Guidelines for Positive Barrier Use in Construction Zones

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ABSTRACT

The need for positive barriers in construction zones is now based on individual judgment, and there is an expressed need for objective barrier placement criteria. The number, diversity, and variability of factors that affect barrier need within a work zone eliminate the possibility of development of a set of totally objective guidelines appropriate for any given circumstance. In an effort to develop procedures for determining barrier need at a given site, a computer program, which determines barrier warrants based on a benefit-cost algorithm, was developed. This program was adapted for use on microcomputers with a user friendly system that greatly simplifies its use. Further, a set of use guidelines for portable concrete barriers (PCBs) was developed for typical work zone sites through the application of the benefit-cost computer program. Barrier end treatment use guidelines were also developed with the computer program. End treatments studied included flaring the barrier away from the travelway and two crash cushions. The optimum flare rate for flared end treatments was found to be 10:1. Crash cushion end treatments were found to be cost beneficial relative to flared end treatments only at extremely high traffic volumes.

Considerable attention has been focused on hazards in construction zones that endanger both the traveling public and working personnel. Efforts are being made on the national and state level to improve safety in these zones. Many studies have been and are being made to evaluate traffic management and control measures, accident data, driver needs, and delineation devices, and to develop positive barriers for work zones.

A major problem highway engineers have faced is the absence of objective guidelines for selection and deployment of positive barriers in work zones. Engineers from 9 states were recently surveyed to determine the current practices regarding the use of positive barriers in construction zones. In general, the survey showed that judgment is the prevalent means by which most states establish barrier need and that the use of positive barriers in construction zones is determined on a project-by-project basis. Further, most of the engineers surveyed expressed a need for objective guidelines for positive barrier use in construction zones.

The benefit-cost method of evaluating safety alternatives has gained widespread acceptance in recent years. This method is normally based on either accident data analysis or encroachment probability predictions of accident frequency and severity that can be expected with each safety alternative.

Numerous accident data studies have attempted to quantify the frequency and severity of work zone accidents as a function of work zone characteristics (1-5). General findings were: accident rates typically show a moderate increase when good traffic control policies are implemented; lane closures, bridge work, and reconstruction of roadways create higher accident rates; there are no clear relationships between work zone characteristics and accident rates and severity; rear-end, head-on, and fixed-object accident rates increase greatly; and accident severities do not increase significantly. Ideally, accident data should provide estimates of work zone accident rates and severities. However, such estimates are impossible to obtain because of the limited quantity and lack of sufficient detail in existing work zone accident data records.

Encroachment probability models are more general in nature and can be adapted to fit almost any highway or work zone configuration. Therefore, this research was undertaken to use benefit-cost methodology with an encroachment probability model to develop simplified objective guidelines for the use of positive barriers in construction zones. The findings of a research project completed in 1983 (6) are described. The reader should refer to the cited report for more detailed information about this study.

REVIEW OF TEMPORARY BARRIER DESIGNS

A review of practices in selected states was made to determine the types of temporary positive barriers and barrier end treatments in use. With few exceptions, portable concrete barrier (PCB) designs are being used when a positive barrier is determined to be warranted. Some typical installations of the barrier are shown in Figure 1. A variety of end treatments has been used on portable concrete barriers including the construction zone GREATcz barrier (7), sand-filled plastic barrels, and flaring the barrier away from the travelway. Of these end treatments, only the GREATcz crash cushion has been crash tested and proven to meet existing performance standards. Another end treatment that has passed recommended performance testing is the steel drum and sand crash cushion (8). Although this cushion has only recently been developed and has little field experience, it offers a low-cost alternative to the GREATcz. Figure 2 shows the two PCB end treatments that have passed recommended crash tests.

IMPACT PERFORMANCE

In developing guidelines for positive barrier use in construction zones, the impact conditions for which a barrier will perform adequately, or performance level, must be quantified. It is generally known that the degree of impact loading or "impact severity" experienced by a barrier during an accident is related to mass, velocity, and impact angle of the

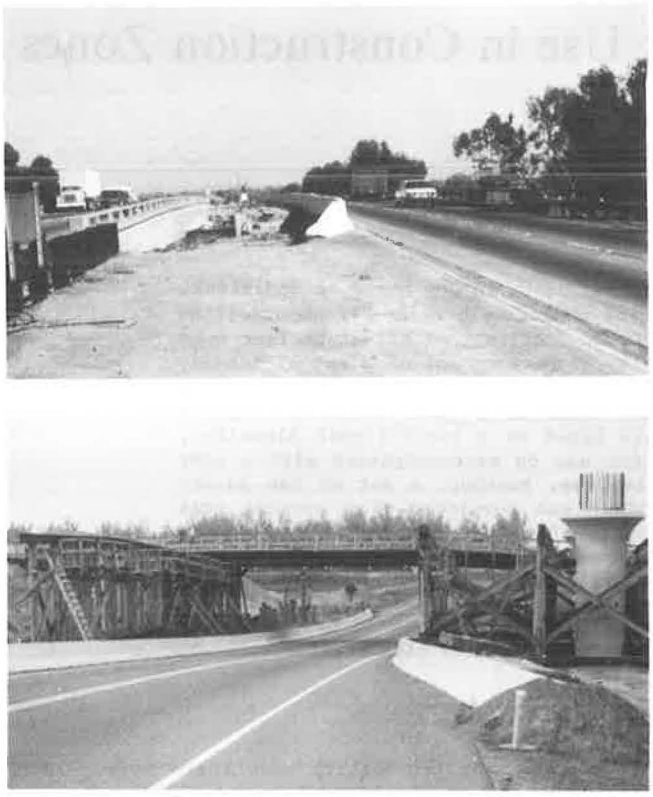

FIGURE 1 Typical use of precast concrete safety shape barriers in work zones: top, bridge widening project; bottom, construction overpass.

