6. Based on observed tire marks, the end of the barrier flare adjacent to the travel way at the start of the work area was the most-often-hit "point location" in the barrier system.

7. There was an average of 9.7 vehicle involvements with the temporary barriers on VA-44 per million vehicle miles of exposure.

8. There was a definite tendency for motorists to stay out of the barrier lane during construction, but this avoidance decreased as the traffic volume increased.

9. Driver awareness of the construction zone was demonstrated by a 3.2-km/h (2-mile/h) reduction in average speed and a lower variance in lateral placement in the barrier lane.

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Cost-Effectiveness of Guardrail-Bridgerail Transition Improvements: Double W-Beam Versus Decreased Post Spacing

EDWARD R. POST, PATRICK T. McCOY, TERRY J. WIPF, AND RICHARD J. RUBY

A study of the performance characteristics of two guardrail-bridgerail transition systems is reported. The two systems were the American Association of Highway and Transportation Officials (AASHTO) stiff-post system and the Nebraska Department of Roads (NDR) "double W-beam" system. The AASHTO system provides larger-sized posts on reduced spacings, whereas the NDR system uses another length of guardrail alongside the face of the existing guardrail with uniform 1.01-m (6-ft 3-in) post spacings. The NDR system eliminates the difficulty of increasing the stiffness of existing systems because of the concrete bridge abutments and/or wing walls that restrict the placement of additional posts on reduced spacings. The objective of the study, which was limited in scope, was to use the BARRIER VII computer program to compare the cost-effectiveness of the two systems. The study considered the effects of impacts with the guardrail transitions by two different-sized automobiles under all possible combinations of speed and angle. The findings show that a reasonable doubt exists as to the cost-effectiveness of the AASHTO system under a wide range of impact conditions. Specifically, the stiff-post system produced more injury-type accidents and resulted in larger exit angles, which increased concern about secondary collisions with other vehicles. The structural adequacy of the guardrail-bridgerail connection in both systems was the single most important design element.

The current accepted practice in designing W-beam approach guardrail is to increase the stiffness of the guardrail by decreasing the post spacing and using larger-sized posts adjacent to a bridge structure. This design practice was established from the results of a limited number of full-scale crash tests of a large-sized automobile weighing 2041 kg (4500 lb) under extreme impact conditions [97 km/h (60 miles/h) and 25°].

In attempting to upgrade existing systems, the Nebraska Department of Roads (NDR) has often found that it was difficult to increase the stiffness of approach guardrail by adding posts because of the extended concrete foundation footings. As a compromise, NDR has designed a transition section in which the stiffness of the guardrail is increased by installing another length of guardrail alongside the face of the existing guardrail.

The NDR design has been questioned by some engineers because its performance has not been verified by full-scale crash tests. The objective of this study was to conduct a study of limited scope in which computer-model simulations would be used to ascertain the cost-effectiveness of decreasing the post spacing adjacent to a bridge structure in comparison with using the NDR "double W-beam" design. This study takes into consideration the effects of impacts by different-sized

Figure 1. Existing double W-beam approach guardrail.

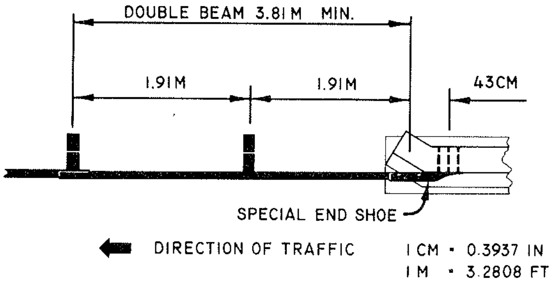
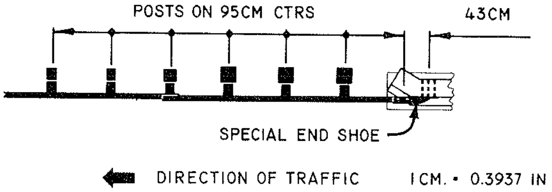


Figure 2. Guardrail improvement alternative.



automobiles with the approach guardrail under all possible speed and angle combinations.

