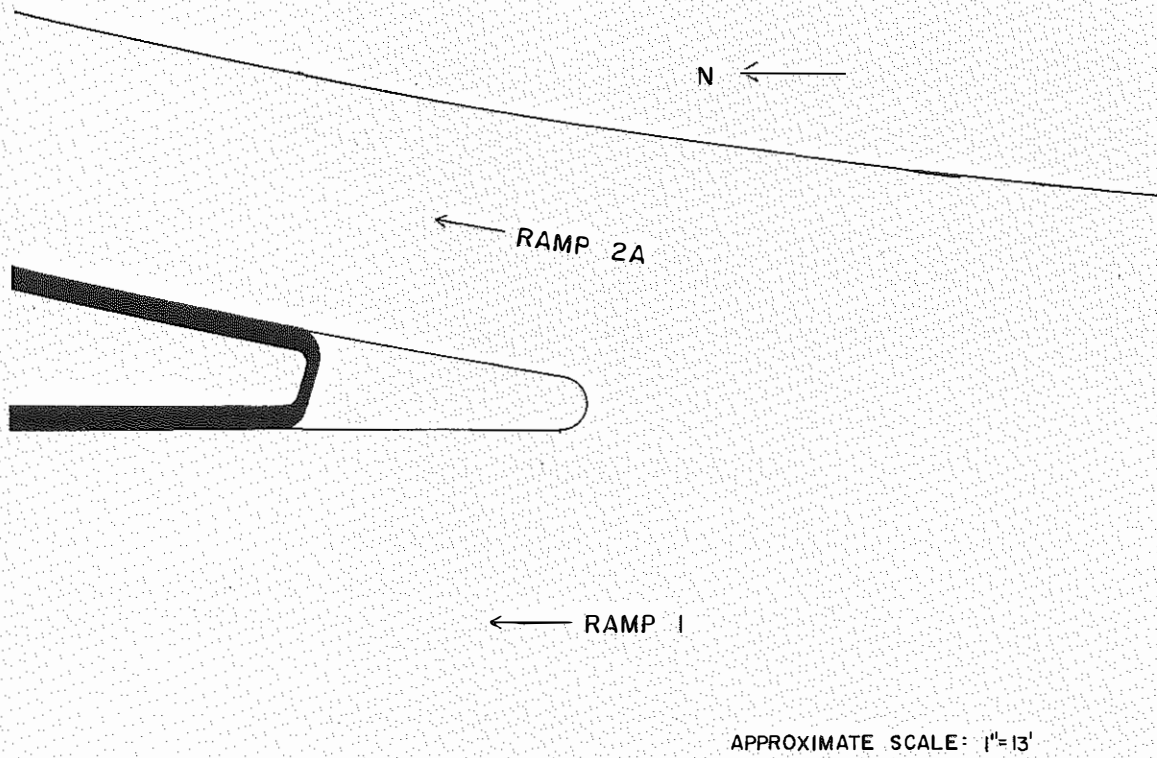


Figure 4. Plan View of Location 2(c) and Proposed HI-DRO Cushion.

Figure 5. HI-DRO Cushion Installation at Location 3(a).



Figure 6. HI-DRO Cushion Installation at Location 3(b).

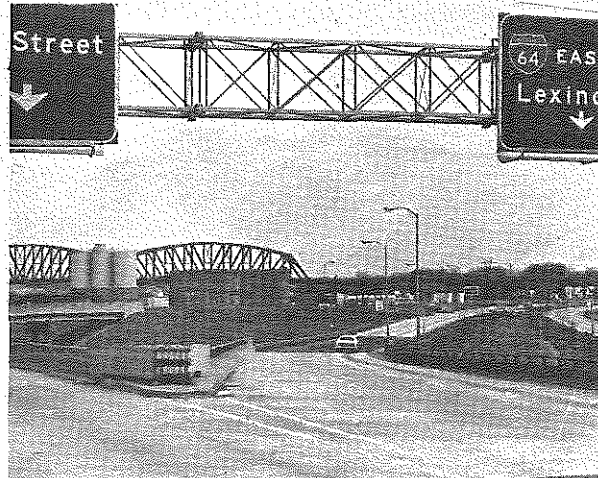


Figure 7. Fitch Inertial Barrier Installation at Location 3(c).



respectively.

Location (d) is pictured in Figure 8. In November 1971, the Division of Research recommended that the existing nine-foot long concrete nose be removed and a HI-DRO Cushion installed. The Energy Absorbing Barrier Committee approved the recommendation. Installation of the barrier is to be accomplished in conjunction with a forthcoming safety improvement project scheduled for this section of roadway.

Location 4; Kenton County; I 275 - US 25 and US 42 Interchange, Gore between Ramps A and C

The necessity for an impact attenuation device has been eliminated through design changes and contour grading. Construction of this interchange has not been completed. A plan view of the gore area is pictured in Figure 9.

Location 5; Jefferson County; Jefferson Freeway-Westport Road Interchange

As shown in Figure 10, the necessity for an impact attenuation device has been eliminated through contour grading.

Location 6(a), 6(b); Jefferson County; I 264 Shively Interchange with US 31W

(a) Gore at Bridge 7

(b) Gore at Ramp 7

This interchange is under construction, and the gore area at Location (a) is being corrected by contour grading. Figure 11 is a plan view of Location 6(a), and the Fitch Inertial Barrier planned for Location 6(b) is shown in Figure 12.

Figure 8. Location 3(d) before Installation of a HI-DRO Cushion.

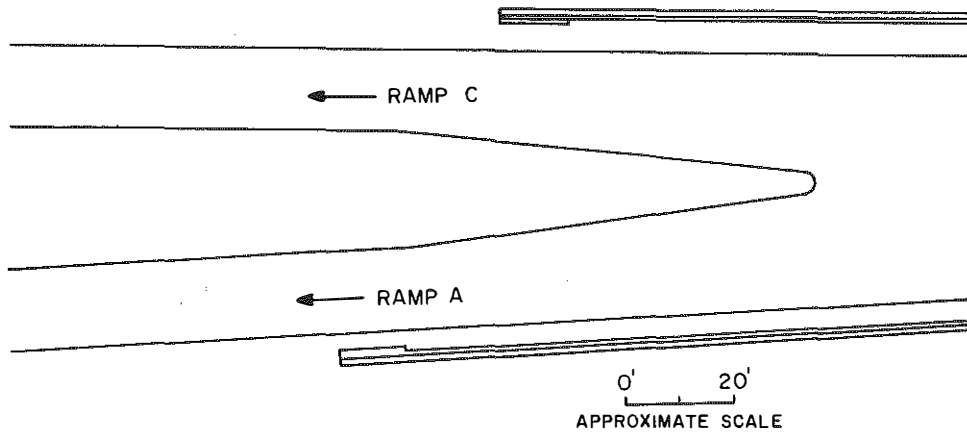


Figure 9. Plan View of Location 4.

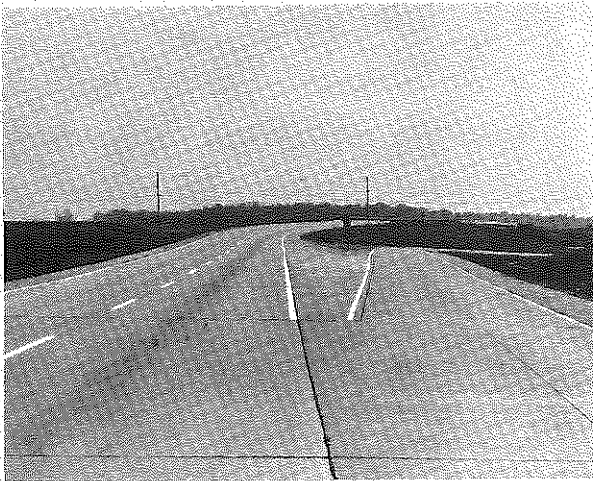


Figure 10. Contour Grading at Location 5.

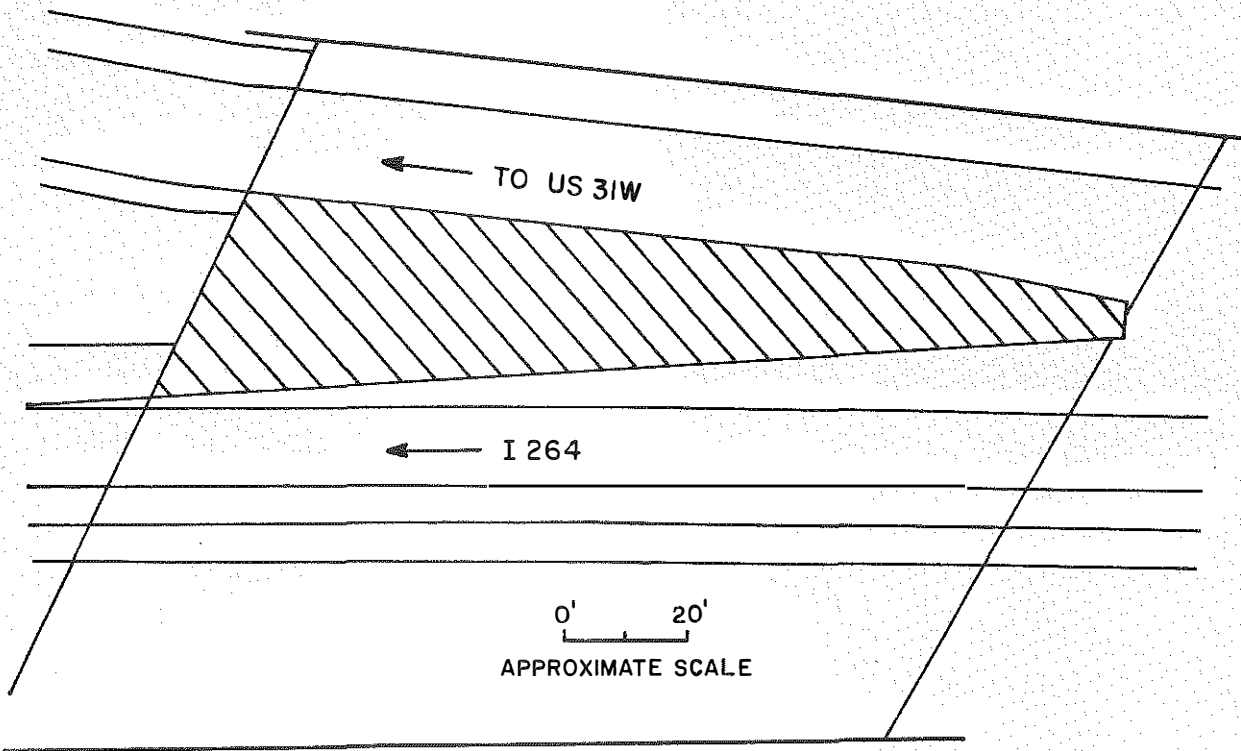


Figure 11. Plan View of Location 6(a).