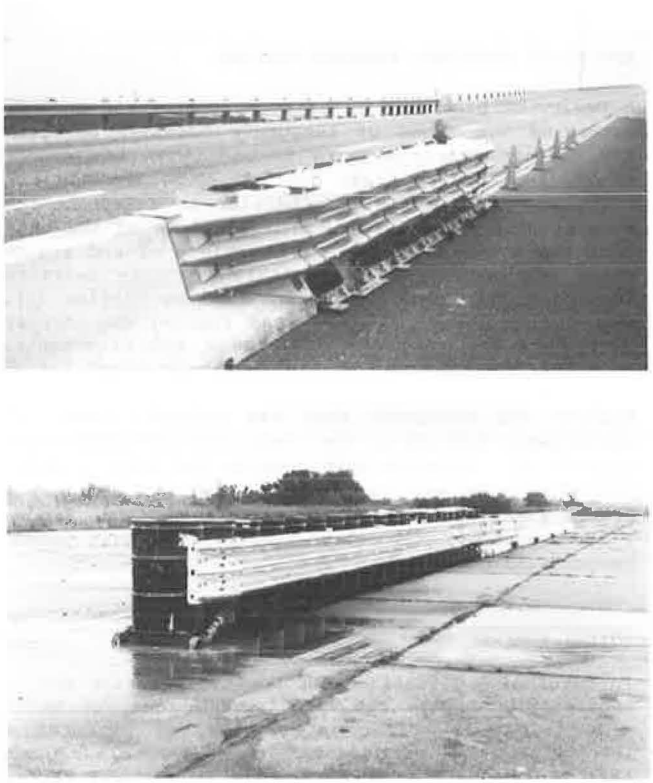

FIGURE 2 End treatments for portable concrete barriers that have been tested successfully: top, GREATcz; bottom, barrel and sand.

vehicle striking the barrier. Studies have shown the following relationship to be good indicator of impact severity and the demands imposed on longitudinal barriers (9-11):

$$IS = 1/2\ m(V \sin\theta)^2$$

where

IS = impact severity (ft-lb),
m = vehicle mass (lb-sec^2/ft),
V = vehicle impact velocity (ft/sec), and
θ = vehicle impact angle (angle between resultant velocity vector of vehicle and face of barrier).

For any barrier system there is a limiting value of IS beyond which the barrier will not contain or smoothly redirect the impacting vehicle, or both. The limiting value of IS is defined herein as the barrier's "performance level" (PL). When a vehicle strikes the barrier with an IS greater than its PL, the vehicle may penetrate the barrier. Table 1 gives a summary of performance levels established by Ivey (9) for many commonly used work zone barrier designs.

TABLE 1 Estimate of Performance Limit for Representative Work Zone Barriers *(9)*

Description of Joint	Performance Level, PL (ft-kips)	Estimated Displacement (ft)[a]
Tongue and groove	20.4	1.0
Steel dowel	20.4	1.0
Lapped joint	36.5	1.0
Pin and rebar	97.3	2.0
Vertical I-beam	97.3	1.0
Channel splice	97.3	2.0

[a]Values given are deflections expected to occur at given PL.

BARRIER COSTS

As part of the subject study, researchers at the Highway Safety Research Center (HSRC), University of North Carolina, gathered barrier cost and labor requirement information from six work zones in four different states. The work zones studied employed PCB barriers with performance levels (PL) ranging from 20,000 to 97,000 ft-lb. As part of another study, costs and labor associated with the use of PCBs were examined (9). Data from these sources were used to arrive at nominal cost figures for commonly used PCBs. A major finding was that high-performance precast concrete barriers are not significantly more costly than are low-performance barriers. The initial cost of PCBs with a PL of 96,000 ft-lb was found to be approximately $21.00 per foot and the salvage value was estimated at $10.50 per foot. Normal maintenance costs, exclusive of accident damage repair costs, were found to be quite low.

Another important cost is that required to restore a damaged barrier following impact by an errant vehicle. Barrier damage is generally believed to be proportional to the degree of impact loading on the barrier. As discussed earlier, barrier loading can be quantified by the impact severity (IS), and it follows that barrier repair costs should be roughly proportional to IS.

Average costs to repair PCBs have been collected from a limited number of highway work zones as mentioned previously. The researchers found that a large number of impacts caused no barrier damage and that

the average cost to repair PCBs after accidents causing damage was approximately $100. Accident reports were also collected from the construction zones studied. Some of the accident reports show estimated impact conditions and barrier repair costs. PCB crash test reports also give impact conditions and barrier damage. Data from these two sources were used to develop a straight line least squares fit between IS and barrier repair costs. Figure 3 shows the relationship developed and the raw data points.

