ROADSIDE SAFETY

John A. Deacon
Assistant Professor of Civil Engineering
University of Kentucky
Lexington, Kentucky

I. INTRODUCTION

It has been encouraging to observe in recent years the increasing attention that has been focused on improving the safety of traffic operations on the highways and streets of our nation and elsewhere. The talents of the highway designer and manager have been combined with those of many others including educators, enforcers, manufacturers, regulators, and lawmakers to offer a heretofore unprecendented challenge to the rapidly increasing highway accident toll. The highway engineer has concentrated his efforts on three major facets of the problem, including (1) improved driver guidance and stimuli, (2) improved operational control, and (3) an improved fixed facility. It is the purpose of this paper to report some of the proposals that have been advanced for providing a safer fixed facility. Concern will be limited in turn to only one facet of this problem, that is, the fate of errant vehicles after they have accidently left the traveled way.

A. Severity of the Problem

Tables 1 and 2 summarize some of the results of a study of fatal accidents on the Interstate System in 1968 (4, 5). It is important to observe that of the 2,754 fatal accidents that were studied, approximately 60 percent were associated with out-of-control vehicles which left the traveled way. It is to this important aspect of the accident problem that the subject of roadside safety is addressed.

B. Consequences of Leaving the Traveled Way

When a vehicle accidentally leaves the traveled way, one or more of several consequences can occur including the following:

1. Primary consequences

   a. Control of the vehicle is regained.

   (1) Safe reentry into traffic stream.

   (2) Safe deceleration but impossible reentry due to such factors as minor vehicle damage, vehicle stuck, and psychological incapacitation of driver.

   b. Control of the vehicle is not regained.

   **(1) Collision with fixed objects.

   **(2) Overturn.

   **(3) Collision with other vehicle moving in opposite direction (primarily across the median).

   *(4) Collision with other vehicle moving in same direction (usually on original traveled way).

2. Secondary consequences

   *a. Control of vehicle regained. - Control of the errant vehicle is regained but the vehicle reenters the traffic stream unsafely (that is, reentry causes an accident which is not directly associated with the original loss of control).

   *b. Other undesirable consequences. - The original event (that is, the vehicle leaving the roadway) and its primary consequences may produce other undesirable consequences such as accidents to other vehicles as driver attention is inadvertantly directed to the initial accident, accidents associated with rescue vehicles, fire, etc.

C. Corrective Actions and Priorities

1. Undesirable consequences associated with an accidental excursion from the traveled way are indicated in Section IB by means of asterisks (* or **). Those consequences identified by double asterisks (**) are treated in some detail in this paper.

2. The mere fact that a vehicle has inadvertantly left the roadway should not be construed to mean that an accident is inevitable. We are perhaps overly prone to adopt the attitude that a driver whose vehicle leaves the roadway is at fault and therefore must suffer whatever dire consequences await him. In this regard Congressman John A. Blatnik observed the following (9):

   "It is the height of cynicism to contend that the drivers should never have left the road or that many of them must have been drunk, or that somehow the

TABLE 1 FATAL ACCIDENTS ON THE INTERSTATE SYSTEM IN 1968

Accident Type	Number	Percent
All accidents	2,754	100.00
Single vehicle accidents (66.9%)	1,842	
Ran off roadway (79.4%)	1,462	53.09
Struck object (82.6%)	1,208	
Subsequent overturn (39.7%)	480	
Struck second object (37.1%)	448	
Other (23.2%)	280	
Overturn (16.8%)	245	
Other (0.6%)	9	
Other (20.6%)	380	13.79
Multiple vehicle accidents (33.1%)	912	
Vehicle from opposing lanes (18.0%)	164	5.96
Other (82.0%)	748	27.16

TABLE 2 FIRST STRUCK OBJECT IN OFF-THE-ROAD FATAL ACCIDENTS

Object Struck	Number	Percent
Guardrail	364	30.1
Bridge or Overpass	217	18.0
Sign	97	8.0
Embankment	86	7.1
Curb	72	6.0
Divider	71	5.9
Light pole	63	5.2
Ditch or drain	57	4.7
Culvert	51	4.2
Fence (right-of-way)	28	2.3
Tree	26	2.2
Other	76	6.3
Total	1,208	100.0

driver was at fault. Why or how he left the road is not the issue. Whether he left because he was drunk, or stealing a kiss, or because he suffered a bee sting, dozed, had a blowout, was sideswiped, or was forced off is irrelevant to road builders. What is relevant is that those who are responsible for road construction recognize that the roadside is as vital to the safe operation of a vehicle as the pavement itself, and that the duty to make that roadside safe is a very real one."

3. Minimization of the rate and severity of accidents involving collision with fixed objects may be achieved in several ways. The following list is a priority ranking of possible ways to achieve this objective. For example, one should not consider taking action "e" until it has been shown that actions "a" through "d" are inappropriate.

   a. Eliminate objects.

   b. Relocate objects.

   c. Redesign traversable objects.

   d. Redesign yielding objects.

e. Redirect vehicle away from objects.

f. Reduce severity of impact.

4. Means by which the probability of overturn can be minimized include the following:

   a. Minimize the probability of collision with fixed objects.

   b. Remove low profile objects.

   c. Avoid abrupt grade changes.

   d. Use traversable slopes.

   e. Use guardrail.

5. Means by which the probability of collision with vehicles moving in the opposite direction can be minimized include the following:

   a. Physical separation of opposing traffic streams.

   b. Median barrier.

D. Multiple Design Objectives

As viewed by highway users and the highway agencies, the immediate objectives of highway design are to (1) minimize travel time, (2) minimize costs, (3) maximize capacity, (4) maximize comfort and convenience, and (5) maximize safety, all within the constraints of generally limited resources. Coupled with these immediate objectives are more long term ones such as maximization of operational flexibility and others more commonly associated with non-users such as minimization of disruption to the natural environment.

Proper design of highway facilities is thus a complex task involving multiple and oftentimes conflicting design objectives. It must be realized, therefore, that a compromise of safety objectives may sometimes be necessitated by other factors such as limited available right of way or limited financial resources. At the same time, the highway designer must be continually mindful of safety considerations and must always strive to produce the safest possible highway facility.

The safety principles and objectives outlined in this paper apply to all types and classes of highways. Strict application of these principles and objectives may be warranted, however, only for the higher-type facilities or at priority locations on the lower-type facilities.

E. Sources of Design Information

The technical literature is replete with information concerning proper design for roadside safety. However the interested reader will find summary information in three noteworthy publications including (1) "Highway Design and Operational Practices Related to Highway Safety" (10), (2) "A Handbook of Highway Safety Design and Operating Practices" (12), and (3) "Roadside Safety Design" (7). Design details may be found in these and other publications, most notably those of the Highway Research Board.

II. COLLISION WITH FIXED OBJECTS

A. Eliminate Objects

1. Objective

By reducing the number of roadside objects or hazards, the probability of collision is minimized and, hence, the accident rate for this type of accident is reduced.

