THE "FORGIVING ROADSIDE" DESIGN OF ROADSIDE ELEMENTS

R.D. Powers, Federal Highway Administration
J.W. Hall, University of New Mexico
L.E. Hall, University of New Mexico
D.S. Turner, University of Alabama

INTRODUCTION

The symposium session on the cross section dealt almost exclusively with the geometric features of the roadway -- most commonly lane width, lane configuration, and shoulder width and type. Alignment and curvature were also addressed. In a "perfect" world, the highway engineer would need to look no further than this because motorists would never "accidentally" leave the paved portion of the roadway. However, in spite of engineers' best efforts to design fail-safe facilities, accident data demonstrate that motorists leave the roadway for numerous reasons -- with errors in judgment leading the list. In a less enlightened time, the highway engineers seemed to shrug collectively and matter-of-factly proclaim that they designed roads to drive on, and had no responsibility towards the driver who could not keep his vehicle on the road. To a lesser extent, this attitude can still be found today. Nevertheless, many engineers recognize that they can almost always lessen the severity of an accident when a driver does run off the roadway. The concept applied to lessening the severity of run-off-the-road accidents has been named "the forgiving roadside." The US, where this concept was pioneered, has a more extensive background in this regard than other countries; the following discussion is based largely on US experience and standards.

AASHTO's 1967 report *Highway Design and Operational Practices Related to Highway Safety* was the first official document that focused attention on the hazardous elements of roadside design and suggested appropriate treatment for many roadside elements (*1*). This guide, popularly known as the AASHTO "Yellow Book," was revised and updated in 1974 (*2*). In 1977, AASHTO's *Guide for Selecting, Designing, and Locating Traffic Barriers* (Barrier Guide) provided detailed guidance on the use and design of longitudinal traffic barriers (roadside barriers, median barriers, bridge railings) and crash cushions (*3*). This publication was instrumental in helping to attain the high degree of traffic barrier standardization that currently exists in the US. Finally, in 1988, AASHTO formally approved its *Roadside Design Guide* (*4*), a manual that incorporates much of the information contained in the 1974 Yellow Book and the 1977 Barrier Guide as well as additional research findings and state-of-the-art practices of several state highway agencies.

Obviously, the least hazardous roadside environment would contain no objects that an errant vehicle could impact, but would allow the driver to regain control and either stop or return to the travel lane without injury or damage. The Yellow Book (*1*) introduced the concept of a roadside "clear zone" that was relatively flat and free of obstructions. It has become generally accepted that the width of the clear zone should depend on speed, and should be wider at those locations (like the outside of horizontal curves) where vehicles are more likely to leave the traveled portion of the roadway. Although the idea of a clear zone originated in the US and much of the early research was done there, over the past 25 years the concept has been accepted as an important cross section design consideration in other countries. Current examples of clear zone criteria from several countries were gathered through an international survey (*5*) and are shown in Table 1.

CATEGORIES OF ROADSIDE ELEMENTS

Essentially, there are four general categories of roadside design elements addressed in the *Roadside Design Guide*:

1. roadside topography or slopes,
2. drainage features,
3. highway appurtenances such as sign and light supports, and
4. traffic barriers.

For each of these features, the following sections will review the historical development, describe the current situation, highlight existing shortcomings, and identify where efforts might be directed in the near future. The estimated severity of impact with these obstacles is summarized in a recent NCHRP Synthesis (*6*).

Roadside Slopes

Except for urban streets, the pavement itself is usually at a different elevation than the surrounding terrain. Thus a vehicle leaving the roadway will be difficult to slow or steer effectively. It is evident that flatter roadside slopes facilitate safer encroachments. The Yellow Book (*7*) stated "there is a growing realization ... that side slopes on embankments and in cuts should provide a reasonable opportunity for recovery for an out-of-control vehicle. Rates of slope of 1:6 or flatter can be negotiated by a vehicle with good chance of recovery and should ... be provided where it is feasible." On fill heights between 7.5 and 15 m, 1:4 slopes were recommended and many states constructed a so-called barn-roof section consisting of a flat slope (typically 1:6)