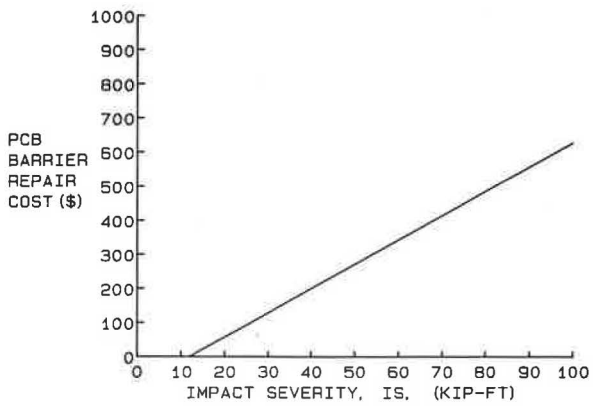

FIGURE 3 PCB repair costs.

Estimates of end treatment costs were limited to the two systems that have been successfully crash tested as end treatments for concrete barriers, the GREATcz and the steel drum and sand cushion. Initial cost estimates for the GREATcz system were obtained from the manufacturer. Similar estimates for the steel drum and sand cushion were obtained through basic cost estimating procedures. Table 2 gives estimated costs for the two systems. End treatment repair costs for the steel drum and sand cushion were estimated from crash test results. GREATcz system repair costs were assumed to be half those of the steel drum and sand system. Plots of repair cost versus IS for the two end treatments are shown in Figure 4.

TABLE 2 Crash Cushion Costs and Impact Severities

	Barrel and Sand Crash Cushion	GREATcz Crash Cushion
Initial cost ($)	4,000.00	11,000.00
Salvage value ($)	2,500.00	8,000.00
Maintenance cost ($/yr)	200.00	100.00
Severity index corresponding to 60 mph impact	5.0	5.0

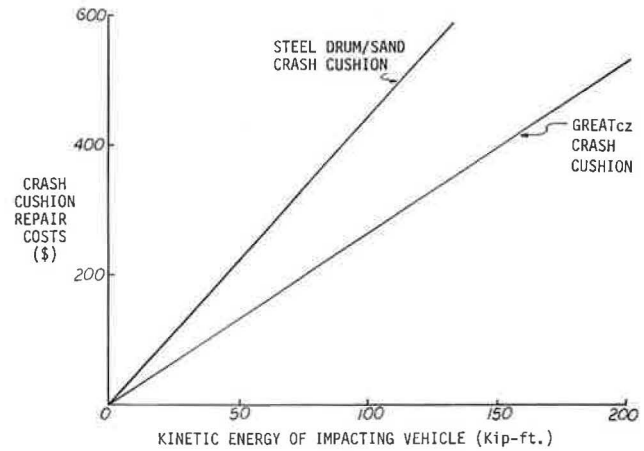

FIGURE 4 Repair costs for crash cushion end treatments.

BENEFIT-COST METHODOLOGY

The benefit-cost methodology compares the benefits derived from a safety improvement to the direct highway agency costs incurred as a result of the improvement. Benefits are measured in terms of reductions in societal costs due to decreases in the number or severity, or both, of accidents. Direct highway agency costs are comprised of initial, maintenance, and repair costs of a proposed improvement. A ratio between the benefits and costs of an improvement is used to determine if the improvement is cost beneficial:

$$B/C_{2-1} = (SC_1 - SC_2)/(DC_2 - DC_1)$$

where

B/C_{2-1} = benefit-to-cost ratio of Alternative 1 compared to 2,
SC_1 = societal cost of Alternative 1, and
DC_1 = direct cost of Alternative 1.

When studying the cost effectiveness of work zone barriers, safety treatment Alternative 1 is normally an unprotected work zone and Alternative 2 is PCB protection of the work zone.

The benefit-to-cost ratio makes possible comparison of the benefits and costs of two alternatives, one of which is normally viewed as a safety improvement in comparison with the other. If the improvement has a benefit-to-cost ratio less than 1.0, the improvement normally should not be implemented. It does not follow, however, that all improvements with a benefit-to-cost ratio greater than 1.0 can be implemented. Budgeting limitations prevent the funding of all projects that have a benefit-to-cost ratio of 1.0 or more.

ESTIMATION OF BENEFITS AND COSTS

Benefits or reductions in societal accident costs and safety improvement repair costs can only be estimated through predictions of accident frequency and severity. As mentioned previously, an encroachment probability model is the only available method of predicting construction zone accident frequency and severity. Encroachment probability models have been used by numerous authors to predict roadside accident frequencies and severities (12-15). A similar model with certain improvements was used in this study. The most notable improvement was the development of a procedure to estimate the frequency of multiple vehicle accidents resulting from automobiles inadvertently crossing the centerline of a two-lane, two-way highway.

The societal cost or severity of an accident and the damage incurred by highway appurtenances due to an accident are related to many factors, including object struck and speed and angle of impact. Quantification of the costs associated with a predicted accident is therefore a formidable task.

Accident severity has frequently been measured in

terms of severity indices as shown in the 1977 AASHTO Barrier Guide (13). To a limited extent the severity indices associated with accidents involving certain roadside features such as barriers, signs, ditches, and driveways have been determined via crash testing, computer simulation, and accident data. However, severity indices for many features had to be inferred or extrapolated from limited data, as shown in Figures 5 and 6. Techniques for determining severity indices used in the present effort are presented elsewhere (6).