2. Ways to achieve objective

   a. Reduce number of light poles. - Light poles represent one of the most frequently occurring roadside obstacles.

      (1) Mount luminaires higher. - By increasing the mounting height from 40 to 60 feet, pole spacing may be increased from 25 to 50 percent thereby reducing the required number of poles (7). Luminaire design may have to be modified accordingly, however, in order to preserve suitable uniformity ratios.

      (2) Use high-mast lighting. - For interchange illumination, flood lighting systems mounted 150 feet in height and approximately 600 feet apart will virtually eliminate the hazard associated with light poles (7).

      (3) Use in-pavement delineators and lights.- Where overhead lighting is used primarily to provide directional guidance and delineation to the driver, it may be replaced in whole or in part by lane delineators and/or in-pavement lighting systems.

      (4) Use median lighting systems. - By installing lighting poles in the median and using each pole to support two luminaires, the number of poles can be reduced by 50 percent. Such a system is particularly effective where the poles can be isolated by means of an existing median barrier system.

   b. Reduce number of signs. - In some instances it may be possible to reduce the number of signs by eliminating those that do not provide absolutely essential regulatory, warning, or guidance information. Often, too, signs facing opposite directions can be mounted back-to-back on a single pole in conjunction with a median barrier installation.

   c. Reduce use of guardrail. - It is highly imperative to realize that a guardrail is, in itself, an obstacle and should never be used unless the consequences of striking the guardrail are less severe than those which might be anticipated were the guardrail to be omitted. Table 2 indicates that a guardrail is the most frequently struck first object in off-the-road fatal accidents (Interstate System in 1968). Use of guardrails may be reduced by removing, relocating, or redesigning the hazards from which the vehicle is being protected, as well as through the use of impact attenuation devices.

d. Remove trees. - Although trees assist in developing an aesthetic environment and sometimes serve other valuable functions, such as noise reduction, their location near the traveled way should generally be prohibited unless they offer no substantial resistance to impact.

e. Prohibit utility poles near roadway. - Utility poles, as other hazardous objects having no traffic or highway related function, must never be located near the traveled way.

f. Use two span bridges. - This eliminates two major obstacles, the shoulder piers.

g. Reduce use of curbs.

(1) From a safety standpoint, the use of either mountable or barrier curbs near the pavement is undesirable since (1) impact with a curb may cause loss of control or overturn or may otherwise prevent a normal recovery, and (2) curbs trap water near or on the paved surface. On high-speed facilities, curbs should only be used where drainage, delineation, or access control can be provided in no other acceptable way.

(2) Barrier curbs should never be used at the median edge of the pavement for high-speed facilities.

h. Combine sign and light poles. - Oftentimes signs can and should be mounted on suitably located light poles thereby eliminating a potentially hazardous support structure.

B. Relocate Objects

1. Objective

Where it is impossible to completely remove an object or potential hazard from the roadside, it may be possible to relocate it a sufficient distance from the traveled way (laterally) or at a less critical location (longitudinally) in order to minimize the probability of collision.

2. Distance of relocated object from traveled way

a. Reference 12 summarizes some of the limited research which suggests that clear roadside areas of 20-, 30-, and 40-feet distance from the pavement edge should permit recovery of approximately 65, 80, and 87 percent of the out-of-control vehicles, respectively, if flat slopes are used in the recovery area. Based on this research, it has been recommended that potential hazards be placed at least 30 feet from the pavement edge.

b. The choice of a specific clear or recovery area width is a complex one and depends on the nature of the obstacle, the attainable right-of-way width, economics, design speed, and many other factors.

c. The designer should be quick to realize, however, that (1) any clear area is better than none, (2) the incremental effectiveness of increasing clear area width decreases as the distance from the pavement increases, (3) the recommended 30-foot width is not a perfectly defined point and a larger value should be provided wherever feasible, and (4) wider areas should be provided where the probability of an out-of-control vehicle is greatest, such as on curves and in gore areas.

3. Clear area

a. Increase span length for overhead sign support structures.

b. Increase span length of overcrossing bridge structures.

c. Relocate signs.

d. Relocate drainage structures. - For example, it may be possible to relocate a culvert headwall by lengthening the culvert.

e. Relocate lighting poles. - By increasing the height of luminaire mounting, it is no longer essential to place the pole immediately adjacent to pavement.

4. Mount signs on overpassing bridge structures rather than on sign supports

Overhead signs can often be effectively mounted on overpassing bridge structures. Such a location should be seriously considered whenever the desired sign location is within about 1000 feet of an existing overpassing structure (7). Figure 1 illustrates the use of an overpassing structure in this way.

5. Increase recovery area at gores

The gore area at an exit ramp is a location particularly susceptible to encroachment by out-of-control vehicles. For this reason it deserves particular attention from the viewpoint of roadside safety.

a. Avoid placing major signs or other obstacles in gore. - Figure 2 shows an unacceptable installation of a major sign in a gore area. Such signs should be located upstream from the gore.

b. Increase recovery area. - For example, in the gore of elevated structures increase the lateral and longitudinal distances from the pavement to the bridge parapet wall.

6. Exploit existing guardrail and barrier installations

a. Place sign and lighting supports and other objects behind existing guardrails, barriers and retaining walls in those circumstances in which the rail, barrier, or wall is required for other purposes such as median barriers or guardrails at steep hill slopes. Figure 3 shows an overhead sign, one support of which is designed as an integral part of the median barrier installation and the other located behind an existing guardrail installation.

b. In general, no curb of any type should be placed between the pavement and a paralleling guardrail or barrier installation.

7. Place concrete sign supports below grade

There is rarely any justifiable reason for placing any portion of a concrete sign support footing above grade. Doing so only increases the size of the hazard (increasing the likelihood of an accident) and the potential severity of impact.

8. Avoid placing signs in median

Signs applicable to one-directional travel should not be placed in medians unless a median barrier is in place, since their supports are exposed to vehicles from both directions thereby increasing the likelihood of collisions.

C. Redesign Traversable Objects

1. Objective

It is sometimes possible to modify, by design, a potential object so that it can be traversed safely by an errant vehicle thereby allowing normal driver recovery. Such objects should be so modified whether they are located within or beyond any prior designated clear or recovery area.

2. Drainage structures

Minor drainage structures such as culvert headwalls and drop inlets are particularly amenable to redesign such that they can be safely traversed by an errant vehicle.

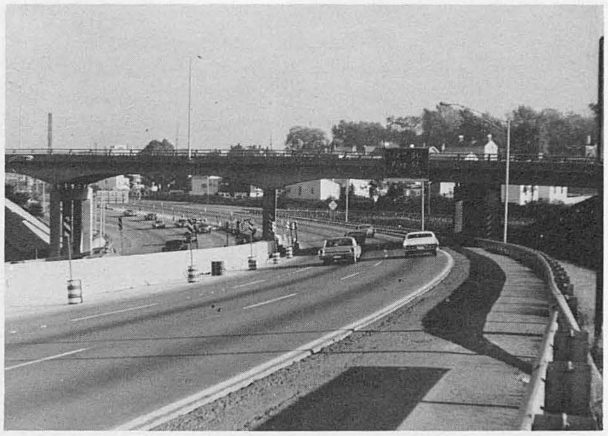

Figure 1. Sign mounted on overpassing structure.