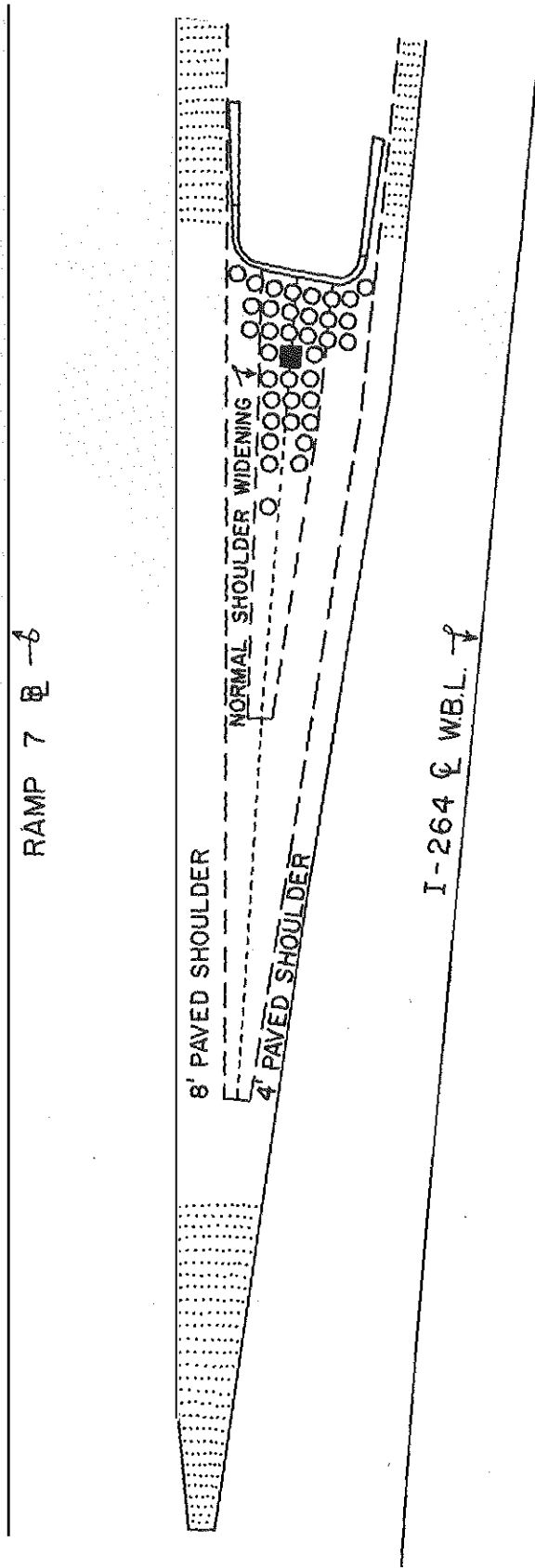


Figure 12. Plan View of Location 6(b).

Location 7; Kenton County; I 75 - 5th Street Interchange, Gore at Southbound Exit Ramp

A Fitch barrier was installed November 5, 1970. The Fitch-type barrier was replaced with a HI-DRO Cushion barrier on October 10, 1972. This site will be discussed in depth in the next section of the report. The former Fitch installation and the present HI-DRO barrier are shown side-by-side in Figure 13.

Location 8(a), 8(b); Franklin County; I 64 - US 127 Interchange:

- (a) Gore at westbound exit from I 64 to US 127
- (b) Gore at eastbound exit from I 64 to US 127

Both of these sites have been corrected by contour grading. Figures 14 and 15 depict Location 8(a) before and after contour grading was accomplished. Likewise, Location 8(b) is shown in Figures 16 and 17.

Location 9; Shelby County; I 64 - KY 395 interchange, Gore at eastbound exit from I 64 to KY 395

No modifications were necessary, and this site has been dismissed from consideration. This site is shown in Figure 18.

Location 10; Fayette County; I 75 - US 25 & US 421 Interchange, Gore at northbound exit from I 75 to US 25 and US 421

This gore has also been eliminated as a potential safety barrier site by contour grading. Figures 19 and 20 show the site before and after contour grading.

Location 11(a), 11(b); Whitley County; I 75 - US 25 Interchange:

- (a) Gore at southbound exit from I 75 to US 25
- (b) Gore at northbound exit from I 75 to US 25

These two sites were dismissed from consideration after further investigations revealed that modifications were not necessary. Existing conditions are shown in Figures 21 and 22.

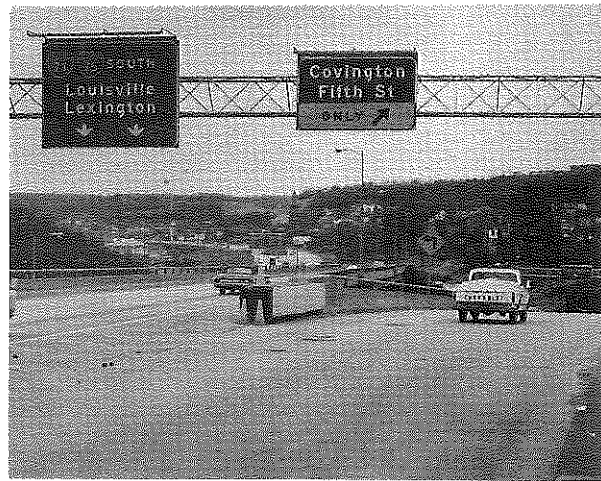


Figure 13. Former Fitch Barrier and Present HI-DRO Installation at Location 7.



Figure 14. Location 8(a) before Contour Grading.

Figure 15. Location 8(a) after Contour Grading.

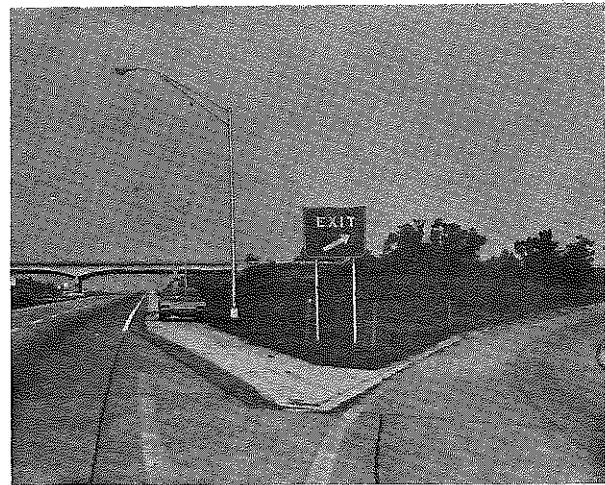


Figure 16. Location 8(b) before Contour Grading.



Figure 17. Location 8(b) after Contour Grading.

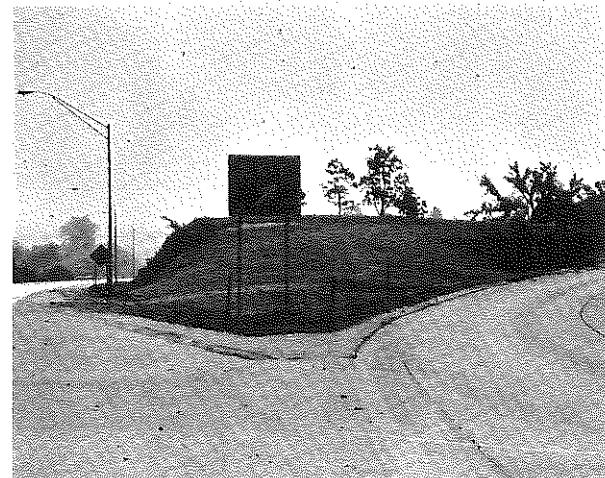


Figure 18. Existing Conditions at Location 9.

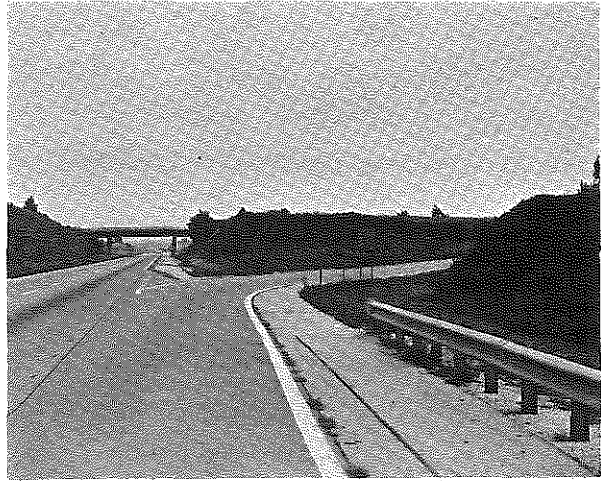


Figure 19. Location 10 before Contour Grading.



Figure 20. Location 10 after Contour Grading.



Figure 21. Existing Conditions at Location 11(a).

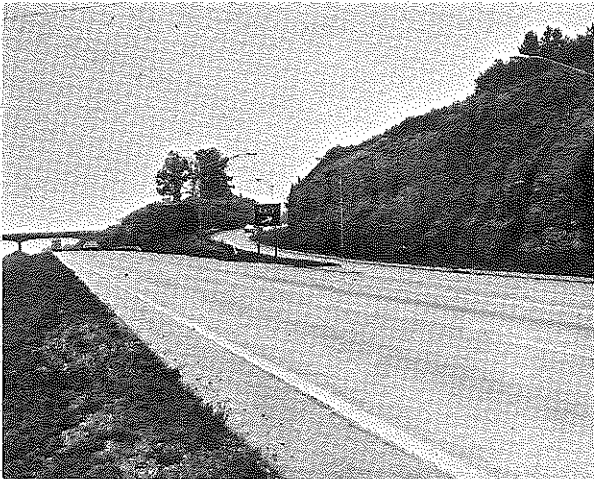
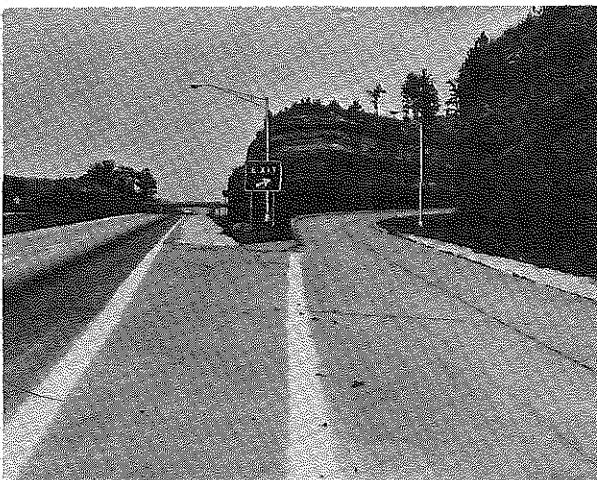


Figure 22. Existing Conditions at Location 11(b).