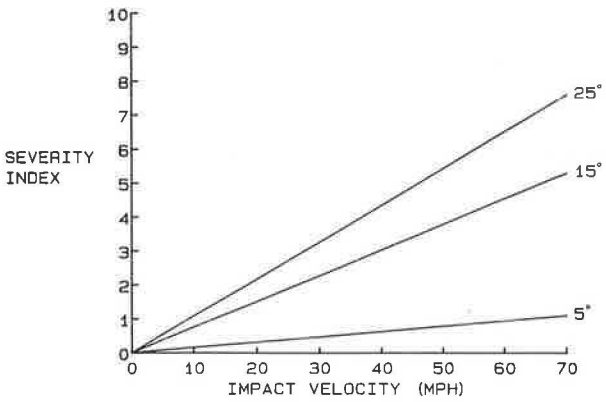

FIGURE 5 Accident severity versus impact speed for PCB.

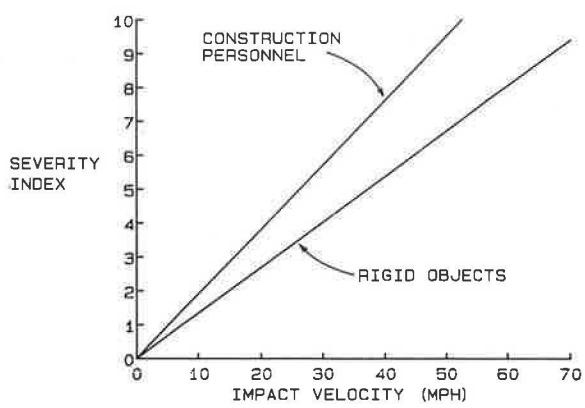

FIGURE 6 Impact severities of construction zone activities.

Direct costs arising from safety appurtenance repair can be estimated from crash test results and available accident data as described previously. Direct initial costs and normal maintenance costs can be determined through basic cost estimating procedures or previous contractor bids.

ASSUMPTIONS AND LIMITATIONS

A number of assumptions are necessary in an analysis of the type employed herein. These assumptions are as follows:

1. It was assumed that recommended traffic control and delineation devices (16) will be used regardless of the presence or absence of a positive barrier.
2. It was assumed that the rate of inadvertent encroachments from the travelway will not be altered by the presence of a positive barrier. The validity of this assumption depends to a large degree on the validity of Assumption 1.
3. It was assumed that the use of a positive barrier will not, on the average, appreciably alter access to the work zone. In other words, it was assumed that the total direct cost of a project, excluding barrier costs, is not altered by the presence of positive barriers. It is believed that worker productivity will be enhanced by the presence of a barrier, balancing any negative effects the restriction of access may have.

The analysis procedures and results presented herein, when combined with good engineering judgment, should enable an agency to develop a rational and uniform set of guidelines for the use of work zone barriers. However, the guidelines should not be viewed as absolute because of the diverse and complex nature of the problem and the inexactness of the analysis procedure. Those responsible for establishing policies for barrier use should become familiar with the procedure, its limitations, and the input parameters used in developing the criteria.

APPLICATION OF BENEFIT-COST METHODOLOGY

A computer program was written to facilitate implementation of the benefit-cost methodology. The original version of the program was written for use on a mainframe computer. The guidelines presented herein were determined by application of this program. The methodology has also been programmed for use on microcomputers with user friendly input features. This version of the program will allow engineers to apply the benefit-cost methodology to individual work zones.

BARRIER END TREATMENT

Barrier end treatments are a major factor in the cost-effectiveness of work zone barriers. Two basic treatments were examined, namely flaring the barrier away from the travelway and crash cushions.

For analysis of flared end treatments, it was assumed that the flare would begin at the upstream end of the work zone. If sufficient room is available to start this flare before the end of the zone, flaring the barrier becomes more cost beneficial relative to other end treatments. Three different barrier flare rates, 17:1, 10:1, and 6:1, were examined over a wide range of barrier end offsets. General findings were that the 6:1 and 10:1 flare rates were approximately equivalent, and that both end treatments are cost-effective over a wide range of conditions. The 10:1 flare rate is recommended because it provides a somewhat safer treatment at essentially the same cost. A 10:1 flared end treatment with a flare offset of 20 ft was found to be cost-effective over a wide range of conditions and was therefore used for all subsequent studies. Although the 17:1 flare rate was not found to be cost-effective compared to the other flare rates, this flare rate is the most cost beneficial when the flared region can be started within the required work zone because the flared region does not increase the required length of barrier.