Figure 2. Unacceptable sign in gore area.

Figure 3. Exploitation of existing guardrail and median barrier installations in the location and design of sign supports.

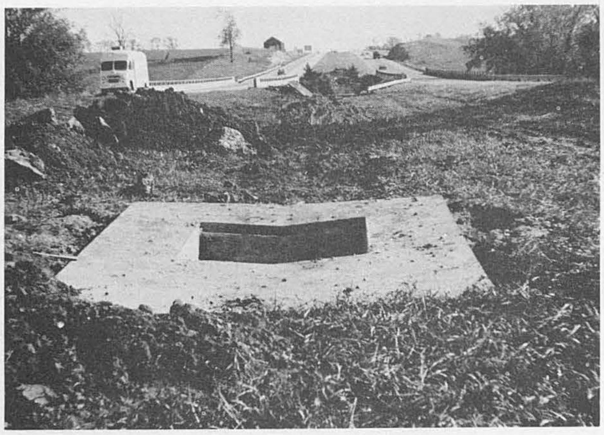

Figure 4. Traversable median drainage inlet under construction.

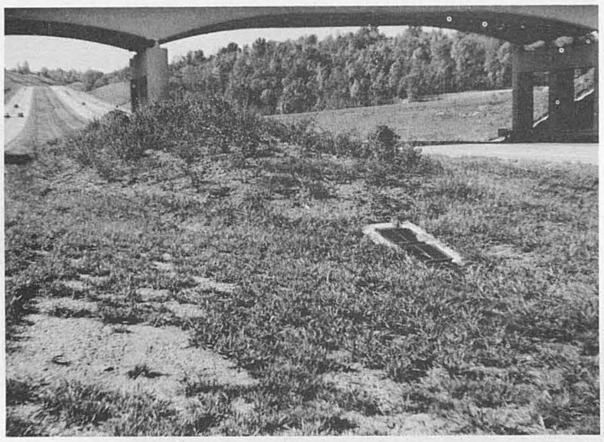

Figure 5. Traversable median drainage inlet at toe of earth berm.

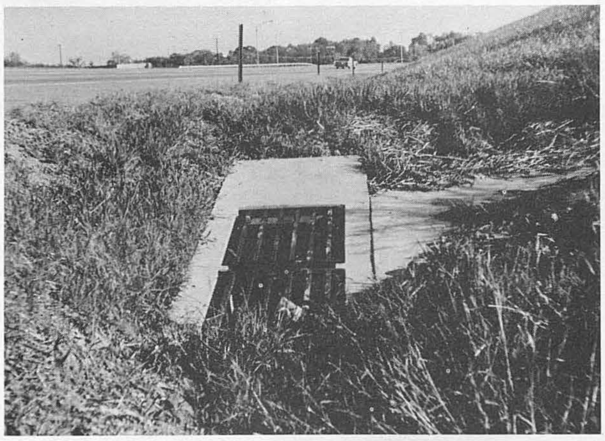

Figure 6. Cross drain in side ditch.

a. Design requirements

(1) No vertical projections above grade.

(2) Traversable grate over inlet.

(3) Proper grading of ditches (flat slopes, rounded transitions, no mounds).

(4) Capability of carrying required discharge.

b. Median inlets.

c. Ditch inlets.

(1) Cross drains

(2) Driveway or ramp culverts

d. Culvert headwalls and end walls.

e. Figures 4-9 illustrate various types of traversable drainage inlets. Surprisingly such inlets often add little or nothing to the initial construction costs.

3. Roadside drainage ditch and depressed median ditch

a. A vehicle traversing a roadside drainage ditch may be subjected to severe decelerations and perhaps overturn depending on a large number of factors including speed, angle of impact, and drainage ditch design.

b. Proper ditch design to reduce accident severity employs a trapezoidal section with rounded corners and side slopes no steeper than 4 to 1.

4. Curbs

Barrier curbs can often be redesigned as mountable curbs with an improved possibility for regaining control following impact.

5. Continuous full-width shoulders over structures

By providing continuous full-width shoulders over structures, roadway continuity is preserved and the probability of collision with the bridge parapet or approach guardrail is considerably lessened. Improved accident experience can also be anticipated due to the increased lateral distance to the "relocated" bridge rail. The vehicle in the center of Fig. 10 is on a structure across which continuous full-width shoulders have been provided.

6. Continuous medians over structures

When separate structures are used on divided highways, a potentially dangerous hole is left in the median between the two structures. Such a hazard may be eliminated by use of a single structure which carries the median across the undercrossing. Such a structure should be seriously considered for median widths less than 20 or 30 feet (10).

7. Continuous shoulders at exit ramps

a. On main line.

b. On ramp. - Figure 11 shows a discontinuous and improperly transitioned shoulder at an exit ramp. Also shown by this figure is a properly designated main-line shoulder.

8. Continuous shoulders at entrance ramps

Full width shoulders should be continued into and beyond the merging area.

9. Clear recovery area with flat traversable slopes beneath overcrossing structures

10. Holographic signing

Holographic signing offers the possibility of projecting highway signs optically so that they are perceived in their usual location but require no support structure or projection surface. A brief discussion of this experimental concept is found in Ref. 2.

11. Median crossovers

Insofar as possible, median crossovers should be eliminated from high-speed facilities. If their provision is considered to be absolutely essential, however, they should be constructed at grade if at all possible. Figure 12 shows a median crossover with an objectionable finished grade above that of the normal median cross section. A vehicle striking this "mound" would likely bound out of control.

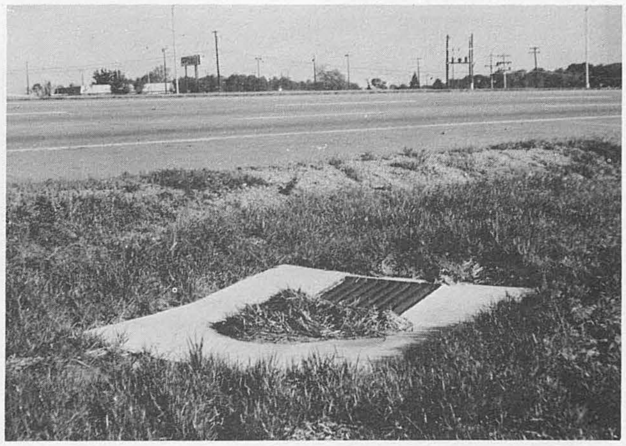

Figure 8. Traversable side ditch inlet.