Location 12; Jefferson County; I 65 - Chestnut Street Interchange, Gore at Northbound exit from I 65 to Chestnut Street.

A Steel Crash Cushion is planned for this location as part of a future safety improvement project. The existing gore area is shown in Figure 23.

Location 13; Jefferson County; I 65 - St. Catherine Street Interchange, Gore at southbound exit from I 65 to St. Catherine Street.

At the present, no decision has been made as to the type of impact attenuation device which will be installed at this site. The site is shown in Figure 24.

Location 14; Jefferson County; I 64 - I 264 (New Albany) Interchange, Northbound directional split from I 264 to I 64.

A Fitch Inertial Barrier, shown in Figure 25, was installed on July 2, 1971. Further discussion of this installation can be found in the next section of this report.

Location 15; Jefferson County; I 64 - 3rd Street Interchange, Gore at westbound exit from I 64 to 3rd Street

No decision has been made regarding the type of barrier to be installed. The site is shown in Figure 26.

Location 16; Jefferson County; Riverside Expressway - 22nd Street Interchange, Gore at eastbound exit from Riverside Expressway to 22nd Street.

A Steel Crash Cushion is to be installed after modifications to the gore area. Modifications are to be included in the 9th Street interchange project. A photograph of this gore area is presented in Figure 27.

Location 17; Campbell County; I 471 - I 275 Interchange, Gore between I 471 southbound and Ramp F on I 275.

The plan view schematic of the Fitch Inertial Barrier chosen for this bifurcation is depicted in Figure 28.

Location 18, Madison County; I 75 - US 25 Interchange, Gore at southbound exit from I 75 to US 25 (Loop to Richmond).

Figure 29 indicates that contour grading has solved the problem at this gore area.

A summary of the present status of each site is presented in Table 1.

Figure 23. Location 12 (Existing Condition) before Planned Installation of a Steel Crash Cushion.

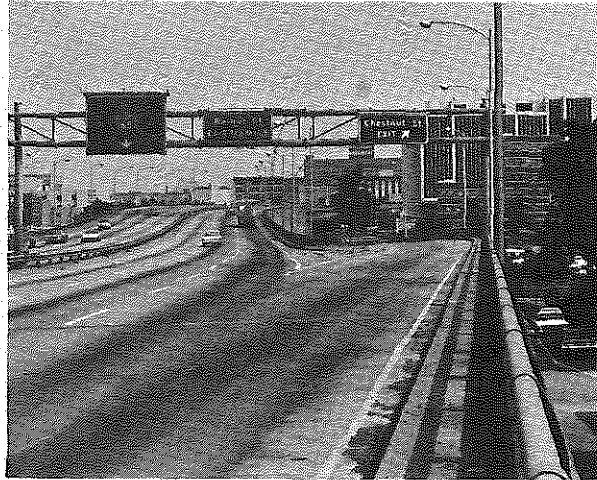


Figure 24. Present Conditions at Location 13.

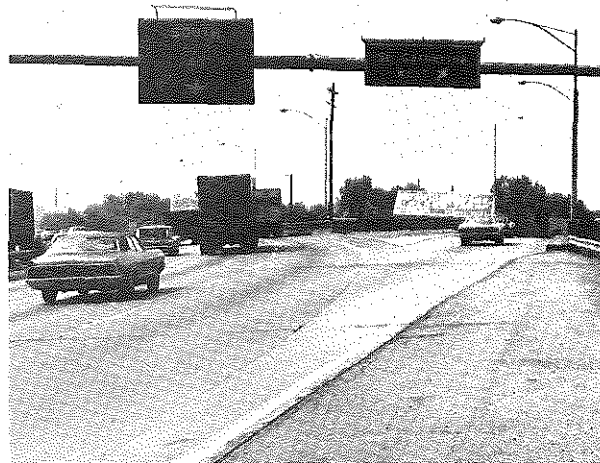


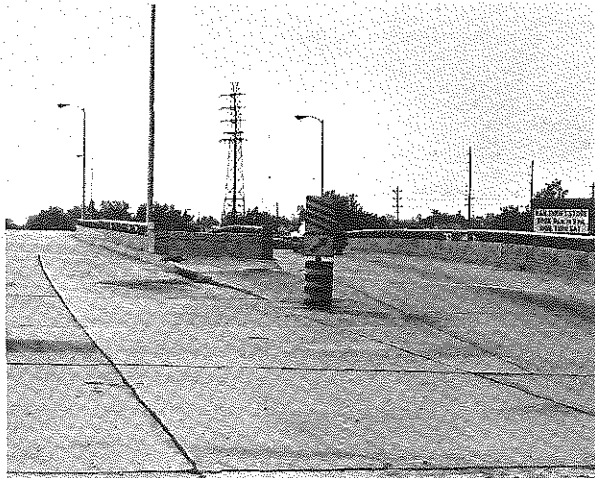
Figure 25. Fitch Inertial Barrier Installation at Location 14.





Figure 26. Existing Conditions at Location 15.

Figure 27. Location 16 (Existing Condition) before Planned Installation of a Steel Crash Cushion.



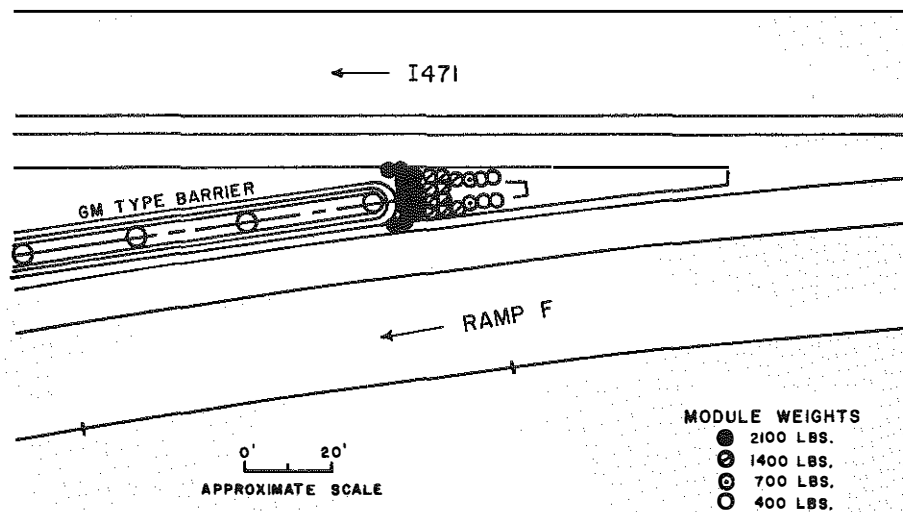


Figure 28. Plan View of the Fitch Inertial Barrier Design Planned for Installation at Location 17.



Figure 29. Location 18 after Contour Grading.

TABLE I
SUMMARY OF THE PRESENT STATUS OF EACH SITE

SITES CONSIDERED FOR BARRIER INSTALLATIONS	PRESENT STATUS	FIGURES
1. Campbell County; I 471 - 5th Street Interchange, Gore at Ramp "L".	Fitch Barrier planned	1
2. Jefferson County; I 64 (Riverside Expressway) - 9th Street interchange:		
(a) Gore at Ramp 3	Fitch Barrier planned	2
(b) Gore at Ramp 4	Fitch Barrier planned	3
(c) Gore between Ramps 1 and 2A	HI-DRO Cushion planned	4
3. Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65):		
(a) Southbound secondary gore between Ramps 4 and 8	HI-DRO Cushion was installed in Sept., 1970	5
(b) Northbound secondary gore between Ramps 3 and 6	HI-DRO Cushion was installed in Sept., 1970	6
(c) Mainline exit northbound	Fitch Barrier was installed on Aug 13-14, 1970	7
(d) Mainline exit southbound	HI-DRO Cushion planned	8
4. Kenton County; I 275 - US 25 & US 42 interchange, Gore between Ramps A and C	Has been contour graded	9
5. Jefferson County; Jefferson Freeway - Westport Road interchange. Gore at Ramp 5	Has been contour graded	10
6. Jefferson County; I 264 Shively Interchange with US 31W:		
(a) Gore at Bridge No. 7	Has been contour graded	11
(b) Gore at Ramp No. 7	Fitch Barrier planned	12
7. Kenton County; I 75 - Fifth Street Interchange, Gore at southbound exit ramp	Fitch Barrier was installed on Nov. 5, 1970, HI-DRO Cushion replaced Fitch Barrier on Oct. 10, 1972	13
8. Franklin County; I 64 - US 127 interchange:		
(a) Gore at westbound exit from I 64 to US 127	Has been contour graded	14, 15
(b) Gore at eastbound exit from I 64 to US 127	Has been contour graded	16, 17
9. Shelby County; I 64 - KY 395 interchange, Gore at eastbound exit from I 64 to KY 395	Dismissed from consideration	18
10. Fayette County; I 75 - US 25 & US 421 interchange, Gore at northbound exit from I 75 to US 25 and US 421	Has been contour graded	19, 20
11. Whitley County; I 75 - US 25 interchange:		
(a) Gore at southbound exit from I 75 to US 25	Dismissed from consideration	21
(b) Gore at northbound exit from I 75 to US 25	Dismissed from consideration	22
12. Jefferson County; I 65 - Chestnut Street interchange, Gore at northbound exit from I 65 to Chestnut Street	Steel Crash Cushion planned	23
13. Jefferson County; I 65 - St. Catherine Street interchange, Gore at southbound exit from I 65 to St. Catherine Street	Barrier planned-type has not been selected	24
14. Jefferson County; I 64 - I 264 (New Albany) interchange, northbound directional split from I 264 to I 64	Fitch Barrier was installed on July 2, 1971	25
15. Jefferson County; I 64 - 3rd Street interchange, Gore at westbound exit from I 64 to 3rd Street	Barrier planned -- type has not been selected	26
16. Jefferson County; Riverside Expressway - 22nd Street interchange, Gore at eastbound exit from Riverside Expressway to 22nd Street	Modifications to be made to gore area; Steel Crash Cushion planned	27
17. Campbell County; I 471 - I 275 interchange, Gore between I 471 southbound and Ramp on I 275	Fitch Barrier planned	28
18. Madison County; I 75 - US 25 interchange, Gore at southbound exit from I 75 to US 25 (Loop to Richmond)	Has been contour graded	29

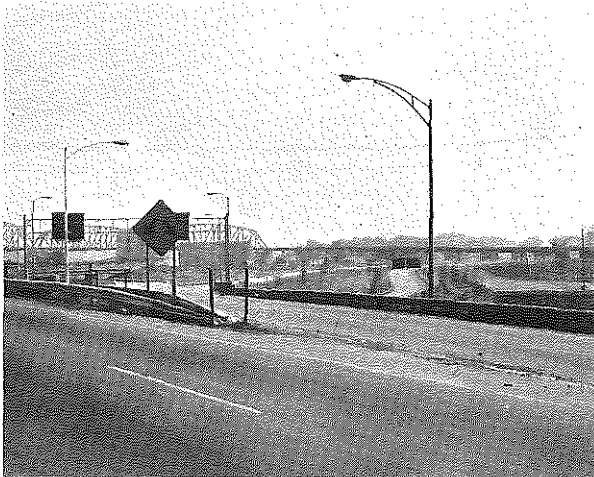
SITES WITH ABSORBING BARRIERS

Five energy absorbing barriers are presently in service on Kentucky interstate highways. More descriptive information concerning these barriers and the experience with each through May 1, 1972 follows.