The two crash cushions studied were the GREATcz (7) construction zone crash cushion and a steel drum and sand cushion (8). Estimated crash cushion costs are given in Table 2 and shown in Figure 4. Figure 7 shows the traffic volumes and barrier offsets at which each of the two cushions first becomes cost beneficial. Surprisingly, these end treatments do not appear to be cost beneficial until traffic volumes become relatively high. Note that the higher

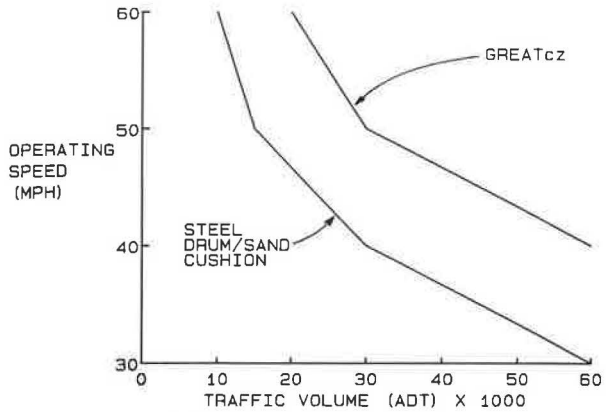

FIGURE 7 Guidelines for use of crash cushion end treatments (project duration = 1 year).

cost GREATcz crash cushion was not found to be more cost beneficial than the steel drum and sand cushion under any highway condition studied and that, for most reasonable traffic volumes, flaring the barrier was found to be more cost-effective than either crash cushion.

GUIDELINES FOR BARRIER USE IN SPECIFIC WORK ZONE ACTIVITIES

During the early phases of the study, numerous highway work zones across the country were visited and construction activities were photographically recorded. Films of these work zones were carefully reviewed in an effort to determine activities, distributions of obstacles and construction personnel, zone length, project duration, and so forth found in typical construction zones. This analysis revealed that, from the standpoint of number, type, and offset of roadside hazards, no two construction zones are alike. However, it was found that a large percentage of work zone activities can be placed in one of three basic categories. These are roadway widening, bridge widening, and construction of roadside structures such as bridge piers for an overpass structure.

It was impossible to define a single typical work zone for each of the construction zone categories identified. However, project-dependent parameters such as project duration, construction zone length, and number of rigid hazards were then varied over a limited range to determine a group of "typical" work zones for each construction zone classification. Guidelines were then developed for barrier deployment in each typical zone.

Another common construction zone activity of interest is the use of two-lane, two-way operations (TLTWO) on what is normally a divided highway. Fewer unknown parameters are of significance to this type of activity, and it was therefore not necessary to define a typical zone to develop barrier need. In addition to developing guidelines for barrier use in the TLTWO, an attempt was made to determine an optimum geometric configuration or layout for the barrier.

Barrier end treatments are a major factor in the cost-effectiveness of work zone barriers. As mentioned previously, flaring the barrier away from the travelway at a 10:1 flare rate over a distance of 200 ft was found to be cost beneficial over a wide range of conditions. This end treatment was used for all barrier applications studied.

BARRIER WIDENING

At the initiation of a bridge widening project, traffic is normally shielded from the construction zone by the existing bridge rail. After the bridge rail is removed, traffic exposure to the work zone can normally be divided into three distinct phases. During the initial phase, new bridge deck is under construction and a dropoff exists near the edge of the travelway. The new deck is poured during the second phase and the dropoff is moved to the edge of the new traffic lanes. The final phase is completed after the new bridge rail is in place and traffic is no longer exposed to a dropoff. Each of these phases is assumed to comprise one-third of the entire project duration.

Other hazards assumed to be present in the bridge widening construction zone included either four or eight workers and two large pieces of equipment. The equipment hazards were assumed to be in the zone only during the final phase of the project. Figure 8 shows the assumed locations of the workers and equipment in a bridge widening work zone. It should be noted that the lateral position of workers and equipment and equipment size affect the probability that a vehicle will strike these hazards. It was assumed that the longitudinal position of these objects had no influence on probability of impact.

Eight typical work zones were established for the bridge widening project. Variations between the zones involve the number of workers, the number of heavy equipment hazards, and the severity of the

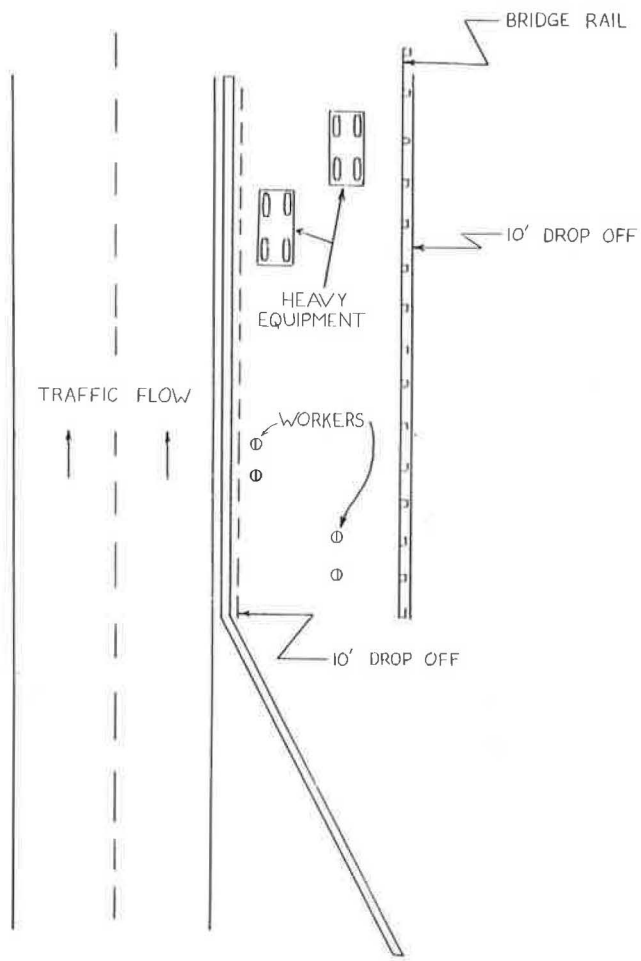

FIGURE 8 Typical bridge widening construction zone.

dropoff hazards. A bridge normally crosses a highway or a terrain discontinuity such as a river or a stream. The severity index associated with a vehicle running off a bridge at a grade separation was assumed to be approximately 15 percent greater than the severity index for leaving a bridge over a terrain discontinuity.