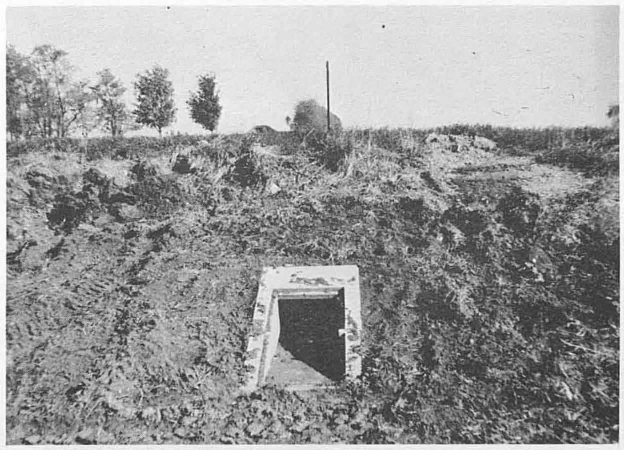

Figure 9. Traversable culvert entrance under construction.

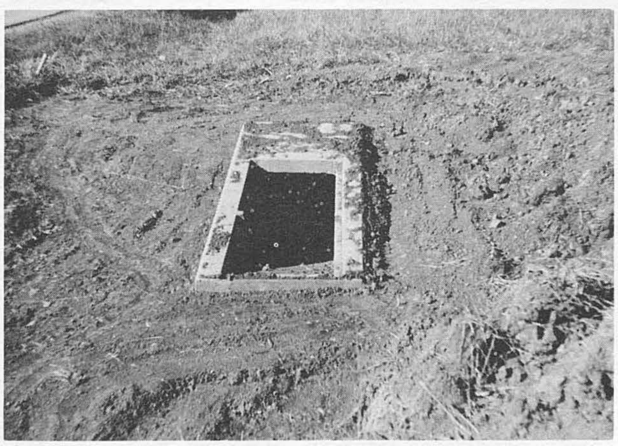

Figure 7. Cross drain in side ditch under construction.

Figure 10. Continuous full-width shoulders carried over a structure.

Figure 11. Discontinuous and improperly transitioned shoulder at exit ramp.

Figure 12. An objectionable mound created by a median crossover.

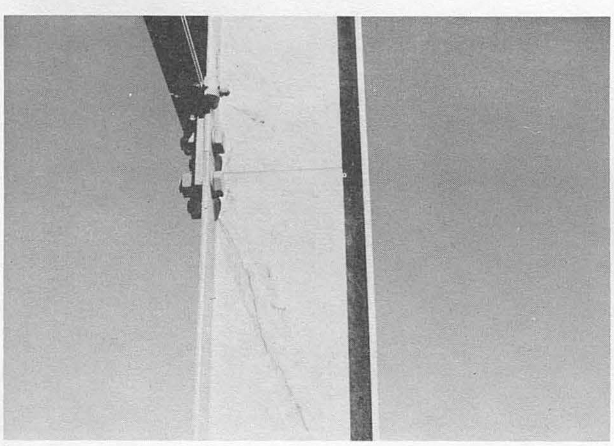

Figure 13. Upper hinged joint of a breakaway sign support.

D. Redesign Yielding Objects

1. Objective

Some objects which cannot be eliminated, relocated, or made traversable can be redesigned so that on impact they yield or break before intolerable levels of deceleration are reached. Only objects which can be out of commission for a short period following a collision can be treated in this way. Design is accomplished primarily through a reduction in shearing resistance.

2. Principles of design

a. Yielding, fracture, or slip must occur before intolerable levels of deceleration are reached (for a range of vehicle types and speeds).

b. A secondary collision between the object and the vehicle must be prevented.

c. Damage to the impinging vehicle should be as small as possible.

d. Repair of the object following impact should be simple, quick, and economical.

e. The object following impact should not interfere with normal traffic operations.

f. Performance must be satisfactory for a wide range of impact angles.

g. Wind loads and dead loads must be successfully resisted.

3. Breakaway sign supports

a. Effective types.

(1) Hinged joint and slip base. - The vehicle strikes the post above the slip base which shears as a result of the impact causing the post to rotate about an upper hinged joint and to clear the vehicle as it passes through. Figure 13 shows the weakened-plane upper hinged joint of such a support and Fig. 14 shows the slip base.

(2) Single small post slip base. - A slip base for single post mounting of small signs is designed to provide rotation of the entire assembly over the vehicle as it passes through. Figure 15 shows such a support which is frequently located in the gores of exit ramps.

(3) Fracture joint A-frame. - Tubular A-frame members are connected by shear pins at frangible joint connectors. Joints are so located that following fracture the support clears the impacting vehicle.

(4) Other A-frame support.

(5) Wood posts (notched or weakened).

b. Effectiveness. - Of 82 accidents involving break-away sign supports in Texas, there was only one serious injury (caused by a secondary collision) and, in 43 of these, the vehicle left the scene of the accident unaided (7). Tamanini reports (11) that there has been only one reported fatality involving collision with a breakaway sign (nationwide as of April, 1970).

4. Breakaway lighting poles

There are a number of suitable designs for breakaway lighting poles some of which are acceptable for existing as well as new installations. Figure 16 shows one such design. In general, all new installations, even where "protected" by guardrails, should be of the breakaway type.

5. Multi-legged sign bridges

For overhead sign bridges having three or more supports, it is desirable to employ a breakaway design for one or more of the supports. Such designs effectively reduce the severity of impact as well as prevent collapse of the entire structure. Research is currently underway at the Texas Transportation Institute to perfect an acceptable design.

E. Redirect Vehicles Around Objects

1. Objective

When objects cannot be eliminated, relocated, or redesigned, it is often feasible to redirect the vehicle around the object. It must be remembered, however, that: (1) accident severity is reduced only when the consequences of striking the redirection device are less severe than might otherwise be anticipated, (2) accident frequency is reduced only if the redirection device provides improved delineation, and (3) accident frequency is often increased since redirection devices are usually larger targets and are located closer to the pavement than the objects being screened.

2. Methods

Redirection is usually accomplished by means of longitudinal barriers such as guardrails, bridge rails, earth berms, and median barriers. It is usually effective only for small impact angles of less than about 25 degrees. Greater impact angles result in severe decelerations or further degradation of vehicle control. To be effective, a longitudinal barrier must restrain the vehicle and not allow it to vault over, penetrate, or wedge beneath the barrier.

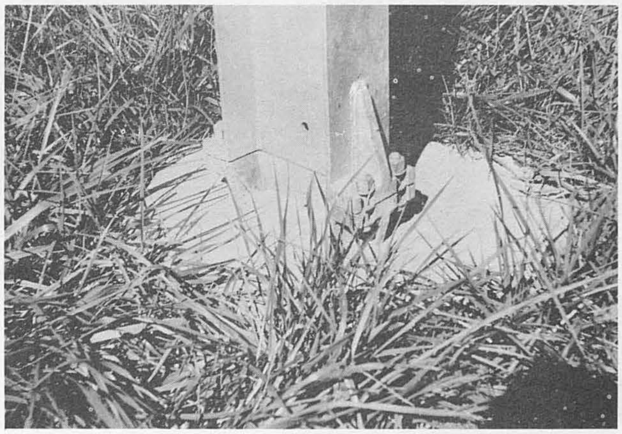

Figure 14. Slip base of a breakaway sign support.