Fitch Barrier at Location 3(c) -- Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65), Mainline exit from I 65 northbound.

Figure 30 pictures this site as it existed until May 1970. The gore had a history of many accidents and had an alarmingly high severity rate. Specifically, in a 37-month period before the barrier was installed, 24 accidents were investigated by police. There were two fatalities and seven Type "A" injuries, i.e., visible signs of injury (bleeding, distorted members, etc.) or victim had to be carried from the site. Two injuries were Type "B" (bruises, abrasions, swelling, etc.) and one was a Type "C" injury, i.e., no visible injury but complaint of pain or momentary unconsciousness; fourteen were non-injury accidents. Ten of the accidents occurred in daylight and fourteen in darkness.

Figure 30. Location 3(c) as it Existed Until May 1970.



To decrease the severity of accidents in this gore area, plans were made to increase the recovery area between the bifurcating roadways by filling back to the bridge structure, turning the guardrail on a longer radius, and installing a Fitch barrier. This procedure would provide a crash cushion and also increase the recovery area by some 100 feet. Figure 31 shows this gore area after guardrail removal and leveling.

The Fitch Inertial Barrier system, containing 43 modules, was installed on August 13-14, 1970. The system is schematically depicted in Figure 32; the barrier installation was previously shown in Figure 7. At the time of installation, modules cost \$120 each, making the cost of materials for the initial installation approximately \$5500.

In almost two years since the barrier was installed, four accidents have occurred. Increased recovery area and possibly the conspicuous nature of the Fitch barrier itself are considered responsible for this large decrease in accidents. Of the four hits, only one was a major impact with the barrier (on February 11, 1971) destroying eight modules as shown in Figure 33. This apparently was a drive-away situation since no police report was made. The path of the errant vehicle was such that it could have hit a bridge wing had the barrier not been present. Each of three minor impacts of the barrier involved sideswiping of two modules near the rear of the barrier and adjacent to the mainline flow of traffic. Two of these three were apparently drive-away situations; however, one involved the most serious injury to date at a barrier location in Kentucky. The accident occurred on October 11, 1971. The vehicle left the roadway, nearly missed the barrier, but shattered two rear modules adjacent to the mainline, then rode atop the guardrail, knocked down a light standard, and finally hit the bridge wing ahead. The driver was hospitalized overnight with Type "A" injuries.

The average cost of replacement for these four hits and vandalism damages was \$146 per module. Included in this cost were materials, labor, and equipment usage. Table 2 summarizes information concerning hits at this location.

One problem encountered at this location was the cross slope of the gore area. It is believed to have caused several, lighter, top-heavy, modules to tip over under their own weight as a result of the strong axes of the inserts being placed along the slope. Another problem is the rather unpleasing appearance the barrier has developed with time. Specifically, the barrier is dirty, due to vehicle spray and dust.

Figure 31. Location 3(c) after Guardrail Removal and Leveling.

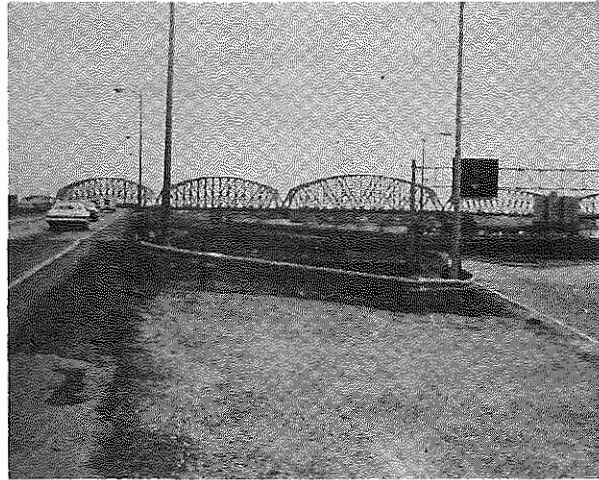


Figure 32. Schematic of Fitch Inertial Barrier at Location 3(c).

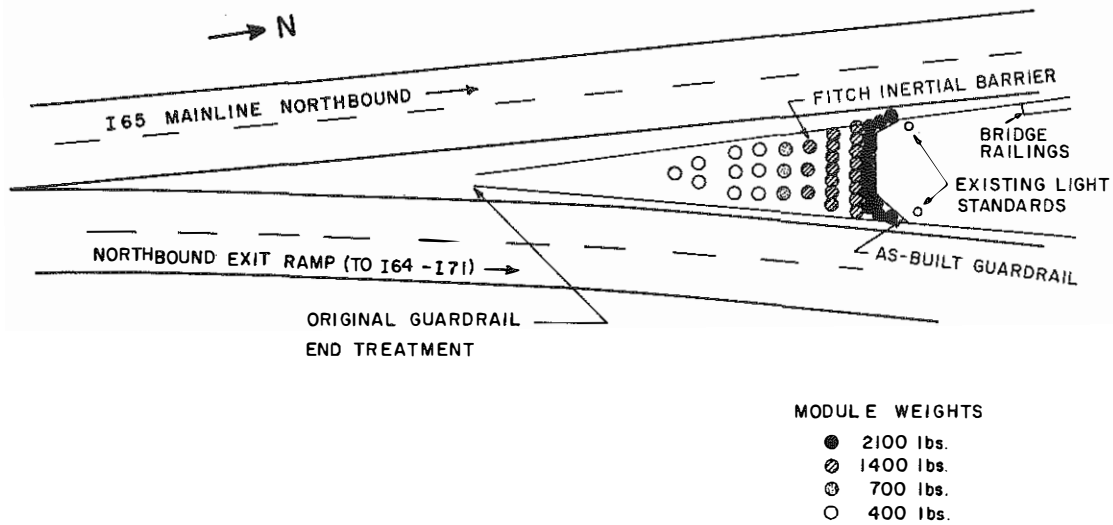


Figure 33. Aftermath of a Major Impact at Location 3(c).



TABLE 2

SUMMARY OF IMPACTS WITH FITCH BARRIER AT LOCATION 3(c)

HIT NO.	DATE	MODULES DESTROYED	INJURIES	REPLACEMENT COST	REMARKS
1	2/11/71	8		\$ 1168	No Record
2	2/17/71	2		\$ 292	No Record
3	10/11/71	2	Hospitalized Overnight	\$ 292	Damage to Guardrail and Light Standard
4	1/12/72	2		\$ 292	No Record

HI-DRO Cushion at Location 3(a) -- Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65), Southbound secondary gore between Ramps 4 and 8

Figure 34 pictures this site prior to the installation of the HI-DRO Cushion system. The site was deemed appropriate for a barrier installation because of its potentially hazardous configuration and because a site inspection showed positive proof that this area had been the scene of several accidents -- which, for various reasons, were not reported to the Louisville Police Department.

A HI-DRO Cushion system was chosen primarily for research or comparison purposes and because of length and width restrictions of the gore area. The system, designed by Energy Absorption Systems, Inc., Sacramento, California, was delivered and installed at a cost of \$6100. Installation was by state forces in September 1970. The barrier is shown in Figure 5.

Since installation, there have been four known hits. All were rather insignificant, and none was reported to the police. Apparently no injuries were sustained. Three of the four impacts were recorded on film by a camera monitoring system. Circumstances contributing to the first hit, which was of least significance and probably involved contact with only a restraining cable, are unknown. The most severe damage was obvious vandalism; a late model car slowly but intently approached the front of the barrier; the driver then applied power and pushed the barrier back some three feet. Another filmed hit revealed snowy roadway conditions and an out-of-control vehicle sliding sideways into the front of the barrier system. These first two hits were recorded by the camera system under nighttime conditions. The most recent hit occurred during wet daytime conditions and involved a

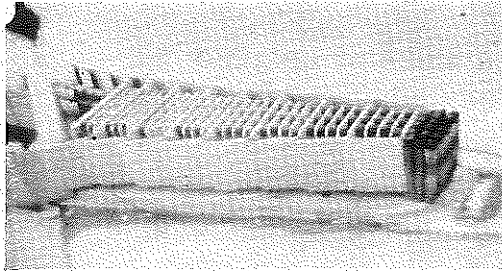
six-wheeled, Pepsi-Cola Truck. Figure 35 is a sequence of photos made from the movies of this impact. The driver paused long enough to help his co-worker, who was thrown to the floor, back to his seat and then drove away.

All four impacts involved very minor damage to the barrier system. Following the vandalism hit, which was the only hit to involve significant barrier displacement, the barrier was repositioned without difficulty. The repair cost, including labor, materials and equipment usage, was estimated at \$60 for each of the first three hits. Table 3 summarizes the available information pertaining to these four impacts.

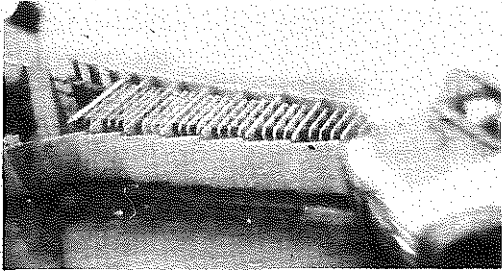
Figure 34. Location 3(a) Prior to Installation of a HI-DRO Cushion System.