Figure 8 also shows the assumed geometric configurations of a construction zone barrier used to shield traffic from a bridge widening project. Although not explicitly shown in this figure, the roadway is assumed to be a four-lane divided highway and is typical of many roadside construction zones studied. For divided highways, traffic exposed to the work zone is only one-half the total traffic volume.

Guidelines for deployment of the PCB were developed for each of the bridge widening zones studied in the form shown in Figure 9. The line plotted in this figure corresponds to a benefit-to-cost ratio of 1.0 for a project duration of 1 year. As shown in Figure 9, barrier need decreases sharply as highway operating speed decreases.

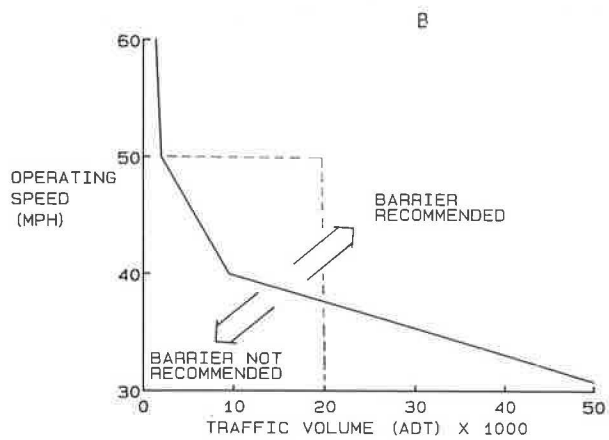

FIGURE 9 Typical guidelines for PCB protection of bridge widening zones (bridge over grade separation).

Guidelines such as those shown in Figure 9 can be used to determine when barrier implementation becomes cost-effective. Use of the guidelines is illustrated in the following example for a bridge widening project.

Example 1
Typical Bridge Widening Zone 1
(bridge over a grade separation)

Operating speed	50 mph
Project duration	1.0 yr
Average daily traffic	20,000 ADT

From Figure 9 the benefit-to-cost ratio of PCB use is determined to be greater than 1.0 and barrier use merits further consideration. As has been discussed, the decision should be made in conjunction with benefit-cost analyses of other safety projects in view of limited safety funds.

ROADWAY WIDENING

Hazards located in roadway widening projects are normally limited to four basic types: construction personnel, dropoffs, heavy equipment, and light equipment. Figure 10 shows the assumed hazard distribution and barrier configuration for a roadway

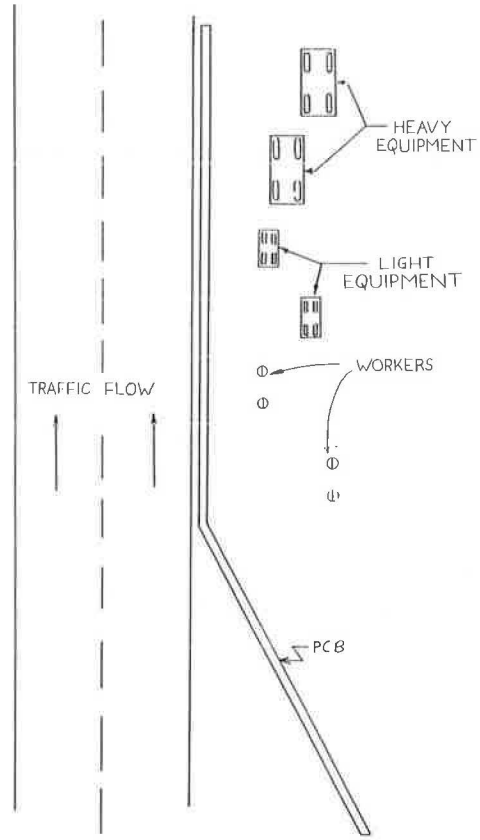

FIGURE 10 Typical roadway widening construction zone.

widening project. Sixteen typical work zones were established for roadway widening construction projects. Variations among the zones include number of construction personnel, number of heavy equipment hazards, work zone offset, and depth of dropoff. The pavement edge dropoff is assumed to be either 1 ft for simple pavement widening or 10 ft for vertical realignment projects.

Guidelines for PCB barrier implementation were again developed for each of the 16 typical roadway widening zones. Combinations of construction zone length and average daily traffic (ADT) which produce a benefit-to-cost ratio of 1.0 were plotted as shown in Figure 11. Use of these guidelines is demonstrated in the following example.

Example 2
Typical Roadway Widening Zone 4
(vertical realignment--dropoff depth = 10. ft)

Operating speed	40 mph
Average daily traffic	30,000 ADT

Figure 11 shows the benefit-to-cost ratio of PCB use in this zone to be less than 1.0 and therefore barrier use is not normally recommended.