STUDY SITE

The highway used as a study site is classified as a two-lane major arterial rural state highway that will carry a design hourly vehicle volume of 400-750. The traffic lanes are 3.66 m (12 ft) wide, and the paved shoulders are 2.44 m (8 ft) wide.

Details of the type 4 bridge approach guardrail are shown in Figure 1. The double section of guardrail extends over a length of 3.81 m (12.5 ft) and is bolted to 15x20-cm (6x8-in) posts spaced 1.91 m (6.25 ft) on centers. A "special" end shoe is used to connect the guardrail to the concrete bridge parapet.

A plan view of the proposed improvement alternative is shown in Figure 2. This design is very similar to the T1 design of the American Association of State Highway and Transportation Officials (AASHTO) (1, p. 43). The six posts adjacent to the bridge have a reduced post spacing of 1 m (3 ft 1.5 in) on centers, whereas the last three posts have larger [25x25-cm (10x10-in)] timbers.

COMPUTER SIMULATION MODEL

During the past three decades, many highway organizations have relied heavily on experience and judgment in the design of roadside appurtenances; full-scale trial-and-error tests were often conducted to determine the feasibility of these appurtenances. Significant advancements in technology and an increase in safety have evolved from these efforts. However, this type of design approach appears to be insufficient by itself because one or more full-scale tests were required to effectively evaluate the influence of any one variable. Conducting many full-scale tests can be both time-consuming and costly.

Mathematical model simulation provides a rapid and economical method of investigating the many variables involved in a run-off-the-road automobile collision or maneuver. A limited number of full-scale tests can then be conducted to confirm the simulation results. When supplemented by experience, judgment, and testing, model simulation can be a very helpful tool in achieving efficient and safe designs.

The BARRIER VII program developed by Powell (2,3) was used in this study to determine the dynamic effect of an automobile interacting with a traffic barrier system. The traffic barrier is idealized as a plane framework composed of inelastic one-dimensional elements of a variety of types. The automobile is idealized as a plane rigid body surrounded by a cushion of springs. A large-displacement dynamic structural analysis problem is solved by numerical methods.

The analysis is two-dimensional in the horizontal plane. Out-of-plane effects, which include vertical displacements of both the automobile and the barrier, are not considered. The automobile slides along the barrier, and the effects of normal force, friction forces, and wheel drag forces are considered in determining its motion. The necessary input data consist of the barrier configuration, the properties of the barrier members and the automobile, and the velocity and trajectory of the automobile before impact. Output consists of barrier member forces, barrier deflections, time histories of automobile positions, and velocities and acceleration of the automobile.

A final comment should be made about the BARRIER VII program. It is a two-dimensional program and therefore placed limitations on this study. BARRIER VII cannot predict the roll motion of the vehicle, wheel snagging, or vehicle vaulting, nor will it predict situations in which the vehicle could break through the guardrail. In all BARRIER VII simulations, the rail will return to the elastic state, even though at times there may be sufficient plastic hinges formed so as to create a local mechanism. As far as this study was concerned, all guardrail performance runs were based on successful guardrail tests.

The output results from BARRIER VII that were of direct interest in this study were vehicle accelerations, exit angles, dynamic deflections, forces in the rail member adjacent to the guardrail-parapet connection, and damage to the guardrail system. The results for all impact combinations are given in Table 1.

In determining damage to the guardrail system, the BARRIER VII program will show whether a post has failed. Rail damage can be assessed based on the deflections that occur in the system. The length of rail reported as damaged is in increments of 3.81 m (12.5 ft), since this would be the minimum length of rail that could realistically be replaced.

It was felt that the structural adequacy of the guardrail-parapet connection could be predicted by using the force histories that the BARRIER VII program outputs. If any tensile force in the rail member directly adjacent to the parapet connection reached 355.8 kN (80 000 lbf) and was maintained for a few time steps, it would be assumed to cause the connection to reach yield and then fail.