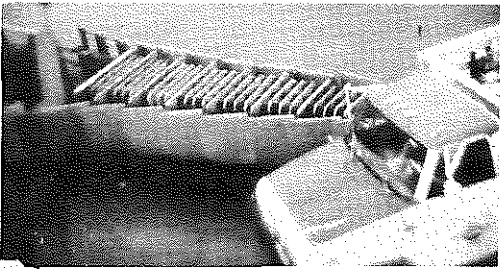
Figure 35. Impact of a Six-Wheeled Truck with HI-DRO Cushion at Location 3(a).



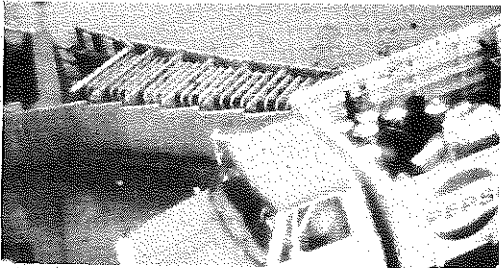
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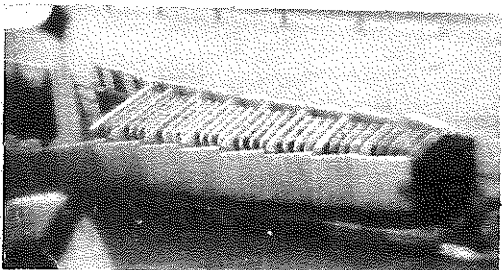
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TABLE 3

SUMMARY OF IMPACTS WITH HI-DRO CUSHION AT LOCATION 3(a)

HIT	DATE	INJURIES	REPAIR COST	REMARKS
1	2/71		\$60	
2	6/23/71		\$60	On Film; Vandalism
3	11/23/71		\$60	On Film; Snow conditions; Vehicle slid into barrier sideways
4	2/72		Not Available	Wet Daytime conditions; 6-wheeled truck

Problems encountered at this location have been threefold: 1) concrete curb considerations, 2) freezing of liquid in individual cells, and 3) inability of side panels to stay in position. At the time of installation of the HI-DRO Cushion System, removal of the concrete curb was thought to be impractical and the barrier was installed atop the curb. This practice has been the subject of considerable debate and criticism due to possible adverse ramping effects of the curb. However, it was not possible to assess the effects of the concrete curb because of the low speeds at which the barrier was impacted. It appears that the optimum situation would entail deletion of such curbs. Future plans are to eliminate the curb in the design stage or to remove it at existing locations before barrier installation if no structural damage to the bridge would result.

On several inspections of the system during winter months, alarming amounts of frozen liquid in the cells were observed. This appeared to be the case during the impact recorded on film during snowy conditions. Obviously, this condition significantly reduces the effectiveness of the barrier. District 5 engineers attributed the freezing to the inability to obtain proper solution of calcium chloride in the water in individual cells.

Finally, the problem of side panels not staying in position was encountered. This is an unpleasing attribute as well as a potential hazard to motorists. The panels are held in place by a small fender panel clip which merits the attention of the manufacturer.

HI-DRO Cushion at Location 3(b) -- Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65), Northbound secondary gore between Ramps 3 and 6

Figure 36 pictures this site prior to installation of the HI-DRO Cushion system. This site was also chosen for an impact attenuator due to its hazardous configuration. Inspection of the site showed visible signs of accidents -- not reported to the Louisville Police Department.

A HI-DRO Cushion system was designed by the manufacturer, and materials and costs were \$6275. It was installed in early September 1970 and is pictured in Figure 6.

Since installation, there has been only one known impact; this occurred on January 14, 1972. Contributing circumstances are unknown since no police report was made. The hit was of such magnitude that the barrier had to be taken to the district garage for repairs. Total cost for repair (including labor, materials and equipment usage) was \$321. Evidently, the impact was at a relatively high speed or involved a large vehicle.

Figure 36. Location 3(b) Prior to Installation of the HI-DRO Cushion.



This HI-DRO Cushion was also installed atop a concrete curb and was subject to other problems discussed previously. However, the concrete curb at this location was larger than the one at Location 3(a), and consequently more of the curb remained exposed after the barrier was installed. Apparently, the ramping effects were not severe in the impact since the vehicle was presumably driven away after causing very substantial damage to the barrier.

Fitch Barrier at Location 7 -- Kenton County; I 75 - Fifth Street Interchange, Gore at southbound exit ramp

Figure 37 pictures this site prior to installation of a Fitch barrier. In a three-year period before installation, 33 police-investigated accidents were reported. Fifteen of the accidents were classified as "rear-end", six were "obliques", five were "fixed objects", five were "single vehicle", and two accidents were "multiple rear-ends". The road surface was dry during 20 of the accidents and wet during the other 13 accidents. One of the accidents took place at dusk, 15 in daylight and 17 in darkness. Twelve injuries were Type "A", nine injuries were Type "B" and ten were Type "C". In 20 accidents, there was no indication of injury. There were no fatalities.

The Fitch Inertial Barrier System, containing eleven modules, was installed on November 5, 1970. The design schematic is illustrated in Figure 38; the actual installation is shown in Figure 13. This barrier was designed by the Division of Research using the manufacturer's design manual (11). Total cost of materials and installation was \$1513.

As of May 1, 1972, the barrier had been impacted 18 times. Magnitudes of the impacts ranged from very little damage to almost complete destruction of the barrier. Six impacts were police-reported accidents. Six impacts (including one police-reported impact) were also recorded on film by the camera monitoring system. Thus, some record of 11 of the 18 impacts was made; unrecorded accidents were considered drive-away situations. In all, 12 impacts were designated as drive-away situations. Of the six police-investigated hits, after which vehicles had to be towed from the scene, four involved no injuries, one involved a Type "A" and a Type "B" injury, and one a Type "C" injury. Eight impacts occurred during darkness and two during daylight. Light conditions under which seven accidents occurred are unknown. While the number of before and after accidents was roughly the same, severity of injuries was decreased substantially after the barrier was installed. It should be noted that some "before" accidents might not have been reported if they were drive-away situations, whereas there was visual evidence of all accidents after the installation of the barrier. Five

of the six known drivers were interviewed by Research personnel. Three stated they felt the barrier had saved their lives. One felt he would not have hit anything had the barrier not been installed, and one was indifferent.

Since there was such a large number of impacts at this location, each one will not be discussed separately; instead, Table 4 is presented as a summary of these accidents. Figure 39 shows the aftermath of Hit 6 at Location 7. Figure 40 is a sequence of photographs made from the filmed record of an actual impact.

As of May 1, 1972, there had been a total of 100 modules destroyed. District 6 engineers submitted cost estimates so that overall estimates could be calculated. Based on this information (Table 4), the cost of replacement (including labor, materials and equipment usage) was found to be \$136 per module. Thus, the total cost of maintenance was estimated at \$13,600.

Obviously, the frequency of hits and the corresponding high maintenance costs were the main problems at this location. The bridge wall at this site is fronted by a 22-foot long curb of gradually decreasing height. At the time of installation, it was decided that removal of the curb was impractical, and plans were made for the installation of the Fitch modules on the curb itself. However, width and cross slopes of the curb interfered. Consequently, the 24-foot long barrier was placed ahead of and in front of the 22-foot curb. Available recovery area was diminished; and, possibly, some hits would not have occurred had this not been done.

Figure 37. Location 7 Prior to Installation of the Fitch Inertial Barrier.



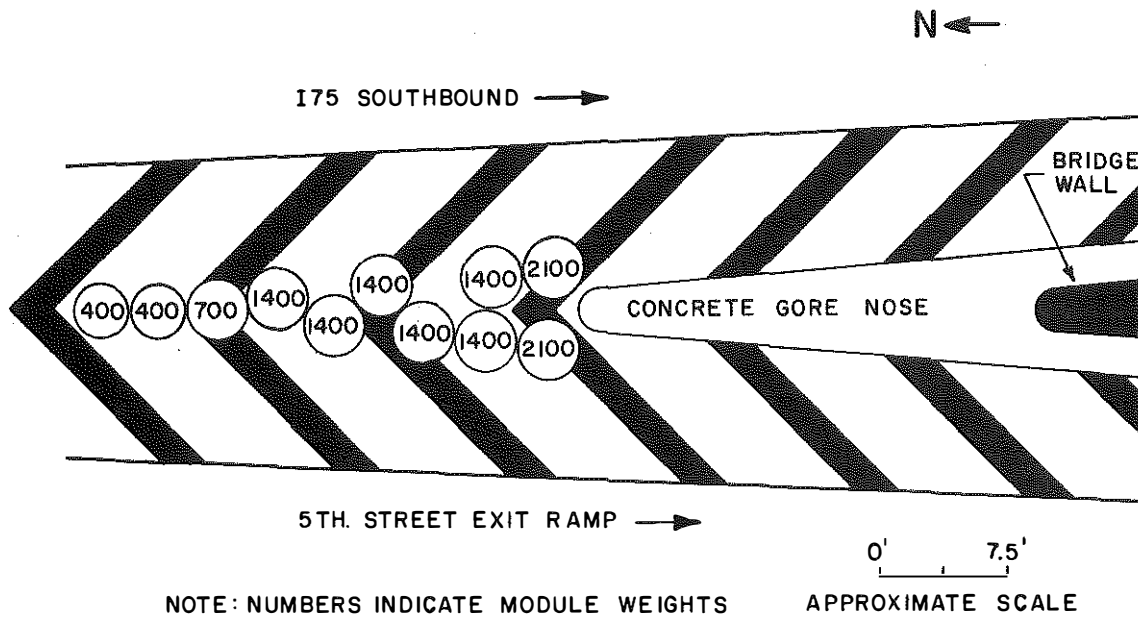


Figure 38. Schematic of Fitch Inertial Barrier at Location 7.

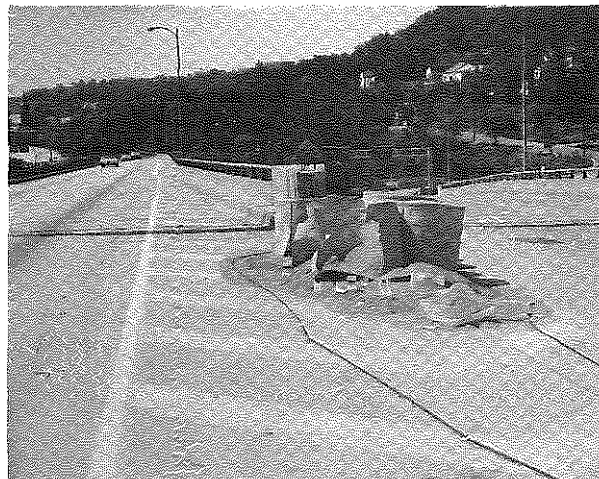
Other problems were observed at this location. Apparently, bridge vibrations caused at least two modules to split along a riveted seam. No other explanation could be offered. Also, the camera monitoring system, when actuated by maintenance personnel removing debris and reinstalling modules after impacts, showed wet sand being shoveled from the roadway and put into replacement modules. This practice seemed to invite adverse performance of the barrier during freezing weather.