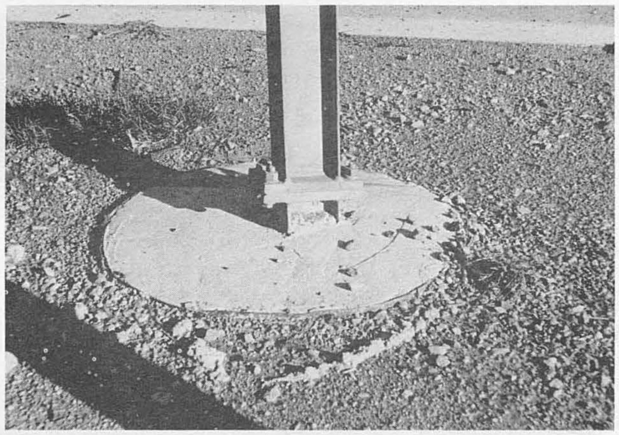

Figure 15. Single small post slip base.

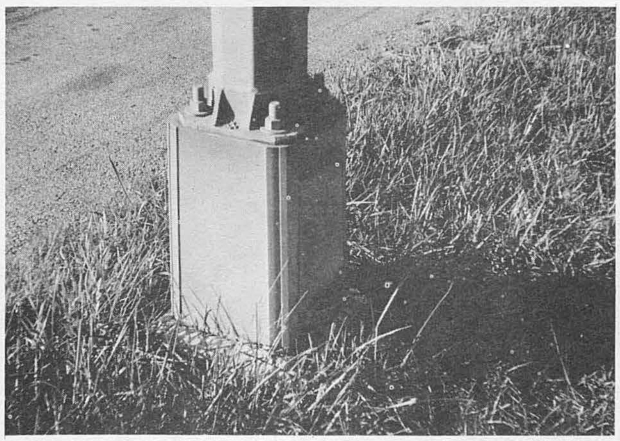

Figure 16. Breakaway lighting pole.

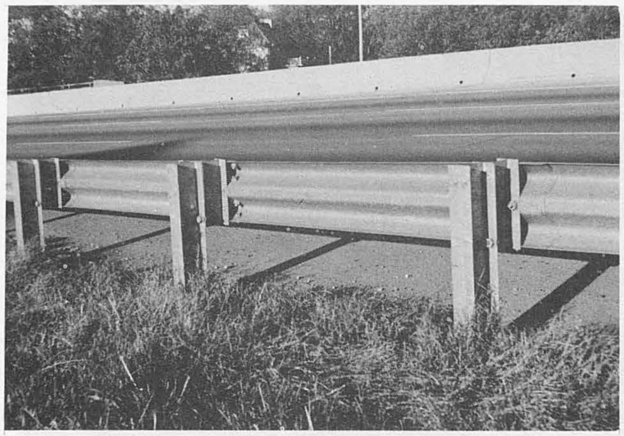

Figure 17. Blocked-out guardrail.

3. Guardrail

a. Design. - A guardrail should be designed to minimize the detrimental effects of impact and to maximize vehicle control so that secondary impact or overturn is improbable. If possible, the path of the vehicle should be redirected to a safe recovery area or maintained near and parallel to the guardrail. While a number of types of guardrails are available, the most common type is the W-section, therefore the following discussion relates only to this type.

(1) Length. - A minimum length of 50 feet is required to develop beam strength (7).

(2) Height. - A height of about 27 inches to the top of the rail appears adequate to prevent vaulting of passenger vehicles (7).

Figure 18. End treatment of guardrail.

(3) Post spacing. - A post spacing of 6 to 8 feet seems optimal to prevent the rail from laying down upon impact (7).

(4) Blocking-out. - The W-beam rail should be blocked out from the post to prevent the striking vehicle from becoming snagged by the post, as illustrated in Fig. 17.

(5) Washers should be used to prevent the boltheads from tearing through the rail.

(6) End treatment. - Guardrail ends must be firmly anchored to prevent vehicle penetration and turned down and perhaps flared away from the pavement to prevent impaling the vehicle. One way to treat the approach end of a guardrail section is shown in Fig. 18. The trailing end should also be anchored to allow full beam strength to be developed.

(7) Exposed backside treatment. - Where an exposed backside of a guardrail may be struck by an errant vehicle, consideration should be given to installing a double W-beam section.

(8) Bridge approaches. - Guardrails should be firmly anchored to the bridge structure and should be aligned with the bridge railing or carried continuously across the structure. Extra posts should be utilized as the bridge is approached to increase rigidity and eliminate the possibility of pocketing.

b. Location

(1) General. - In general a guardrail should be located close to the shoulder so as to minimize the expected angle of impact. A dike or curb should never be placed in front of a guardrail. A guardrail should never be V-shaped.

(2) Length. - A guardrail should be extended a sufficient distance upstream from the hazard to prevent a vehicle from entering the hazardous area from the rear of the rail. This has historically been an especially significant design failure, particularly for guardrails on steep slopes.

(3) Short sections. - Short sections of rail with small separations should be closed to form a continuous rail, thereby alleviating end treatment difficulties.

(4) Object protection. - A guardrail should never be used to protect a roadside object. Except under unusual circumstances, the sole function of the guardrail is to protect the errant vehicle

and its occupants. Figure 19 shows an improper use of guardrail since the guardrail is a much more significant hazard than the rail signals.

(5) Specific locations.

(a) Massive and rigid fixed objects. - Use only where the object is both rigid and massive, such as at bridge piers, culvert headwalls, and large overhead sign supports. Figure 20 illustrates such a use. Guardrailing is generally ineffective, however, at small, fixed object locations.

(b) Embankments. - Criteria have been established, based on probable accident severity, that assist in determining what combinations of embankment height and slope warrant guardrail treatment (7). Guardrailing should also be provided if a dropoff, such as a retaining wall, is located within about 30 feet from the pavement.

(c) Lateral drainage channels.

(d) Longitudinal drainage channels. - A guardrail should be placed at these locations only when it is impossible to design or construct a traversable drainage ditch.

(e) Rock cut slopes. - Guardrailing should be provided if there are exposed rock cut slopes near the pavement edge.

(f) Deficient bridge rails.

(g) Special conditions. - A guardrail may be necessary to protect an abutting property occupant from danger due to vehicle encroachment.

(h) Median openings at structures. - Guardrails may be used to prevent vehicles from entering a highly hazardous area created by a discontinuous median at structures. Great care must be exercised, however, in assuring that the angle at which an out-of-control vehicle strikes the rail is favorable. This means that the guardrail should be placed near to and parallel with the pavement shoulder. Figure 21 shows one of the earlier installations. In Fig. 22, the guardrail has been raised and the probable angle of impact improved.

Figure 19. Improper use of guardrail.