PROBABILITY OF INJURY

The criteria used in the majority of the evaluations conducted during the past decade on the safety aspects of roadside-hazard improvements were based on levels of vehicle acceleration that would be tolerable to an unrestrained vehicle occupant. One method used to accomplish this task was the definition of a severity index, computed as the ratio of the measured resultant automobile acceleration to the resultant "tolerable" automobile acceleration. An improvement that resulted in a severity-index

Table 1. Results of BARRIER VII simulation.

		Existing System				Stiffened Post			
Speed (km/h)	Angle (°)	Severity Index[a]	Maximum Tensile Force in End Rail (kN)	Vehicle Exit Angle (°)	Probability of Injury[b]	Severity Index[a]	Maximum Tensile Force in End Rail (kN)	Vehicle Exit Angle (°)	Probability of Injury[b]
1021-kg Automobile									
64	10	0.48	0.4	1.5	0.19	0.55	0.4	1.8[c]	0.22
	15	0.78	0.9	2.9	0.30	0.88	0.4	3.7[c]	0.35
	20	1.03	5.8	5.4	0.41	1.26	0.9	7.5[c]	0.50
	25	1.16	36.5	10.9	0.46	1.81	5.8	16.0[c]	0.72
80	10	0.63	0.4	1.7	0.25	0.76	0.0	1.9	0.30
	15	0.95	7.1	3.4	0.38	1.24	0.9	4.4	0.50
	20	1.26	25.8	6.4	0.50	1.86	2.7	9.0[c]	0.74
	25	1.27	92.5	7.7	0.51	1.96	51.2	14.6[c]	0.78
97	10	0.82	1.8	1.3	0.33	1.00	0.9	2.1	0.40
	15	1.28	10.2	3.4	0.51	1.41	0.9	4.4	0.56
	20	1.34	82.7	6.0	0.54	2.21	21.8	9.8	0.88
	25	1.56	136.1	6.0	0.62	2.24	85.8	15.7	0.90
1732-kg Automobile									
64	10	0.45	0.9	3.3	0.18	0.55	1.8	2.9[c]	0.22
	15	0.67	1.8	7.7	0.27	0.87	16.0	6.4[c]	0.35
	20	0.72	7.6	10.0	0.29	1.25	74.7	14.5[c]	0.5
	25	0.84	78.3	14.0	0.34	1.12	123.2	21.6[c]	0.45
80	10	0.61	0.9	3.3	0.24	0.75	5.3	3.1	0.30
	15	0.87	2.2	6.7	0.35	1.23	53.4	7.2[c]	0.49
	20	0.83	64.9	10.8	0.32	1.31	92.1	15.4	0.52
	25	1.02	128.1	16.3	0.41	1.33	222.8	25.0[c]	0.53
97	10	0.80	0.4	2.8	0.32	1.04	9.8	3.2	0.42
	15	0.97	23.1	8.9	0.39	1.43	106.3	8.8	0.57
	20	2.12	101.9	13.1	0.95	1.31	228.2	13.8	0.52
	25	3.09	171.7	21.5	1.00	1.58	321.1	28.0	0.63

Note: 1 km = 0.62 mile; 1 kN = 225 lbf.

[a] Computed by using Equation 1.

[b] Obtained from Post and others (4).

[c] Secondary impact.

value of 1 or less was considered to be safe; an improvement resulting in a severity-index value greater than 1 was considered to be unsafe. The work reported here expands the existing technology to include the probability of occurrence of roadside injury-type accidents. An in-depth discussion of a tentative relationship between severity index and the probability of occurrence of injury-type accidents is given by Post and others (4).