Due to unusually high maintenance costs and recovery area constraints of this Fitch installation, a decision was made to replace the Fitch system with a HI-DRO Cushion. The concrete curb was removed down to a horizontal plane at the through-lane gutter line, and a HI-DRO Cushion was installed on the leveled portion on October 19, 1972. Cost of the system, excluding installation costs, was \$8,157.

Fitch Barrier at Location 14 -- Jefferson County; I 64 I 264 (New Albany) Interchange, Northbound directional split from I 264 to I 64.

Figure 41 pictures the site as it existed before modifications and installation of a Fitch barrier. Prior to installation, this site was only partially open to traffic. Consequently, no attempt was made to obtain accident data before the installation.

Figure 39. Impact No. 6 at Location 7 (7 Barrels destroyed).



The concrete curb and sodded area in front of the bridge wall were completely removed and replaced with bituminous paving -- thus making the gore area fairly level and flush with both roadway edges. The barrier was installed on July 2, 1971. During installation, it was decided to install an additional 1400-pound module in the third row from the rear. With this addition, the barrier contained 25 modules and is shown schematically in Figure 42 (see Figure 25). Total cost of materials and installation was \$3,738.

TABLE 4

SUMMARY OF IMPACTS WITH FITCH BARRIER AT LOCATION 7

IHT NO.	DATE	MODULES DESTROYED	INJURIES	REPLACEMENT COST	REMARKS
1	1/24/71	8	None	\$ 1088	Driver fell asleep
2	2/15/71	2		\$ 272	No record
3	4/1/71	8		\$ 1088	No record
4	4/7/71	3		\$ 408	No record
5	5/8/71	1		\$ 136	No record
6	5/23/71	7	Cuts, Bruises, Chipped Tooth	\$ 952	Tire blowout
7	8/8/71	9	None	\$ 1224	Heavy Fog
8	11/8/71	7	None	\$ 952	Ice, wind; Truck involved
9	11/21/71	6		\$ 816	On film (head-on)
10	11/28/71	2		\$ 272	On film (Sideswipe)
11	11/28/71	NA			On film (bump)
12	12/11/71	7		\$ 952	No record
13	12/25/71	6		\$ 816	No record
14	1/4/72	9		\$ 1224	Forced into barrels by truck
15	1/10/72	4		\$ 544	No record
16	2/9/72	3		\$ 408	On film (Snowy conditions)
17	2/15/72	9		\$ 1224	On film (too dark)
18	4/29/72	9	None	\$ 1224	Driver fell asleep

*Based on an average cost of replacement per module

Figure 40. Photographs of Actual Impact in Progress at Location 7. (Vehicle Backing Away from Damaged Barrier in Photograph No. 5).



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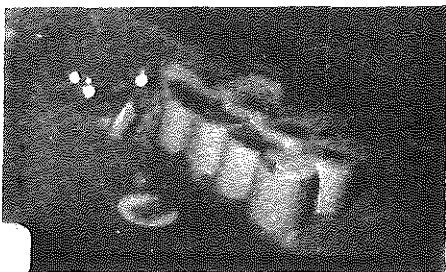
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Figure 41. Location 14 Prior to Installation of a Fitch Inertial Barrier

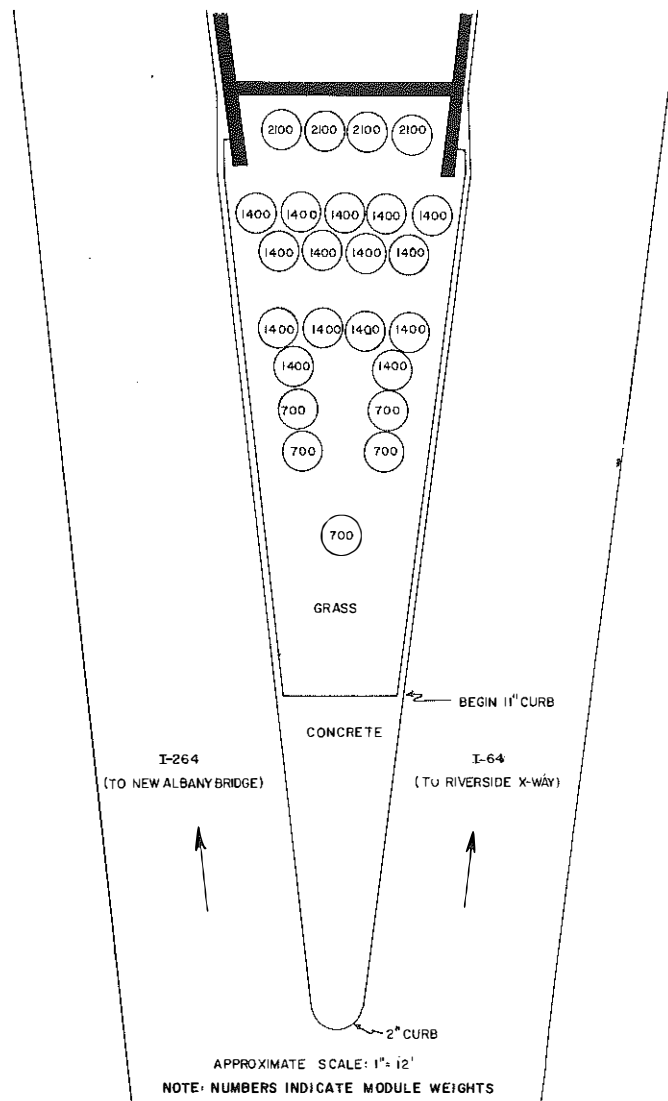
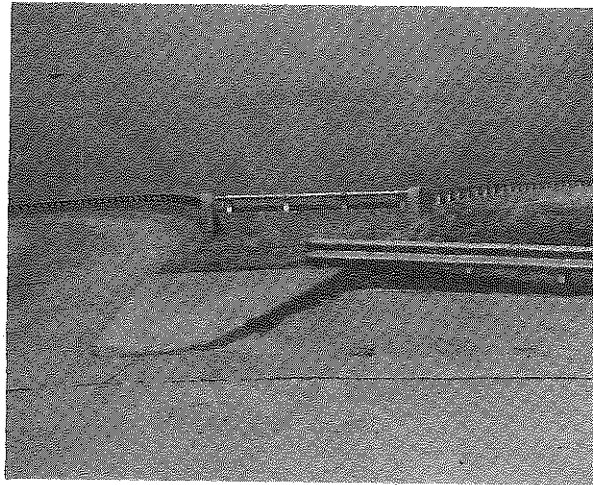


Figure 42. Schematic of Fitch Inertial Barrier Designed for Location 14.

There have been two impacts with this barrier -- both were major. The first hit occurred on November 7, 1971; 18 modules were destroyed. Figure 43 shows the aftermath of this first impact. The second hit, in which 19 modules were destroyed, occurred on January 29, 1972. There were no police reports of these apparent drive-away situations. Considering the apparent magnitude of these impacts, the Fitch system was extremely effective. Costs of replacement modules, including 10 which were vandalized, are shown in Table 5.

This site was relatively problem-free. However, District personnel complained of excessive sand and debris after impacts, causing some disruption of normal traffic flow. Research personnel also noted some freezing of moist sand during winter. Special Provision No. 86-A requires that the modules contain a sand-salt mixture (95 percent air-dried natural sand and 5 percent commercial quality salt thoroughly mixed with the sand to prevent freezing).

CAMERA MONITORING SYSTEM

To more thoroughly evaluate the effectiveness of the barriers, several locations were monitored with movie cameras actuated by the encroaching vehicle. The Texas Transportation Institute's experience (12) with camera monitoring systems of this type was reviewed and used as a guide.

The first system was installed in August 1970 at the Fitch barrier at Location 3(c) -- Kennedy Interchange, I 65 northbound mainline exit -- and was described in detail in a previous report (3). This system employed a single camera and was found to be inadequate for nighttime photography. Consequently, two movie cameras -- one adjusted for daylight conditions and one for nighttime conditions -- were installed. A general description of the dual-camera monitoring system is presented in Figure 44. Vehicle actuation was accomplished by securing pneumatic tubing around the energy absorbing barriers. The tubing was connected to air relays located at the rear of the barrier. When an encroaching vehicle passed over the tubing, the relay in the power supply box was actuated, which in turn sent power from two 12-volt car batteries connected in series to the camera.

The photo electric cell which controlled the interchange lighting was also responsible for the day or night camera being in a ready state. The interchange voltage was stepped down to 110 volts AC; when these lines received current, i.e. at nighttime, a 110-volt AC relay in the power supply box was actuated, removing the day camera from a ready state and putting the night camera into a ready state. Also, by utilizing available interchange power, the car batteries were recharged at night as needed.

Figure 43. Aftermath of an Impact at Location 14.