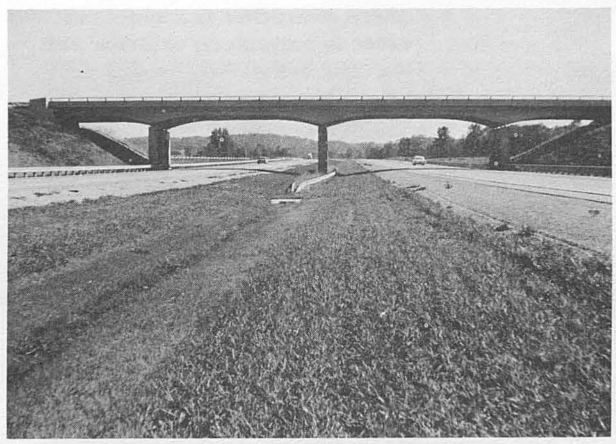

Figure 20. Guardrail protection at a median pier.

Figure 21. Guardrail protection at median opening.

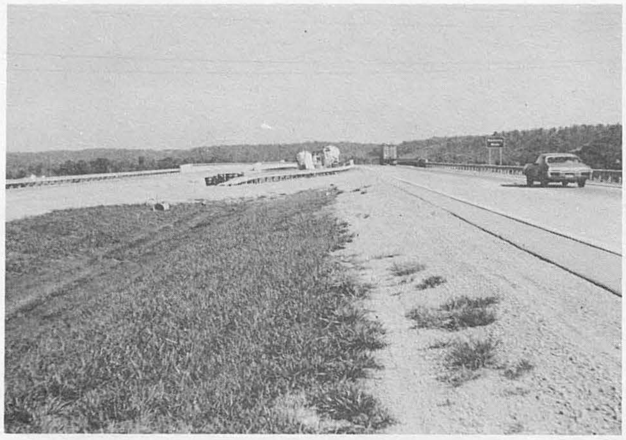

Figure 22. Improved guardrail protection at median

(i) Bridge approaches. - One of the most common uses of guardrails is on the approaches to bridges where redirection is required in order to prevent: (1) collision with the rigid bridge end, or (2) transversal of a frequently steep embankment slope.

(j) Permanent bodies of water.

4. Earth berms

Earth berms have been used for the dual purposes of redirection and energy dissipation in gore areas, at median piers, and in wide medians. Figure 23 shows an earth berm intended to prevent impact with a median pier. The effectiveness of this type of installation is largely unknown at this time.

5. Sloping concrete wedges or prows

Concrete wedges have often been placed in the gore areas of elevated structures for the alleged purpose of vehicle redirection. Their effectiveness in accomplishing this function is questionable.

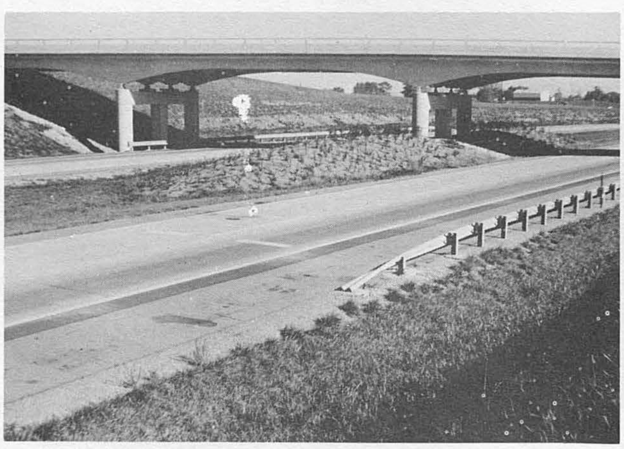

Figure 23. Earth berm at median pier.

6. Bridge rails

a. It is apparent that vehicle redirection devices (that is, barriers) are essential at bridge edges. In listing service requirements for such a bridge barrier rail system, Olson (7) points out that bridge rail systems should:

(1) Provide lateral restraint,

(2) Minimize vehicle decelerations,

(3) Smoothly redirect colliding vehicles,

(4) Remain intact following collision,

(5) Protect pedestrians (if they use the facility) as well as vehicle occupants,

(6) Have proper end treatment to prevent collisions with the end of the bridge rail system,

(7) Provide delineation while permitting adequate visibility,

(8) Project inside any required curb face,

(9) Be susceptible to quick repair,

(10) Be designed considering first safety, then economy, and finally aesthetics.

b. Other interesting concepts have been proposed for bridge rail systems that, in addition to the redirection function, provide some attenuation capability particularly for lightweight vehicles (14).

F. Reduce Severity of Impact

1. Objective

When it is impossible to eliminate, relocate, or redesign an object and when redirection is either not feasible or the consequences of redirection are potentially more severe than those of an attenuated crash, the severity of impact may be reduced to a humanly tolerable level by means of an energy absorbing barrier. Such a barrier absorbs or dissipates the kinetic energy of the impacting vehicle in a controlled manner so that accident severity is lessened. These barriers are called crash cushions, crash attenuation devices, or energy absorbing barriers.

2. Principle of operation

The kinetic energy associated with a moving vehicle must be dissipated when that vehicle impacts with a fixed rigid object. The forces and accelerations created upon impact depend in part on the distance over which the deceleration occurs. A rigid, immovable object can produce extremely high decelerations which occur over very short periods of time. Such large decelerations can directly cause severe injury or death or can produce the same effects through secondary collisions of the occupants and the vehicle interior. Energy absorbing (crash attenuation) systems increase the distance over which deceleration occurs thereby reducing the decelerations to tolerable levels while increasing the time of deceleration.

3. Principles of design

Many different energy-absorbing barriers have been proposed that offer promise for use in the highway environment. Major design considerations include the following:

a. The deceleration levels must be tolerable for the occupants of many vehicle types (light vs. heavy) and for an acceptable range of vehicular speeds.

b. Damage to the impinging vehicle should be as small as possible.

c. Repair of the barrier following impact should be simple, quick, and economical.

d. Reasonable angles of impact must be accommodated.

e. The impacting vehicle should be stopped or redirected without vaulting, ramping, or overturning. In general the vehicle should be restrained within the original boundaries of the cushion.

f. Upon impact, the damaged cushion should not endanger other traffic or the vehicle occupants.

4. Types

a. Dragnet vehicle arresting system.

b. Tor Shok.

c. Fitch inertial barrier. - This system, shown in Figs. 24 and 25, operates by transferring momentum from the vehicle to the sand within the drums.

d. Rich HiDro cells. - When a vehicle impacts with the HiDro cell barrier (Figs. 26 and 27), the liquid within each cylinder is forced from the orifice at the top.

e. Texas crash cushion (barrels).

f. Vermiculite concrete.

g. Polyurethane.

h. Embedded posts.

Figure 24. Fitch Inertial Barrier.