CONCEPT OF SEVERITY INDEX

The severity of the collision of an automobile with a traffic barrier is expressed in terms of a severity index (SI). The SI is computed as the ratio of the measured or computed resultant automobile acceleration to the resultant tolerable automobile acceleration that defines an ellipsoidal surface. This ratio can be expressed mathematically as follows (5,6):

$$SI = (G_{\text{total auto}}/G_{\text{total occupant}}) = \sqrt{(G_{\text{long}}/G_{XL})^2 + (G_{\text{lat}}/G_{YL})^2 + (G_{\text{vert}}/G_{ZL})^2} \quad (1)$$

where

$G_{\text{total auto}}$ = resultant automobile acceleration,
$G_{\text{total occupant}}$ = resultant tolerable acceleration,
G_{long} = automobile acceleration along longitudinal x-axis,
G_{XL} = tolerable acceleration along x-axis,
G_{lat} = automobile acceleration along lateral y-axis,
G_{YL} = tolerable acceleration along y-axis,
G_{vert} = automobile acceleration along vertical z-axis (= 0), and
G_{ZL} = tolerable acceleration along z-axis.

The computations of SI in this paper are based on accelerations tolerable to an unrestrained occupant, and the automobile accelerations are averaged over a time duration of 50 ms. The relation between SI and injury levels is discussed in detail by Post (4).

RESULTS OF BARRIER VII SIMULATIONS

Automobiles of two sizes were used in this study: the standard-sized vehicle [1732 kg (3820 lb)] and the increasingly popular compact vehicle [1021 kg (2250 lb)]. Three impact speeds--64, 80, and 97 km/h (40, 50, and 60 miles/h) and four impact angles--10°, 15°, 20°, and 25°--were considered.

Point of Vehicle Impact

For all combinations of impact conditions, the initial impact location was 6.68 m (21.9 ft) upstream from the concrete parapet connection. The single impact location was chosen so that there would be adequate time and distance for successful redirection of the automobile under all conditions considered in the study, if indeed redirection were to occur. In the case of the lower speeds and lower impact angles, it would have been possible to move the initial impact location closer to the parapet and still have successful redirection. It was felt that there would be a trade-off in relation to the degree of hazard in these cases when the existing system was compared with the stiff-post system. The stiff-post system would yield significantly higher accelerations, whereas in the existing system it seemed likely that forces would occur in the rail near the parapet connection that would be large enough to cause failure of the guardrail-parapet connection. In the stiff-post system, higher severities occur because of significant increases in acceleration; in the existing system, higher severities occur because of the increased likelihood of impact with the parapet. It seemed reasonable, therefore, to select a single location of impact for all impact conditions.

Guardrail-Parapet Connection

One point raised in the preceding discussion that needs to be examined is the importance of the guardrail-parapet connection. This connection is required to withstand a 355.8-kN (80 000-lbf) load. As the data given in Table 1 indicate, the tensile forces in the guardrail adjacent to the connection become quite high in some cases. It becomes very important then that the design engineer look carefully at the structural details of the connection. This means not only making sure that there are an adequate number of bolts and a structurally adequate rail for the connection but also ensuring the strength of the parapet that will be receiving these rather large forces. Whenever the connection fails, there is an almost certain chance of vehicle impact with the parapet and a 100 percent probability of injury.

The critical consideration in the design of the guardrail transition is the guardrail-parapet connection. Thus, if upgrading of a transition section were required and if there were any question about the structural adequacy of the guardrail-parapet connection, the stiff-post system would appear to be the best solution because it develops smaller tensile forces in the rail at the connection than does the existing system, which decreases the chance for connection failure.

Characteristics of Vehicle Redirection

The redirection characteristics of the two systems considered in this study were important, since a higher exit angle after impact with a guardrail increases the chance of the vehicle being redirected into traffic in the opposing lane. It was interesting to note that the stiff-post system generates higher exit angles than the existing system. This can be explained by the fact that larger normal forces are developed in the stiff-post system between the guardrail system and the automobile than are developed in the existing system. These larger forces tend to redirect the automobile at a higher yaw rate than that found in the existing system. In some cases, secondary impacts occurred in interactions between the stiff-post system and the vehicle. The guardrail was initially in contact with the front portion of the car, and the large normal forces quickly increased the yawing motion until the rear portion of the vehicle suddenly struck the rail. The cases in which secondary impact occurred are noted in Table 1.