ROADSIDE STRUCTURE CONSTRUCTION

Construction projects involving erection of roadside structures such as bridge supports at grade separations normally require construction of falsework structures. Large falsework structures are costly; pose a serious hazard to motorists; and, if damaged when struck by an errant vehicle, could cause injuries to workers and involve significant cost to

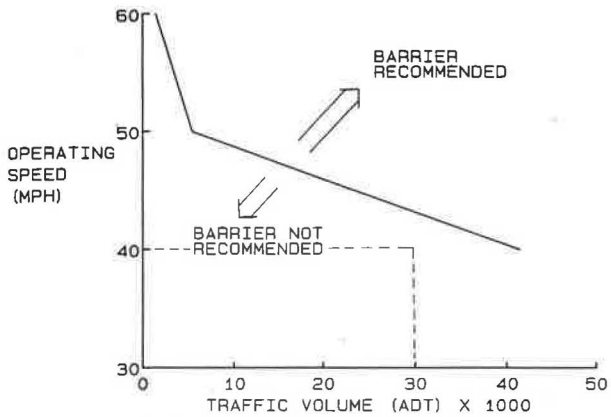

FIGURE 11 Typical guidelines for PCB protection of roadway widening construction zone (with vertical realignment activity).

restore. After removal of the falsework, a rigid support structure that can pose a serious hazard to motorists usually remains. For the purpose of generating barrier placement guidelines, it was assumed that the falsework would remain in place for one-half the total project duration and that a rigid support structure would remain during the balance of construction.

Other hazards assumed to be present during the construction of roadside structures include two heavy equipment hazards and either eight or twelve construction personnel. Figure 12 shows the assumed construction zone geometric configuration and hazard distribution. Note that heavy equipment and worker hazards are assumed to be present only while the falsework is present. A total of 12 zones were studied. Variations among the typical roadside construction zones included the number of workers, size of falsework, and the offset of the construction zone.

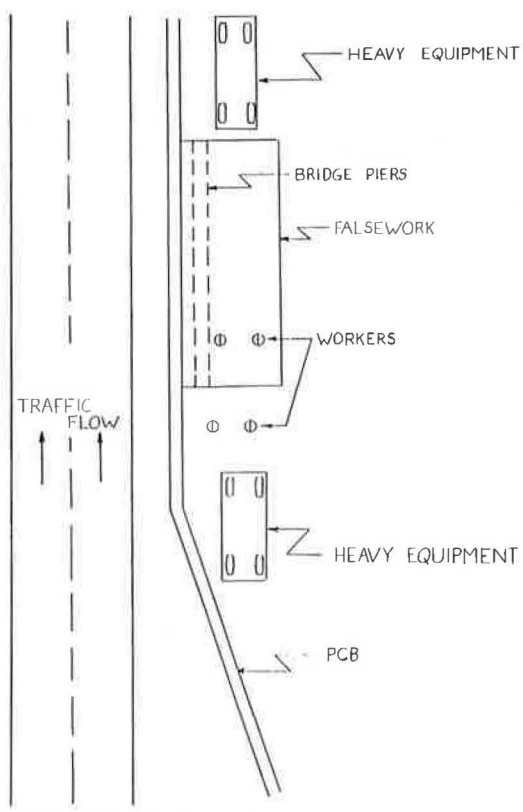

FIGURE 12 Typical roadside structure construction zone.

Guidelines for barrier implementation were developed on the basis of average daily traffic, highway operating speed, and damage to falsework resulting from an impact. Lines corresponding to a benefit-to-cost ratio of 1.0 were plotted for average daily traffic versus operating speed. Figure 13 shows guidelines developed for a typical roadside structure construction zone. Use of these guidelines is illustrated in the following example.

Example 3

Typical Roadside Structure Construction Zone 11

Potential structural damage	$100,000
Operating speed	50 mph
Average daily traffic	5,000 ADT

Figure 13 shows that the benefit-to-cost ratio for barrier use in this zone is greater than 1.0 and therefore barrier use merits further consideration as discussed previously.

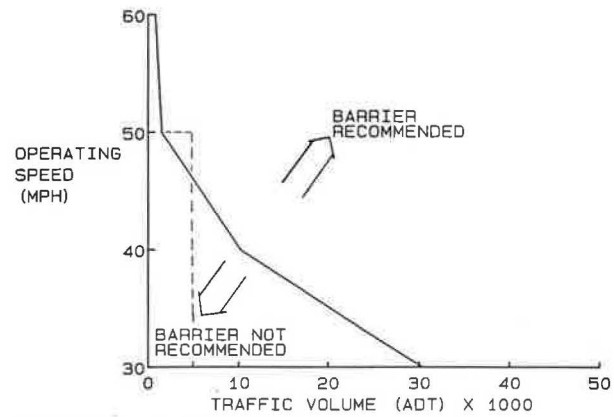

FIGURE 13 Typical guidelines for PCB protection for major structural elements under construction (falsewark cost = $100,000).

TWO-LANE, TWO-WAY TRAFFIC OPERATIONS

Frequently, during long-term construction activities on a four-lane divided highway, all traffic is diverted to one side while the other side is closed for maintenance. This creates a two-lane, two-way operation (TLTWO) on what is normally a divided highway. For these work zones, multiple vehicle median crossover accidents are of primary concern.