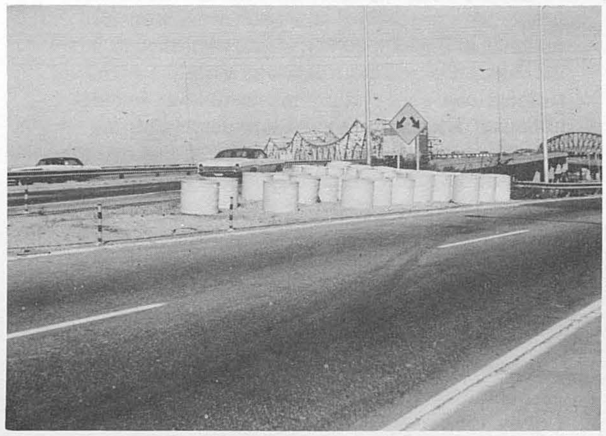

Figure 25. Fitch Inertial Barrier.

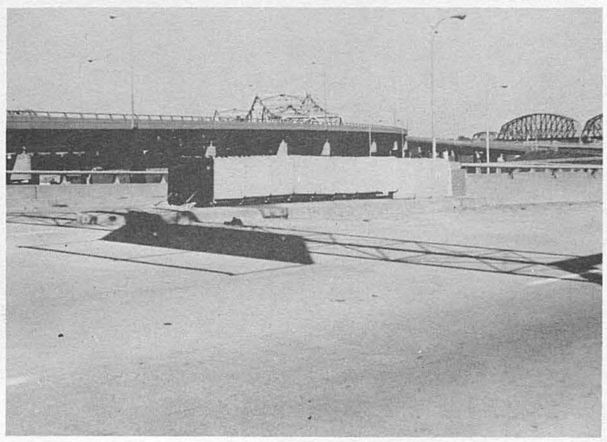

Figure 26. Rich HiDro Cell Barrier.

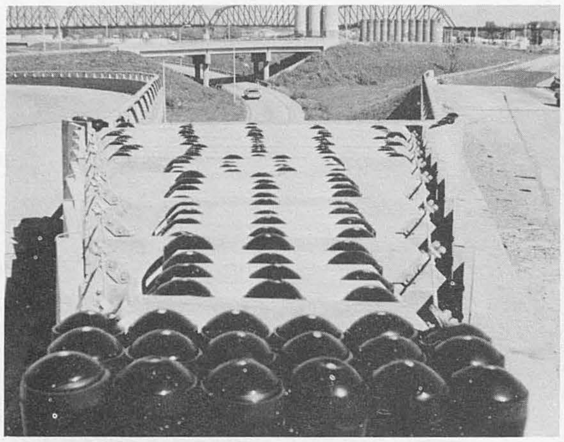

Figure 27. Rich HiDro Cell Barrier.

5. Suitable locations

When use of a crash cushion is being considered, it must be realized (1) that accident frequency is likely to increase due to increased target size, and (2) that impact with a crash cushion is usually relatively severe though survivable. Therefore, their use should be limited to locations where other measures are unsuitable and potential accident severity is high. Crash cushions are most appropriate where the probable impact is head on or nearly so.

a. Rigid roadside objects with impact angles unfavorable to redirection. - To date most crash attenuation devices have been placed in gore areas (particularly on elevated facilities) where redirection is virtually impossible and where a rigid object exists (such as a bridge parapet wall). However, as experience with these devices is accumulated, it is anticipated that they may be extensively used elsewhere. Accident experience accumulated to date is generally most favorable.

b. Median openings at structures. - The Dragnet vehicle arresting system would seem to be particularly appropriate for use at median openings. Smaller openings are easier to cover by crash cushions than larger ones. Larger openings appear to require longitudinal barriers such as guardrailing.

c. Dead ends.

6. Experimental nature

The Federal Highway Administration, as of July 21, 1970, considered all available types of impact attenuation devices to be of an experimental nature. At the same time, it is observed that ". . . because of the performance of the impact attenuators that have been installed, we can no longer be justified in building a fixed object in a gore without considering the use of an impact attenuator device." (13).

III. OVERTURN

Overturns are another undesirable consequence of running off the roadway inadvertently. Approximately 26 percent of the 1968 fatal Interstate accidents involved a vehicle overturning off the roadway (Table 1). The highway engineer should employ all feasible means to reduce the probability of overturn.

A. Minimize Probability of Collision With Fixed Objects

The 1968 Interstate accident study (4) indicates that, of the fatal accidents involving overturning vehicles, approximately 66 percent involved first a collision with a fixed object. It follows, therefore, that the means for reducing the probability of collision with fixed objects (see Section II) will also reduce the probability of overturn.

B. Reduce Use of Low Profile Objects

1. The 1968 Interstate accident study also indicates that a disproportionate number of vehicles striking first a curb in fatal accidents subsequently overturn (5). It is recommended therefore that (5):

   a. Use of curbs adjacent to main lanes, in gore areas, and even on the outer edge of shoulders be minimized,

   b. Temporary curbs constructed for erosion control be removed after vegetation has been established, and

   c. Where both curbs and guardrails are used, the face of the guardrail and the face of the curb should be in virtually the same vertical plane.

2. Other low profile objects such as dropoffs or discontinuities at the shoulder edges and elsewhere must be avoided.

C. Avoid Abrupt Grade Changes

Transitions between slopes, ditches, shoulders, etc. must be properly rounded so that they can be safely negotiated by the errant vehicle. Of particular concern in this respect are the slope transitions associated with drainage channels.

D. Use Traversable Slopes

There is some indication that embankments or cut slopes of 6:1 or flatter can be negotiated by a vehicle with a good chance of recovery. Therefore such flat slopes should be provided whenever feasible, particularly near the pavement edges. Special consideration should be given to making gores traversable.

E. Use Guardrail

In some circumstances it is not feasible to provide the flat slopes necessary to permit vehicle recovery and to eliminate overturning. It may be necessary in these situations to use guardrails for protection of the errant vehicle. However, as usual, the guardrail should be located as near to the shoulder as possible in order to produce favorable impact angles.

IV. COLLISION WITH MOVING OBJECTS

The type of collision referred to here is one in which the errant vehicle enters the opposing traffic lanes and collides with another vehicle. This is one of the more severe of all accident types due to the extremely high relative velocities. Not considered as a part of the roadside safety problem are those accidents caused by wrong-way vehicles entering one-way facilities from exit ramps or crossovers.

Collisions with opposing vehicles can be reduced through physical separation of opposing traffic streams or through use of median barriers. Other so-called non-traversable medians (such as deep ditches with steep slopes) are not considered a feasible solution since severe single vehicle accidents may result due to collision with the steep slopes or due to overturn. It must be noted that barrier curbs should never be used since they serve more as deterrents and less as barriers and since impacts with barrier curbs frequently have severe consequences.

A. Median Width

Perhaps the most effective way to reduce the incidence of cross-the-median accidents is to provide sufficient space in which the out-of-control vehicle may be stopped or control regained. This requires median widths of approximately 60 to 80 feet. Such widths must be accompanied by flat slopes (6:1 or preferably flatter) in order to minimize the probability of overturn and maximize the probability of regaining full control. For example, side slopes of 4:1 and 3:1 have been found to cause a disproportionate number of overturns (3).