Figure 3 shows a typical comparison between the redirection characteristics of a vehicle interacting with the stiff-post system and one interacting with the existing system. The data were obtained from simulations performed by using the compact automobile at 64 km/h (40 miles/h) and 25°. The point being monitored was the center of gravity of the vehicle.

Deviations in Severity Indices

In two cases, the SI deviated from a consistent pattern. For the 1732-kg (3820-lb) automobile impacting the existing system at 20° and 25°, the SIs were reported as being larger than for the same vehicle impacting the stiff-post system. An apparent explanation for this was that, at these large encroachment angles, the large vehicle had penetrated far enough into the guardrail system that it was "picking up" the contribution of the stiffness of the guardrail-parapet connection more than did the vehicle under the other impact combinations. The maximum accelerations for these two unique cases, then, were occurring at a later time during the interaction with the guardrail system than in the other cases.

IMPACT-CONDITION PROBABILITIES

The impact-condition probabilities were computed by combining distributions of vehicle speeds and encroachment angles. The vehicle-speed distribution was obtained from an analysis of spot-speed data collected on two-lane major arterial rural highway sections by NDR. It was determined that vehicle speeds on these sections were normally distributed with a mean speed of 89.2 km/h (55.4 miles/h) and a standard deviation of ±7.4 km/h (±4.6 miles/h). The impact-angle distribution was that reported by Hutchinson and Kennedy for median encroachments (7).

Assuming that these two distributions were completely independent, they were combined. The combined distribution of vehicle speeds and impact angles was then used to compute impact-condition probabilities (8). These probabilities indicate that the most likely impact condition is a speed-angle combination of 89-105 km/h (55-65 miles/h) and <7.5°.

The point mass model presented by Ross (9) was used to determine that some high-speed, high-angle impacts were not possible. However, because of a lack of encroachment data on speed-angle combinations to support this conclusion, it was decided that adjustment of the impact-condition probabilities to account for the apparent impossibility of high-speed, high-angle impacts was not warranted.