TABLE 1 Horizontal Clearance Criteria

Country	Examples of Clear Zone Criteria
Australia	Generally, all items such as poles and sign supports should be kept a minimum of 1 m clear of the outer edge of the shoulder.
Czech Republic	Obstructions must be placed behind a ditch or 0.5 m behind a curb.
France	7 to 10 m wide; eliminate all obstacles in clear zone or isolate them with guardrail.
Germany	Depends on design speed: > 70 km/h 1.25 m ≤ 70 km/h 1.00 m ≤ 50 km/h 0.75 m
Hungary	1.5 m (1.0 m in median) on freeways, 1.5 m on arterials, 0.5 m on minor or local roads.
Poland	Follows German procedures.
South Africa	Depends on road type: urban arterial 5.0 m urban collector 4.0 to 5.0 m rural 3.0 m
Sweden	Generally, rigid objects more than 10 m from the edge of the roadway are not shielded by guardrail.
Switzerland	Examples: 0.2 m to signal post, 1.0 m to horizontal and longitudinal obstructions, 0.25 m between bikeways or sidewalks and buildings.
United Kingdom	Generally, the 1.5 m minimum-width grassed verge is kept clear. Obstacles within 4.5 m of pavement edge are shielded by guardrail. On local roads there is a minimum distance of 0.6 m for signs.
USA	Based on vehicle speed, cut versus fill, and roadside slope. Typically 10 m for freeways. For high speed and rural clearances, see (*2*); for urban and low-speed clearances, see (*1*).
Venezuela	The "clear zone" concept is not embodied in the design criteria.
Yugoslavia	Follows AASHTO procedures.

extending beyond the shoulder of the roadway for up to 6 m before starting a much steeper down slope. This design provided an area on which errant motorists could regain control of the vehicle and stop or return safely to the roadway.

The Barrier Guide (*3*) further suggested that negotiating a 1:3 slope was equal in severity (for a restrained vehicle occupant) to striking a guardrail, and cautioned that fixed objects at or near the toe of these slopes required a separate analysis; unfortunately, this point was overlooked by many designers. The Barrier Guide also emphasized the need for liberal slope rounding, both at the top and bottom of the slope, to minimize loss of vehicle control by keeping the vehicle's wheels in contact with the ground at the top and by preventing it from decelerating rapidly at the bottom. The *Roadside Design Guide* (*4*) restates these points but makes a stronger case for unobstructed roadsides by excluding distances on slopes of 1:4 or steeper from clear zone calculations, thus acknowledging that most motorists on such slopes will go to the bottom, which is the area that should be kept hazard free to the extent practical. Once again, the importance of rounded transitions between slope breaks is emphasized.

To achieve maximum safety, then, slopes should be as flat as practical and liberally rounded top and bottom. A slope of 1:6 or flatter is required for recovery, but slopes up to 1:3 can be traversed if they are smooth and unobstructed. A runout area at the toe of the slope is essential if crash severities are to be kept to a minimum.

TABLE 2 Typical Values of Embankment Slopes

Country	Roadway Classification		
	Freeway	Arterial	Minor/Local
Australia		≤ 1:6 up to 10 m high; then 1:1.5 to 1:2	
Canada		rural collector 1:2 to 1:6	rural local 1:2 to 1:3
China	1:1 to 1:1.75	1:1 to 1:1.75	1:1 to 1:1.75
Czech Republic	1:2.5 if < 3.0 m 1:1.5 if ≥ 3.0 m	1:2.5 if < 3.0 m 1:1.5 if ≥ 3.0 m	1:2.5 if < 3.0 m 1:1.5 if ≥ 3.0 m
Denmark	1:2	1:2	1:2
France	based on geotechnical design	based on geotechnical design	based on geotechnical design
Germany	1:1.5	1:1.5	1:1.5
Greece	2:3	2:3	2:3
Hungary	1:2 to 1:2.5	1:1.5 to 1:2.5	1:1.5
Japan	1:1.5 to 1:2	1:1.5 to 1:2	1:1.5 to 1:2
Netherlands	1:2 to 1:3	1:2 to 1:3	1:2 to 1:3
Poland	1:5 to 1:3	1:5 to 1:3	1:5 to 4:3
Portugal	based on geotech design; max 1:1.5 without barrier	based on geotech design; max 1:1.5 without barrier	based on geotech design; max 1:1.5 without barrier
South Africa		rural 1:4	
Spain	1:6 to 1:2	1:4 to 2:3	2:3 to 1:2
Sweden		rural undivided 1:3	
Switzerland	1:2 to 2:3 1:3 and $\Delta h > 4$ m	1:2 to 2:3	1:2 to 2:3
United Kingdom	based on geotech design; 1:2 is common	based on geotech design; 1:2 is common	based on geotech design; 1:2 is common
USA	1:6 for low fill height, 1:3 for moderate height	1:6 for low fill height, 1:3 for moderate height	1:2 maximum
Venezuela	not specified, generally fixed by geotechnical studies	not specified, generally fixed by geotechnical studies	not specified, generally fixed by geotechnical studies
Yugoslavia	varies with barrier & fill height	varies with barrier & fill height	varies with barrier & fill height