In the development of barrier guidelines for TLTWO work zones, it was assumed that opposing vehicles comprise all hazards to encroaching vehicles. Further, no effort was made to evaluate the effect a barrier would have on rear-end accident rates. The reader should refer to Ross and Sicking (6) for a discussion of encroachment rates into opposing traffic lanes and the probability of affecting opposing traffic.

A typical TLTWO work zone can be described by determining the appropriate crossover configuration. Two basic types of barrier layouts were investigated. The barrier configuration shown in Figure 14 was found to be more cost-effective than the other configuration studied for all combinations of work zone length and traffic volume. Note that the treatment involves a barrier flared at a 10:1 rate to an offset of 20 ft from the edge of the travelway. No special end treatments were used on either end of

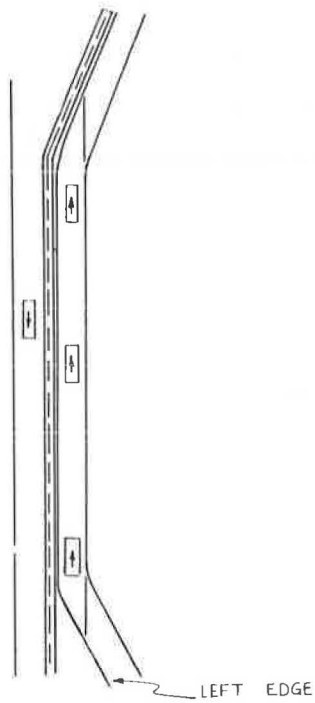

FIGURE 14 Two-lane, two-way traffic operations with positive barrier lane separation.

the barrier. Guidelines were developed by determining combinations of TLTWO operating speed, project duration, and traffic volume for which the benefit-to-cost ratio for barrier implementation equals 1.0 as shown in Figure 15. These guidelines are used in the same general manner as those developed for other barrier applications. It is important to note that the guidelines shown were developed on the basis of the assumption that the work zone contains no at-grade intersections in the TLTWO. If such intersections cannot be avoided, the benefit-cost computer program should be employed to determine barrier warrants on a case-by-case basis.

CONCLUSIONS

The problem of formulating a set of guidelines for barrier use in work zones is indeed formidable. The number, diversity, and variability of factors that affect barrier need within a given work zone greatly complicate the problem. Moreover, there are simply no two work zones that have the same characteristics. In other words, a set of totally objective guidelines appropriate for any given circumstance cannot be developed.

To give engineers the option of determining barrier need for any specific site, a computer program, which automates the benefit-cost analysis, was developed. This program has been adapted for use with microcomputers and made user friendly to facilitate its use by design engineers.

A set of use guidelines for work zone barriers has been developed for typical work zone sites. The guidelines were developed through application of the previously mentioned computer program. The guidelines are applicable to a wide range of traffic volumes, operating speeds, and construction zone characteristics. These simplified guidelines provide the practicing engineer with an objective criterion against which to estimate positive barrier need.

General conclusions from the study are as follows:

1. Barrier end treatment: Flaring the barrier away from the travelway is quite cost beneficial over a wide range of traffic conditions. The optimum flare rate is approximately 10:1 when the flare cannot be started within the construction zone. High-cost crash cushion end treatments are not generally warranted when the barrier can be flared away from the traffic lanes 20 ft or more, even at relatively high traffic volumes.
2. Bridge widening zones: Positive barrier use in bridge widening construction zones on high-speed facilities is generally cost beneficial even at low traffic volumes.
3. Roadway widening zones: PCB use in roadway widening zones involving simple pavement widening is not generally cost beneficial for projects with durations of 1 year or less. However, barrier use in construction zones involving vertical realignment is warranted for moderate traffic volumes.
4. Roadside structure construction: Positive barrier use in these zones is quite cost beneficial, even at traffic volumes as low as 1,000 ADT.

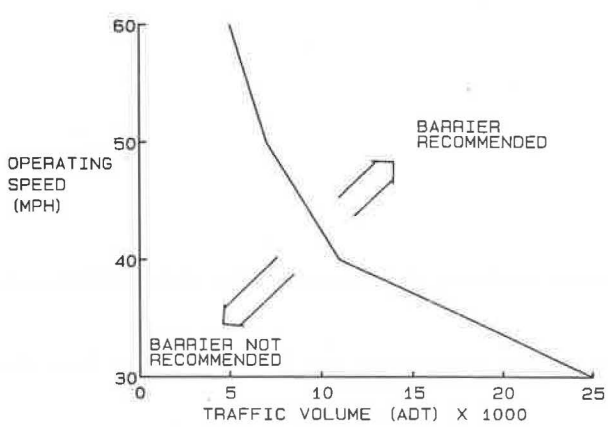

FIGURE 15 Guidelines for conventional PCB use in centerline of TLTW construction zones (project duration = 1 year).

ACKNOWLEDGMENTS

The research reported herein was conducted under DOT Contract DOT-FH-11-9688. Justin True of the Federal Highway Administration served as technical contract manager. His suggestions, cooperation, and patience throughout the contract were appreciated. The cooperation and assistance of the following personnel were also appreciated: Hayes E. Ross, Jr., Texas Transportation Institute; James H. Hatton, Federal Highway Administration; and William W. Hunter, Highway Safety Research Center, University of North Carolina.

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Publication of this paper sponsored by Committee on Safety Appurtenances.