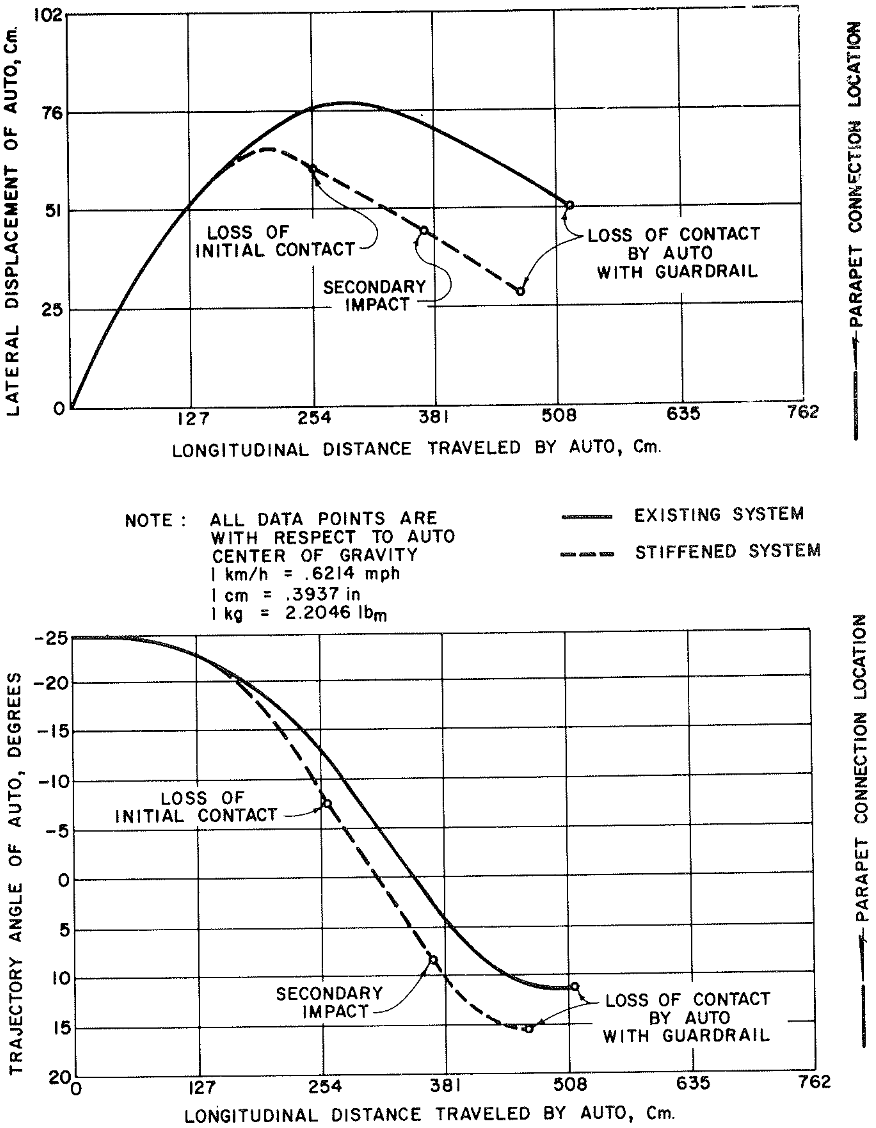
EVALUATION OF IMPROVEMENT ALTERNATIVES

Roadside safety improvement programs must compete with other ongoing highway programs for the limited funds available. The cost-effectiveness method of analysis was used to compare alternatives to making the transition from the semirigid W-beam guardrail to the rigid concrete bridge parapet. The cost-effectiveness method is a management tool intended to provide the highway administrator with a means of evaluating safety-improvement alternatives on a common data base to realize the greatest return on the investment to reduce injury accidents.

Cost-Effectiveness Analysis

The cost-effectiveness analysis conducted in this study was based on the cost-effectiveness priority approach formulated by Glennon (10) and implemented in Texas for managing roadside safety improvement programs on both non-controlled-access and controlled-access highways (11). The following cost-effectiveness measure was used in this approach: Cost-effectiveness = annualized cost of improvement per unit hazard reduction achieved = cost to eliminate one injury (fatal or nonfatal) accident. The measure of effectiveness was defined

Figure 3. Trajectories of 1021-kg automobile under impact conditions of 64 km/h and 25°.



as the difference between the hazard indices before and after an improvement, expressed in terms of the number of fatal and nonfatal accidents per year. Thus, in order to apply the cost-effectiveness priority approach in this analysis, it was necessary to compute the hazard index for each improvement and its annualized costs.

Hazard Index

The hazard index was computed for the improvement alternative by using the following equation:

$$H = [E_f(D)(P)(L)/5280]\,(0.60\,H_1 + 0.40\,H_2) \qquad (2)$$

where

H = hazard index for each improvement alternative (injury accidents per year);
E_f = encroachment frequency (7);
D = directional traffic split = 1/2;
P = lateral impact probability at some offset distance (7);
L = effective length of guardrail transition = 7.62 m (25 ft);
H_1 = hazard-index contribution for impacting vehicles that weigh more than 1021 kg (2250 lb) (assumed to be 60 percent) = $\sum_\theta \sum_v [(SP)(PI)]$;
H_2 = hazard-index contribution for impacting vehicles that weigh less than 1021 kg (assumed to be 40 percent) = $\sum_\theta \sum_v [(SP)(PI)]$;
SP = impact-condition probability for each combination of speed and angle (8);
PI = injury-accident probability for each combination of speed and angle severity index for a certain size of vehicle (4);
θ = vehicle impact angle = 10°, 15°, 20°, and 25°; and
v = vehicle impact speed = 64, 80, and 97 km/h (40, 50, and 60 miles/h).