Typical values of embankment slope standards from responses to the international survey are summarized in Table 2. The flattened slope values espoused by the US are similar to those of several other nations but are by no means accepted worldwide.

Slopes perpendicular to the flow of traffic, such as those found at median crossovers, driveways, and intersecting roads, deserve at least as much attention as embankment slopes. Even a relatively flat 1:6 slope struck in a high-speed impact at 90°will cause the impacting vehicle to become airborne for a substantial distance. To the extent practical, these slopes should be flattened, at least within the appropriate clear zone; this often requires the relocation or redesign of drainage structures.

Drainage Structures

The AASHTO Yellow Book emphasized that the design of drainage features was important for safety as well as hydraulic efficiency. The 1974 version (*2*) stated that "drainage items such as headwalls, dikes and steep-sided ditches are hazards which should be moved away from the roadway to outside the clear recovery width. Even then, if placed in vulnerable areas, efforts should be made to design these items to lessen the hazard of their being struck by an errant vehicle." This publication recommended reappraisal of current designs for all highway drainage structures to ensure that the conflicting goals of roadside safety and roadway drainage were achieved to the greatest extent practical.

Except for shielding with a traffic barrier when appropriate, safety practices relative to drainage features were not specifically addressed in the Barrier Guide. The philosophy contained in the *Roadside Design Guide* (*4*) is an expansion of earlier recommendations; where possible, it calls for traversable slopes and then matching these slopes with whatever drainage features are needed. In other words, smooth slopes should not be made discontinuous to accommodate pipes or culverts; the pipe and culvert openings should be designed to match the slope. This concept reduces the physical dimension of the hazard to the culvert opening itself. The hazard posed by the opening can often be decreased by using pipe safety runners, sometimes referred to as "grates." Research has shown that vehicles can successfully cross openings as wide as 750 mm at speeds of 30 to 100 km/h. While the ride is not perfectly smooth, the likelihood of a sudden stop is essentially eliminated and the probability of an overturn is greatly reduced.

Ditches are another common roadside feature that can be a valid safety concern. Deep or steep-sided ditches may result in violent vehicle deceleration levels when hit at high speeds or sharp angles. Since most run-off-the-road accidents occur at relatively shallow angles, the front slope of an adjacent ditch is most critical and should be made as flat as practical, ideally 1:5 or flatter. When this can be achieved, a steeper backslope can be tolerated if it is smooth and unobstructed. If there is a high probability of encroachment onto a steep foreslope and right-of-way is limited, an enclosed drainage system may be warranted.

Roadside Hardware

Man-made roadside hardware is the third category of obstacle that can be struck by an errant motorist. The most common appurtenances include sign and luminaire supports (*6*). In the US virtually all such supports are designed to yield on impact, thereby preventing sudden vehicle decelerations and occupant injuries. Small signs typically yield by bending or fracturing, while larger ones give way through a slip-base and hinge combination. Cantilevered and overhead signs, which cannot be redesigned to enhance safety, are usually shielded.