TABLE 5

SUMMARY OF IMPACTS WITH FITCH BARRIER AT LOCATION 14

HIT NO.	DATE	MODULES DESTROYED	INJURIES	REPLACEMENT COST	REMARKS
1	11/7/71	18		\$ 2790	No record
2	1/29/72	19		\$ 2945	No record
	Vandalism	10		\$ 1550	Vandalism

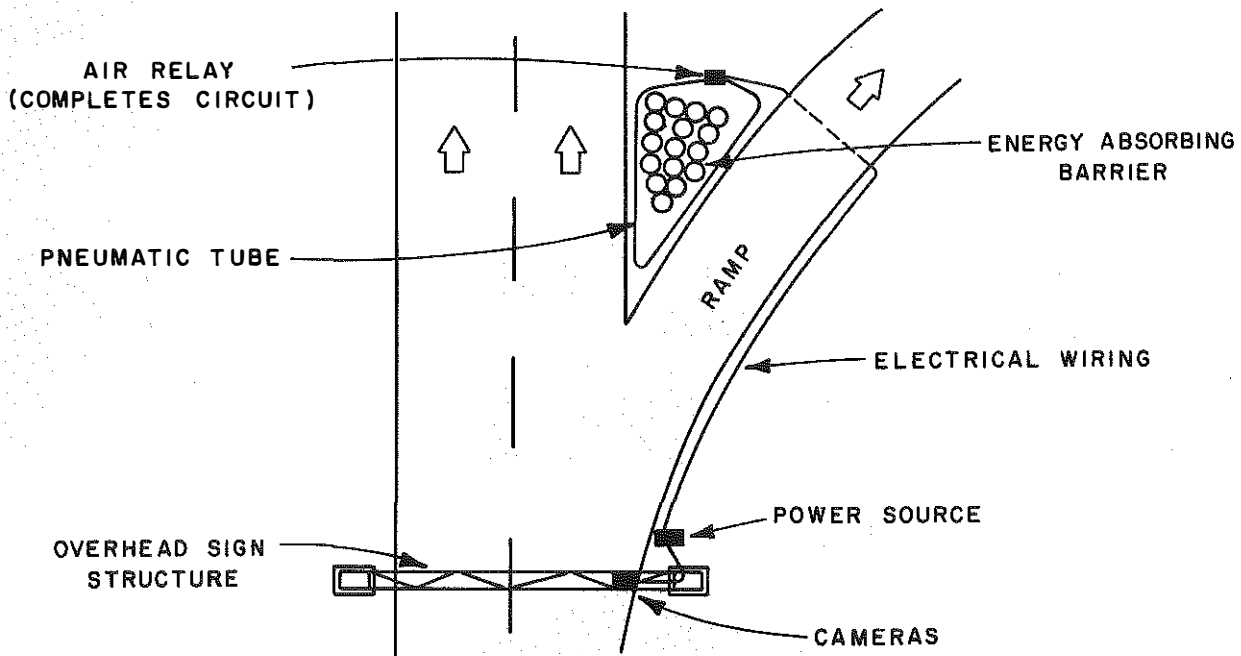


Figure 44. Site Schematic for Dual-Camera Monitoring System.

When a camera was actuated, it ran for a predetermined time (about 15 seconds), after which a time-delay-relay interrupted the circuit and turned the camera off. Electrical counters were included in the power supply system so that quick checks could be made of film footage remaining in the cameras at any given time. A circuit diagram of the entire system is shown in Figure 45.

Cameras selected were 16 mm, U.S. Army gun cameras, Types N-1 and AN-N6. They were mounted in plywood housings with plexiglass fronts; the housings were positioned on overhead sign structures at the gore area. The dual cameras and housing are shown in Figure 46. The day camera was loaded with color, daylight type film; the night camera with 4x reversal black and white film which was forced two stops in the development process.

Three dual camera monitoring systems were installed, and experience with each will be discussed separately. The first such system was installed on April 7, 1971 at the Fitch barrier at Location 3(c) - replacing the single camera system previously employed. Due to the extensive use of this large gore area by motorists and the corresponding difficulty of maintaining the cameras with unexposed film, none of the four hits at this location was recorded on film. Near hits and erratic maneuvers showed some driver indecision. It was also observed that stopping for hitchhikers seems to be a primary usage of gore areas.

The second dual camera system was installed at the Fitch barrier on I 75 near Covington (Location 7: Kenton County; I 75 - Fifth Street Interchange, Gore at southbound exit ramp) on April 29, 1971. The night camera was later equipped with a more suitable lens and the quality of nighttime film improved. Fourteen hits occurred at this location after the camera system was installed. Six of these impacts were actually recorded on film, although two turned out much too dark for adequate viewing and analysis. All were recorded by the night camera.

The third camera system was installed at a HI-DRO Cushion in Louisville (Location 3(a): Jefferson County; Kennedy Interchange (I 71 - I 64 - I 65), southbound secondary gore between Ramps 4 and 8) on May 14, 1971. Figure 47 is a photograph of this camera monitoring system. Three hits occurred at this location after the camera system was installed. All three were recorded on film - two by the night camera and one by the day camera. None of these hits was of the high-speed, high-damage type.

Plans were made to monitor a steel drum type installation with a fourth camera system since a barrier installation of this type appeared imminent. However,

installation of a steel drum barrier has not yet been accomplished.

ECONOMIC COMPARISON

Table 6 shows a summary of estimated costs as of May 1, 1972. Portions of this table were derived from cost estimates submitted by Districts 5 and 6.

Modules for the Fitch system on I 75 in Kenton County were ordered on four separate occasions. Since bidding was involved, prices varied from one order to the next. The first order involved a price of \$120 per module, the second, \$135 per module, the third \$132.50 per module and the fourth, \$95.70, \$100.10 or \$104.50 per module depending on core size. Because all orders were for the same quantity (40) and because it is anticipated that replacement stock will be virtually exhausted when the HI-DRO Cushion is installed at this site, it was justifiable and necessary to average these prices to obtain an average price of \$122 per module for estimating purposes. For Locations 3(c) and 14 in Louisville, modules were purchased for \$120 each and \$130 each, respectively. Correspondingly, these prices were used in computing cost estimates for these sites. Unused replacement modules were not included in the cost estimates.

Both HI-DRO Cushion systems (Locations 3(a) and 3(b)) in Louisville were installed by State forces. Each system required five men one week to install. Labor costs were estimated to be \$600 for each system and are included under initial cost in Table 5.

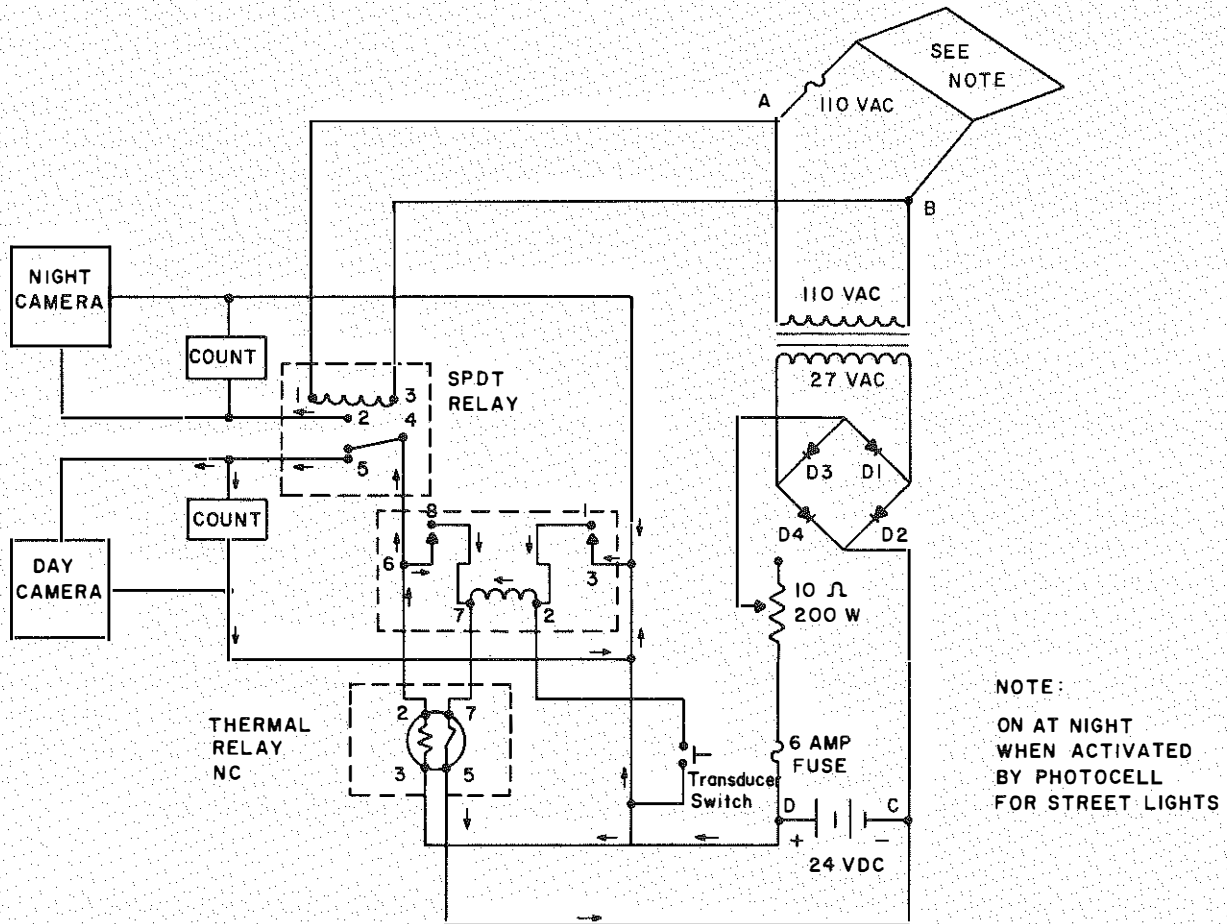
BARRIER-TYPE SELECTION CRITERIA

Based on experience to date, decision-making criteria regarding barrier-type selection are:

1. Performance requirements
2. Gore area and rigid obstruction dimensions
3. Available recovery area
4. Redirectional capabilities
5. Initial and maintenance costs
6. Ease of installation and replacement
7. Aesthetics
8. Other considerations

Performance Requirements

The Federal Highway Administration has suggested the following criteria be used for testing and evaluating vehicle impact attenuation devices (13). All three barrier



CIRCUIT DIAGRAM : CAMERA MONITORING SYSTEM

Figure 45. Dual-Camera System Circuit Diagram.

Figure 46. Cameras and Box before Installation.

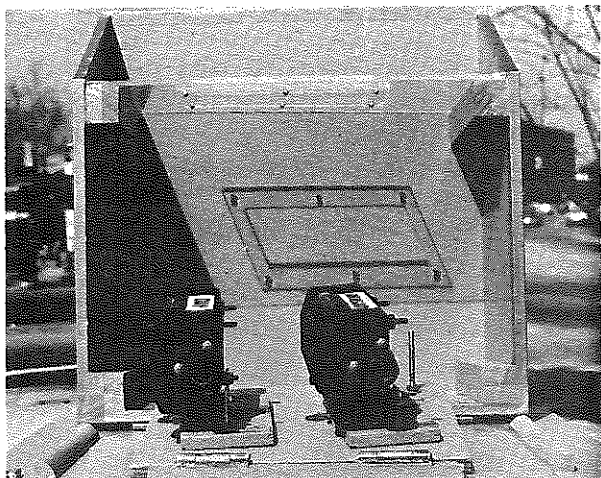


Figure 47. Camera Monitoring System at Location 3(c).