Encroachment Frequency

Knowledge of the frequency at which vehicles encroach on the roadside is very limited. Therefore, the encroachment frequency used by Glennon (10) was assumed to be applicable for the purpose of this analysis. The average daily traffic (ADT) for the study site was assumed to be 7500 vehicles/day, which will result in an encroachment frequency of

Table 2. Results of cost-effectiveness evaluation of two bridge guardrail approaches.

Alternative	Lateral Offset Distance (m)	Lateral-Impact Probability	Hazard Index (injury accidents/year)	Capital Costs[a]		Collision Maintenance Costs[a] ($/year)	Cost-Effectiveness
				Dollars	Dollars per Year		
Existing double W-beam	2.74	0.94	0.0034	–	–	1	–
Reduced post spacing and larger-sized posts	2.74	0.94	0.0041	540	59	1	Not cost-effective[b]

Note: 1 m = 3.3 ft.

[a] Annualized costs were based on a 20-year service life, 9 percent interest rate, and zero salvage value (capital recovery factor = 0.1095).

[b] Not cost-effective because $H_{impr} > H_{exist}$.

$$E_f = 1.1 + (0.000\,415)\text{ADT} \tag{3}$$

where E_f = 4.2 encroachments/year/mile.

Probability of Lateral Impact

Given that an encroachment has occurred, the probability of a vehicle impacting a roadside obstacle decreases as the distance from the edge of the traveled roadway increases. Probabilities of lateral impact were obtained from the relationship used by Glennon (10).

Collision Maintenance Costs

The collision maintenance cost was computed for the improvement alternative by using the following equation:

$$CM = [E_f(D)(P)(L)/5280]\,(0.60\,CM_1 + 0.40\,CM_2) \tag{4}$$

where

CM = annualized collision maintenance cost,
CM_1 = annualized collision maintenance cost contribution for vehicles that weigh more than 1021 kg (2250 lb) = $\sum_\theta \sum_v [(SP)(CS)]$,
CM_2 = annualized collision maintenance cost contribution for vehicles that weigh less than 1021 kg = $\sum_\theta \sum_v [(SP)(CS)]$, and
CS = annualized collision maintenance cost for each combination of impact speed and angle.

All of the remaining terms in Equation 4 have been previously defined in Equation 2.

Evaluation

As defined earlier, cost-effectiveness was described as the annualized cost of an improvement per unit of hazard reduction achieved. The measure of effectiveness was defined as the difference between the hazard indices before and after an improvement. Effectiveness can be computed by using the following equation:

$$E = H_{exist} - H_{impr} \tag{5}$$

where

E = effectiveness (hazard reduction),
H_{exist} = hazard index of existing system, and
H_{impr} = hazard index of stiffened system.

The annualized improvement costs consider both capital costs and collision maintenance costs. Normal maintenance costs were assumed to be small and were neglected. The costs can be computed from the following equation:

$$C = CI_{impr} + CM_{impr} - CM_{exist} \tag{6}$$

where

C = annualized cost of improvement,
CI_{impr} = annualized capital cost of improvement,
CM_{impr} = annualized collision maintenance cost of improvement, and
CM_{exist} = annualized collision maintenance cost of existing system.

The results of the cost-effectiveness evaluation are summarized in Table 2. As Equation 5 indicates, the improvement alternative was not cost-effective because there was no reduction in the hazard index; in fact, the stiff-post system not only did not exhibit a reduction in the hazard index but even indicated a slight increase. This indicates the probability of a higher incidence of injury accidents.

SUMMARY AND CONCLUSIONS

This study on the cost-effectivensss of guardrail-bridgerail transition areas was conducted by the University of Nebraska in cooperation with the Nebraska Department of Roads.