Yielding or breakaway signs are typically tested for acceptance with full-size vehicle crash tests, bogey testing, or pendulum testing. The 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* requires that the change in a vehicle's speed during impact not exceed 16 km/h (*7*). Some -- but not all -- currently used designs meet this specification. A concern with breakaway supports is the disparity between testing conditions and installation practices. In controlled tests, the approach terrain is flat and level, and impacts are with the front of the vehicle. Research indicates that in many run-off-the-road accidents, the vehicle is not tracking; rather, it is skidding sideways. Controlled side-impact testing has found that some breakaway mechanisms do not function properly when hit by the side of a vehicle. Indeed, breakaway hardware was designed for and works best when struck head-on by a vehicle traveling on flat, level terrain. Unfortunately, the widespread use of yielding support designs has been accompanied by less attention to their actual placement. For example, signs are frequently placed on slopes or near ditches where an errant vehicle is likely to impact too high on the support to cause it to yield as designed. Others signs have been installed directly in front of natural hazards that will not yield.

In summary, the designer employing a breakaway device must still be cognizant of the environment in which it will be installed. Sign and luminaire supports must be located where they are least likely to be hit, yet most likely to function properly when they are struck.

TABLE 3 Examples of Traffic Barrier Warrants

Country	Examples of Traffic Barrier Warrants
Brazil	A nomograph is used to calculate an index based on embankment slope, shoulder width, curve radius, grade, slope, and special problems. If the index exceeds an ADT-based safety value, a barrier is mandatory.
China	Use barrier when the design speed ≥ 80 km/h.
Czech Republic	Warrants include height > 4.0 m, embankment slope > 1:3, proximity of lakes, etc.
Denmark	Warrants include fixed objects with a lateral clearance under 3 m for speeds ≤ 80 km/h or 9 m for speeds ≥ 90 km/h; vertical drops of > 1 m or water depth > 1 m; similar criteria are given for rail lines, embankments, etc.
Germany	Defined in RPS guideline; factors include alignment, shoulder cross slope, distance to obstacle, obstacle type and character.
Greece	Use German guidelines, experience, or recommendation of designer or police.
Japan	Decision to install is based on road and traffic conditions for: (1) certain combinations of fill height and side slope, (2) where rocks project on the slope face, and (3) proximity to a sea, lake, river marsh, channel, etc.
Poland	Use of barriers is limited to places where a potential collision with a barrier would be less severe than a collision with an existing embankment or side obstruction
Portugal	Flexible barrier and concrete barrier (New Jersey type) are used. A nomograph is used to calculate an index on the basis of embankment slope, shoulder width, horizontal radius, grade, average slope in the surrounding terrain, and existence of special problems. If the evaluated index exceeds a safety value (dependent on AADT) the barriers are mandatory.
South Africa	On rural roads, barriers are used on slopes steeper than 1:4 when justified by an economic analysis.
Sweden	Use is based on judgement of estimated accidents and the resulting damage, considering the road layout and surroundings. Warrants are tabulated by design speed for categories of slopes, vertical drops, watercourses, rocks, and rigid objects.
United Kingdom	Safety barrier warrants include medians on all motorways and trunk arterial roads, embankments higher than 4 m, or water or other hazards existing within 4.5 m of the paved road.
USA	Warrants are based on vehicular speed, traffic volumes, lateral clearance, type of hazard, expected accidents and severities, and cost-effectiveness analysis; see (*4*).

Traffic Barriers

The fourth item of concern is the selection, design, and use of a traffic barrier or a crash cushion. The presence of these devices is the highway engineer's admission that it was practically or economically impossible to eliminate a hazard, and that it was necessary to shield traffic from the object. The high number of fixed object fatalities in which collision with a traffic barrier is identified as the most harmful event (*6*) demonstrates that the shielding is not a panacea. Since virtually all traffic barriers meeting current design criteria must be successfully crash tested before being placed in service, this statistic is somewhat puzzling. It should be recognized, however, that the ideal installation and impact conditions on the test track are seldom found along the highway. In addition, there remain many kilometers of substandard traffic barriers that were placed long before uniform design installation standards were promulgated. As a practical matter, roadside barriers are primarily intended to contain and redirect only passenger vehicles; most cannot be expected to retain heavy commercial vehicles such as buses and trucks. Nevertheless, the highway engineering community has recognized the existence of problem locations where extraordinary safety measures are necessary and appropriate. As a result, higher, stronger barriers have been installed at these critical locations. More recently, full-scale crash tests with buses and trucks have been used to develop high-performance barriers. Their use, except for bridge railings, remains quite subjective. The information contained in the AASHTO *Guide Specifications for Bridge Railings* (*8*) can be used to evaluate the need for a higher-performance bridge railing. For roadside and median barriers, past accident history at a particular site may give the designer an idea whether or not a higher-performance barrier should be considered.