B. Median Barriers

1. Safety function

   Median barriers are used to prevent vehicles from entering opposing traffic streams. This function is accomplished through deceleration, redirection, or a combination of both.

2. Use

   a. Use is generally limited to high volumes (ADT in excess of 20,000) and narrow medians (less than 40 feet) though special conditions such as high cross-median accident rates may warrant their use elsewhere.

   b. Use of median barriers where there are at-grade intersections or other frequent crossovers should be avoided.

   c. Median barriers are in themselves hazards and their use should be limited to situations in which the consequences of striking the barrier are potentially less severe than other collisions or hazards. Accident frequency usually increases after a median barrier has been installed.

3. Types

   a. Proper barrier type is determined primarily by ease and cost of repair and by median width. Wider medians generally permit greater space in which to decelerate the vehicle (impact attenuation is possible).

   b. Flexible. - Flexible barriers include cables, chain-link fence and cables, and dense plantings. Their function is accomplished solely through energy absorption. Their use is limited to wide medians.

   c. Semi-flexible. - Semi-flexible barriers accomplish their function by a combination of energy absorption and redirection and may be effectively used for medians as narrow as 10 feet or less. They include double flex beams (two "W" sections sometimes with breakaway or yielding posts), box beam, and an interesting one-way system in which the vehicle is not allowed to reenter the original traffic stream.

   d. Rigid. - Rigid barriers should be used only for narrow medians where impact angles are small: their function is accomplished primarily by redirection. The most widely used rigid barrier is the New Jersey or GM concrete barrier, as illustrated in Fig. 28.

   e. Earth berms.

V. PRIORITY LOCATIONS

It is always desirable and in some instances absolutely necessary (1) to attempt to identify locations at which the probability of an off-the-road accident is large and (2) to design the roadside accordingly. In determin-

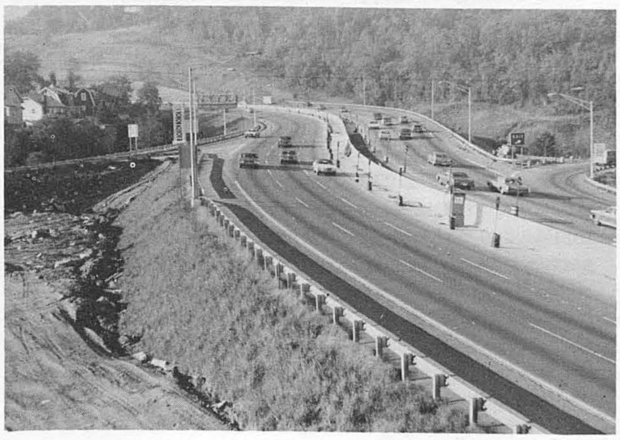

Figure 28. A rigid concrete median barrier under construction.

ing priorities for corrective actions on existing roadways, this process can be greatly assisted through an identification of high accident rate locations. For new facilities the problem is more difficult but in no way less important. Some of the priority locations include the following:

A. Horizontal Curves (both outside and inside)

B. Combined Horizontal and Vertical Curves (particularly crest vertical curves)

C. Lane Drops

D. Other Non-Uniformity in Cross-Section

E. Gore Areas (especially on curves)

F. Bridges and Beyond (icing)

G. Left Entrance and Exit Ramps

H. High Speed Locations (such as bottom of steep grade)

I. Access Points

J. Inadequate Shoulders (width, surface, delineation)

VI. CONCLUSIONS

A great deal is known about the problems of roadside safety and the means for alleviating these problems. The highway designer must develop a deep sense of responsibility for providing a safer roadside environment which will protect the errant vehicle as well as satisfy other design criteria and constraints. He must carefully avoid the tendency to assume that the use or adoption of each safety feature will necessarily result in increased costs for this is often not the case. At the same time, he must be willing to consider the tradeoffs that at other times will result in increased safety only through a higher level of expenditure.

Let me close by again quoting Congressman Blatnik.

> "A good question is whether we can afford safety. Our hearings dwelt on this point. From the testimony it is apparent that the available safety dollar can be stretched. The testimony clearly indicated that the situations are multiple wherein the construction of an unsafe roadside actually cost more than safe construction would have cost . . . In many cases, safety could have been purchased at a nominal additional cost . . . There is no disputing that there are desirable safety features which would cost more money. As to these, it seems to me, the construction of no major road can be justified unless it includes the latest in reasonable safety features. If we cannot afford the safety, we cannot afford the road." (9)

REFERENCES

1. Dearinger, J. A. and Hutchinson, J. W., "Highway Safety and Road Cross Section," A paper prepared for the Automotive Safety Foundation, Jan. 1970.

2. Forster, Harry, "Holosigns," Traffic Engineering, Vol. 38, No. 7, Apr. 1968, pp. 20-24.

3. Garner, G. R., "Median Design and Accident Histories," Research Report, Kentucky Department of Highways, Apr. 1970.

4. Hosea, H. R., "Fatal Accidents on Completed Sections of the Interstate Highway System, 1968," Public Roads, Vol. 35, No. 10, Oct. 1969, pp. 217-224.

5. Hosea, H. R. and McDonald, J. N., "Fatal Collisions with Fixed Objects on Completed Sections of the Interstate Highway System, 1968," Public Roads, Vol. 36, No. 1, Apr. 1970, p. 24.

6. Hutchinson, J. W. and Kennedy, T. W., "Safety Considerations in Median Design," Research Record 162, Highway Research Board, 1967, pp. 1-29.

7. Johnson, J. H. and Messer, C. J., eds., "Roadside Safety Design," Texas Transportation Institute, Texas A & M University, College Station, 1970.

8. Maintenance and Highway Safety Handbook, Highway Users Federation for Safety and Mobility, Washington D. C., March 1970.

9. Roadside Hazards, The Eno Foundation for Highway Traffic Control, Inc., Saugatuck, Connecticut, 1968.

10. Special AASHO Traffic Safety Committee, "Highway Design and Operational Practices Related to Highway Safety," American Association of State Highway Officials, Feb. 1967.

11. Tamanini, F. J., "Designing 'Fail-Safe' Structures for Highway Safety," A paper prepared for presentation at the National Structural Engineering Meeting, American Society of Civil Engineers, Apr. 1970.

12. U. S. Department of Transportation, Federal Highway Administration, "A Handbook of Highway Safety Design and Operating Practices," U. S. Government Printing Office, May 1968, with Supplement Nos. 1 and 2.

13. Williams, G. M., "Impact Attenuators in Gores," Instructional Memorandum 40-1-70, Bureau of Public Roads, July 21, 1970.

14. Woolam, W. E. and Garza, L. R., "Design, Fabrication, and Installation of a Fragmenting-Tube-Type Energy Absorber in Conjunction with a Bridge Rail," Research Record 302, Highway Research Board, 1970, pp. 21-27.