The NDR requested the research study in order to gain more insight into the performance characteristics of two guardrail transition systems: the AASHTO stiff-post system and the existing NDR double-beam system. The stiff-post system increases the stiffness of the guardrail by reducing the post spacings, whereas the NDR system installs another length of guardrail alongside the face of the guardrail and uses uniform post spacings of 1.91 m (6.25 ft) on centers.

The NDR system has been questioned by some engineers because its performance has not been verified by full-scale crash tests. The objective of this study was to use the BARRIER VII computer program to ascertain the cost-effectiveness of the stiff-post system in comparison with the existing NDR double-beam system. The study considered the effects of impacts of the guardrail transition area by two vehicles of different sizes under all possible combinations of impact speed and angle. The significant findings were as follows:

1. The stiff-post system was not cost-effective because it produced more injury-type accidents.
2. The stiff-post system resulted in larger exit angles, thereby increasing the possibility of secondary collisions with other vehicles.
3. Since the stiff-post system produces lower tensile forces in the guardrail, it would perform more effectively than the NDR system if the connection between the guardrail and bridgerail could not be made to meet minimum structural

requirements. It is not, however, recommended that decreased post spacing be substituted for a structurally adequate connection because the tension capability in the guardrail is the single most important design element.

The results of this study will be used in the formulation of NDR policy on guardrail design, installation, and maintenance. The methodology and procedures developed will be included in NDR design procedures and will increase the ability of the department to evaluate new systems through the cost-effectiveness calculations based on BARRIER VII simulations.

Based on the results of this study, there has been shown to be reasonable doubt as to the cost-effectiveness of the stiff-post system under a wide range of impact conditions. A more detailed examination of the total effectiveness of the stiff-post system is needed. Further research should be conducted to compare the performance characteristics of the two systems by means of full-scale testing and computer model simulations.

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Conflicts Between Vehicle Traffic and Utility Facilities

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Conflicts between vehicle traffic and utility facilities are examined in a before-and-after study of a heavily used section of a four-lane major arterial in Knoxville, Tennessee. At the beginning of the study, many utility facilities were located in the roadway and at the back of the curb in close proximity to moving traffic. Some of the underground facilities in the roadway were relocated under or to the far side of the sidewalk, and all utility poles were relocated to the far side of the sidewalk and to one side of the street. Prior to the relocation, there was a high incidence of vehicle collisions with aboveground utility facilities and considerable traffic delays caused by maintenance of underground facilities on this section of highway. In the five years since the relocation, no collisions with utility facilities have been reported. Other factors examined include accidents involving the failure of pavement cuts made when underground facilities were repaired or installed, delays resulting from utility operations, and user costs resulting from traffic delays and accidents in which utility facilities are involved. The study shows not only that serious conflicts exist in certain locations but also that considerable improvement can be achieved through cooperation in planning, design, and operations between highway agencies and utility agencies.

Utility facilities are a part of the transportation system, moving important products, such as water, gas, electricity, and communications, from sources to destinations. Problems occur when utility facilities are brought into direct contact with other transportation facilities, such as the highway and street network. When highways and utilities are merged, conflicts arise that are not easily or economically resolved.

Highways and utilities serve two totally different purposes. The highway and street system is for the purpose of moving people (as well as freight and goods) at high rates of speed and in heavy vehicles. Utility facilities move commodities--water, electricity, sewage, or communications--that are different in nature and for a different purpose.

Utilities have always shared rights-of-way with highways. This need, long recognized by law, varies only slightly from state to state with regard to occupancy and installation rights. Rights and needs to share rights-of-way are generally and mutually recognized; the difficulty occurs when service to one mode is interrupted or interfered with by the opposite mode. Furthermore, other factors, such as aesthetics and crowding, tend to aggravate the perceived adverse relation when conditions such as interrupted service develop.

This paper discusses the problems encountered in conflicts between highways and utilities and their possible solutions. The problems are presented from the following viewpoints:

1. Utilities are generally installed on existing highway rights-of-way.
2. The health, safety, and welfare of the