Traffic barriers are expensive to design and install; once installed, the highway agency has a responsibility (and expense) to maintain the barrier. To assist designers in selecting the proper conditions for barrier installation, several countries have developed warrants for their use. While it is not possible in an abbreviated format to detail all the factors that influence the decision to install a barrier, Table 3 summarizes some barrier criteria used in countries responding to the survey.

APPLICATION OF THE FORGIVING ROADSIDE CONCEPT

This paper has briefly reviewed concepts for safer designs of typical roadside elements. As shown in Table 1, many nations have begun to recognize and implement the "forgiving roadside" concept to some extent. However, perplexing questions still exist about the nature and extent of roadside safety treatments for a specific type of road and the cost effectiveness of this type of work.

In the United States several of these questions have been addressed by research activities. When selectively applied, clear recovery areas have been shown to be cost effective in reducing the severity of roadside accidents (*9, 10*). The issue is no longer whether to incorporate the forgiving roadside policy, but rather to find the most effective and economical ways to incorporate it. The 1989 AASHTO *Roadside Design Guide* (*4*) suggests that two different approaches may be used:

- New roadways should be designed to be as hazard free as practicable. Roadside hazards that cannot be eliminated through design should be designed to yield on impact or should be shielded with an appropriate traffic barrier or crash-cushion. In other words, clear roadside design concepts should be adopted as completely as possible. For new designs, there is generally adequate right-of-way to design, select, and locate facilities and hardware to incorporate the forgiving roadside concept without much additional cost.
- For existing roadways, the roadway geometry is already set, the right-of-way may be restricted, and there may be many obstacles adjacent to the roadway. It can be very expensive to implement the full clear roadside treatment in these instances. Rather than arbitrarily remove all obstacles along existing roadways, AASHTO recommends that the clear roadside be selectively implemented using a systematic review of accident data and other factors. In other words, the highway agency's safety program can identify situations and locations where the application of clear roadside principles will be cost effective in reducing fatalities and injuries. In the case of existing facilities, it may be more important that the clear roadside area be consistent along a given length than for it to be arbitrarily widened.

SUMMARY

The clear roadside is a relatively recent addition to highway design criteria. The U.S. has the most experience with using it, and new roads are reflecting the "forgiving" nature of the new criteria. Even so, it will be many years before it can be applied to all existing roads. Perhaps it is best to consider this as a long-term program which will eventually yield enormous safety benefits through the cost-effective treatment of a limited number of roadways each year. Those interested in a more comprehensive discussion of roadside safety design in the United States should obtain a copy of the updated, metric version of the AASHTO *Roadside Design Guide* when it is published in late 1995.

REFERENCES

1. AASHTO, *Highway Design and Operational Practices Related to Highway Safety*, February, 1967.
2. AASHTO, *Highway Design and Operational Practices Related to Highway Safety*, Second Edition, 1974.
3. AASHTO, *Guide for Selecting, Designing, and Locating Traffic Barriers*, 1977.
4. AASHTO, *Roadside Design Guide*, 1988.
5. Hall, L.E., R.D. Powers, D.S. Turner, W. Brilon, and J.W. Hall, "Overview of Cross Section Design Elements," presented at the International Symposium on Highway Geometric Design Practices. TRB, Boston, Massachusetts, August 30, 1995.
6. Turner, D. S. and J. W. Hall, *Severity Indices for Roadside Features*. NCHRP Synthesis 202. TRB, National Research Council, Washington, D.C., 1994.
7. AASHTO, *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, 1985.
8. AASHTO, *Guide Specifications for Bridge Railings*, 1988.
9. Graham, Jerry L., and Douglas W. Harwood, *Cost Effectiveness of Clear Recovery Zones*. NCHRP Report 247. TRB, National Research Council, Washington, D.C., 1982.
10. *Designing Safer Roads*. Special Report 214. TRB, National Research Council, Washington, D.C., 1987.