TABLE 6

COST ESTIMATION SUMMARY

BARRIER	INSTALLATION DATE	INITIAL* COST	TIMES HIT	REPAIR COST COMPARISONS	TOTAL MODULES REPLACE	TOTAL MAINTENANCE COST	TOTAL COST TO DATE‡
FITCH Location 3(c)	Aug 13-14, 1970	\$ 5978	4	\$146/module	18	\$ 2628	\$ 8,606
HI-DRO CUSHION Location 3(a)	Sept 1970	\$ 6100	4	\$60/hit	NA	\$ 240	\$ 6,340
HI-DRO CUSHION Location 3(b)	Sept 1970	\$ 6275	1	\$321	NA	\$ 321	\$ 6,596
FITCH Location 7	Nov 5, 1970	\$ 1513	18	\$136/module	100	\$13,600	\$15,113
FITCH Location 14	July 2, 1971	\$ 3738	2 ⁺	\$155/module	47	\$ 7285	\$11,023

*Installation and materials cost (no stockpile). Does not include any site preparation of gore area modifications.

+10 barrels were destroyed by vandals.

‡Exclusive of unused replacement modules in stock.

types can be designed to meet these requirements:

Vehicle Weight Range: 2000 to 4000 pounds

Vehicle Speed: 60 mph

Impact Angle: Up to 25° as measured from the direction of the roadway

Average Permissible Vehicle Deceleration: 12 g's maximum while preventing actual impact or penetration of the hazard

Maximum Occupant Deceleration Onset Rate: 500 g's per second

These design criteria should result in installations which will make collisions with fixed obstacles survivable at high speeds. At this level of deceleration, existing evidence indicates that injuries of some sort are to be expected in most high-speed collisions. Lesser deceleration rates are desirable and will tend to reduce the severity and number of injury-producing accidents.

Gore Area and Rigid Obstruction Dimensions

Dimensions of the area or object to be safeguarded are important in the selection of a barrier type. Of the three barrier types under study, it appears that the HI-DRO Cushion type is most adaptable to narrow and relatively short areas. Whereas, the apparent compactness of the HI-DRO Cushion makes it more suitable for some situations, this limitation on size restricts its use considerably. From the latest inquiry pertaining to the size of the HI-DRO Cushion barrier, standard sizes were available up to 8 feet wide, and special units could be constructed up to 12.5 feet wide at a 10 percent increase in cost.

Even though this study indicated some advantages of the HI-DRO Cushion for narrow and short areas, it should be reported that the manufacturers of both the Fitch Inertial Barriers and the Steel Crash Cushion advertise their products as being adaptable to these areas (6, 7).

For any gore area or obstruction greater than 12.5 feet wide, only the Fitch Inertial Barrier and the Steel Crash Cushion were considered. Inasmuch as three Fitch Barriers and no Steel Crash Cushions have been installed, a real comparison of their effectiveness at installations of various widths cannot be made. From experience gained by others, it appears that the width of the area is not important when choosing between these two types of barriers.

Available Recovery Area

Available recovery area is somewhat related to dimensions of the area and rigid obstructions; this factor was emphasized already in regard to the selection of a barrier type. In the design of all three barrier types,

available recovery area was influential in determining which type was most suitable for a particular situation. In general, the Fitch Inertial Barrier and the Steel Crash Cushion require more space to stop a vehicle than does the HI-DRO Cushion under the same conditions. A specific example is the I 75 - 5th Street exit in Covington which required a 24-foot long Fitch Inertial Barrier; the barrier is being replaced by a 17.5-foot long HI-DRO Cushion. This increased recovery area is certainly a major consideration. When attempting to differentiate between barrier types based on available recovery area, it is advisable to design each of the three barriers using the same design criteria and determine if there are significant differences.

Redirectional Capabilities

Ability of a barrier to redirect a vehicle rather than "snag" or "pocket" (or cause severe rotation) is desirable and effective in many cases but not a characteristic of all barrier types. The Fitch Barrier does not effectively redirect a vehicle but tends to slow the vehicle and keeps it from re-entering the traffic stream in an out-of-control condition. Both the HI-DRO Cushion and the Steel Crash Cushion have redirectional capabilities which benefit the errant vehicle unless it is impacted by another vehicle when re-entering the traffic stream.

Redirecting-type barriers also have a ramping tendency, Wood side panels, used in both the HI-DRO Cushion and Steel Crash Cushion barriers, were designed as redirecting devices but have contributed to ramping in some cases. Several modifications have been made, but the ramping problem still persists. A choice of barrier type should include evaluation of the desirability of redirecting capabilities. In many high volume locations with restricted weaving areas, the decision may be to forego the advantage of redirecting.

Initial and Maintenance Costs

Initial-cost estimates are available for all three barrier types, and maintenance costs are available for HI-DRO Cushions and Fitch Inertial Barriers. It appears that the initial costs for HI-DRO Cushions are somewhat greater than the other two barrier types. Initial costs for the Steel Crash Cushion appear to be the least (based on recent price quotations).

Maintenance costs for the three types of barriers are more difficult to evaluate because of the varying costs associated with impacts of differing degrees of damage. A valuable comparison of maintenance costs will be available in the future as the result of a Fitch Inertial Barrier being replaced by a HI-DRO Cushion at the I 75 - 5th Street Exit in Covington. Approximately

two years of documented maintenance experience has been gained at this Fitch Inertial Barrier site, and experience with the planned HI-DRO Cushion could provide a rather unique economic test of these two devices.

It should be emphasized that economic aspects are important, but they become subordinated by other safety-oriented decision-making criteria.

Ease of Installation and Replacement

Only the Fitch Inertial Barrier and HI-DRO Cushion have been installed in Kentucky to date. The Fitch Inertial Barrier is by far the least troublesome to install. Estimates from Syro Steel Company indicate the Steel Crash Cushion is probably similar to the HI-DRO Cushion with respect to ease of installation.

Both the Fitch Inertial Barrier and the HI-DRO Cushion are relatively easy to replace. Damaged Fitch barrels need only to be replaced by new ones and filled with sand; HI-DRO Cushion cells require unfolding the accordion-like cells and refilling them with water. Severe impacts into the HI-DRO Cushion sometimes require the device to be disassembled for repairs. No experience has been gained with the Steel Crash Cushion, and comments about the ease of replacement were drawn from conversations with representatives of Syro Steel Company. Judging from the physical characteristics of the Steel Crash Cushion, it appears that damaged steel barrels and connectors would be more difficult to replace and repair than the other two barrier types.

Aesthetics

None of the three types of impact attenuating devices are particularly pleasing from the driver's view. The bright yellow color of the Fitch barrels makes them appear more obvious as compared to the gray and black HI-DRO Cushion. The scattered appearance of the Fitch

barrels is contrasted by the compactness associated with the HI-DRO Cushion. The Steel Crash Cushion is very similar to the HI-DRO Cushion in appearance, but failure to replace damaged or bent barrels could degrade the appearance. Also worthy of attention is the tendency for yellow Fitch barrels to gradually take on an unpleasing appearance as a result of deposits of dirt, grime, oil, etc. from passing vehicles.

Other Considerations

Although the HI-DRO Cushion has inherent advantages which make them appear very desirable in many instances, there are problems which should be mentioned. A noticeable deterioration of the vinyl plastic cells has been observed at the two HI-DRO Cushion locations. Both have been installed for approximately two years; however, it appears that a longer period without deterioration could be expected even though the devices appear to have suffered no functional damage.

The necessity for adding calcium chloride to the water in the HI-DRO Cushion cells requires considerable attention in the freezing months to insure that the device remains fluid. A similar problem exists with sand in the Fitch Inertial Barriers during the winter months. Five percent of the mixture should be calcium chloride. This problem may arise when a maintenance crew is sent to repair and refill damaged sand containers without the proper mixture.

At least two Fitch barrels have split along riveted seams as a result of vibrations on elevated sections of roadway.

WARRANTS AND JUSTIFICATION

1. Inasmuch as safety barriers are necessitated by former design standards or currently unavoidable design situations (14), it is the responsibility of the highway designer to evaluate all alternatives.
 2. Alternatives may lie between construction cost considerations and reductions in accident and maintenance costs.
 3. Geometric considerations such as restricted sight distance may warrant installation of a safety barrier and (or) other modifications to provide ample recovery area.
 4. An exit ramp through a deep cut is an example of a site limitation where contour grading might not be feasible, and the installation of a safety barrier would then become an expedient alternative.
 5. Elevated sections of roadway with concrete bridge walls in gore areas are the most common sites for installation of an impact attenuating device. For all new construction, the Federal Highway Administration currently recommends (15) space be reserved for potential crash-cushion installations.
 6. An alternative to the installation of impact attenuating devices at off-ramp gores on bridges would be to avoid designing exit ramps on bridges wherever possible. Where this cannot be done, carry the separating lanes farther forward at bridge grade so that the so-called bridge wall is farther from the driver-error zone. Changes in grade should begin beyond the driver-error zone.
 7. Wherever possible, contour grading should be used to free the gore area of obstructions and provide a clear recovery area for out-of-control vehicles.
 8. Impact attenuators should be used only when the logical evaluation of other alternatives leaves no feasible recourse.
1. HI-DRO Cushions and Fitch Inertial Barriers were found to be effective safety devices for cushioning the impact of a vehicle with a fixed object.
 2. A summary of cost per impact for each of the five installations revealed that HI-DRO Cushion costs were less than those for Fitch Inertial Barriers. Initial costs of materials and installation are generally greater for the HI-DRO Cushion as compared to the Fitch Inertial Barrier.
 3. All three energy absorbing barrier types can be designed to meet performance requirements of vehicle weights and speeds at specified impact angles and allowable decelerations of both vehicle and occupant.
 4. Gore area or rigid obstruction dimensions restrict selection of barrier type. The HI-DRO Cushion is generally more adaptable to narrow and relatively short areas. For wide gore areas and obstructions, the Fitch Inertial Barrier and the Steel Crash Cushion are more suitable.
 5. In general, the Fitch Inertial Barrier and Steel Crash Cushion require more space to adequately arrest a vehicle than does the HI-DRO Cushion.
 6. The desirability of redirection capabilities is dependent upon site geometrics, volumes, and speeds. Both the HI-DRO Cushion and the Steel Crash Cushion have redirection capabilities -- the Fitch Inertial Barrier does not.
 7. In the final selection of an impact attenuating device, safety and adequacy for a specific site may be priority considerations.

SUMMARY AND CONCLUSIONS

From a survey of the interstate system, 26 sites were considered to be eligible for safety improvements. Energy absorbing barriers have been installed at five; eleven barriers are planned; seven gore areas have been contour graded; and three sites have been dismissed from consideration. Experience gained from the installation and monitoring of three Fitch Inertial Barriers and two HI-DRO cushions is the basis for the majority of the following comments. General observations pertaining to the Steel Crash Cushion device were drawn from the manufacturer's literature and conversations with their representatives.

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