

# DESIGNING SAFER ROADSIDE DITCHES

Graeme D. Weaver and Eugene L. Marquis, Texas A&M University; and  
Alvin R. Luedecke, Jr., Texas Highway Department

## ABRIDGMENT

The dynamic response of a vehicle during an off-the-road maneuver depends on many roadway and vehicle parameters. Of primary importance are such factors as speed and exit angle, slope steepness, slope of the ditch, and other related geometric and operational features. This research approach to investigating roadside traversals involved use of the highway-vehicle-object simulation model in conjunction with 24 full-scale vehicle tests. This paper presents the results of the study. Included are descriptions of the full-scale methodology and a discussion of the results obtained. Tentative recommendations are presented for design of V-ditches and small-radius round ditches for various combinations of side and back slope.

•THE highway engineer has been handicapped by the lack of objective criteria with which to select safe combinations of slopes for roadside design. To enable him to evaluate alternatives and thus achieve safety in his design, objective criteria must be available to him. The continuing NCHRP Project 20-7 (1) has as its specific objective the development of criteria for safe roadside slope design that will assist in establishing design standards and guidelines.

This paper concerns research efforts (1, 2) conducted by the Texas Transportation Institute to provide objective criteria for the design of safer roadside slopes and ditches. It is directed particularly toward the design of V- and small-radius round ditches and traversable combinations of side and back slope.

## ROADSIDE CRITICAL AREAS

The sequence of events that can occur when a vehicle leaves the roadway is greatly influenced by roadside geometry. Three regions of the roadside are particularly important when safety aspects are evaluated: the top of the slope (hinge point), the side slope, and the toe-of-slope (ditch or intersection of side slope with level ground). The hinge-point and side-slope regions are particularly important in regard to the design of long slopes where a driver could attempt a recovery maneuver or reduce speed before impacting the ditch area. The hinge point adds to the loss of steering control because the vehicle tends to become airborne. A driver's normal instinct is to attempt to return to the roadway, but obviously there is a side-slope steepness at which the vehicle will roll during a recovery maneuver. Also, there are situations where the toe-of-slope is close to the roadway so that the probability of reaching the ditch is high, in which case safe transition regions between front and back slope must be provided.

Each region affects vehicle response in a different way and for a different set of operating conditions. When individual criteria are determined for each, the pieces may be put together to produce safety guidelines for total roadside slope design.

## RESEARCH APPROACH

The work to date, conducted in two parts, has addressed the toe-of-slope region with particular emphasis on safe combinations of slopes forming various ditch shapes because it is here that the maximum vertical g-forces are developed. The first year was devoted to an investigation of vehicle g-forces experienced in traversing four ditch

cross sections (V, round, trapezoidal, and trapezoidal with rounded corners) formed by 12 combinations of front and back slopes ranging from 3:1 to 6:1. The highway-vehicle-object simulation model (HVOSM) was used to study the effects on vehicle behavior.

To verify the model-predicted vehicle response, we conducted 24 full-scale vehicle tests during the second year on slope combinations from 3:1 to 5:1 forming round and V-ditches. The tests were run at a constant 25-deg exit angle (nominal) and four speeds: 30, 40, 50, and 60 mph. The HVOSM predicted, with remarkable consistency, the vehicle response resulting from traversal of the ditch-slope configurations. Extremely close correlation was obtained between predicted and actual resultant average accelerations.

#### CRITERIA

Vertical g's make up the dominant accelerations in ditch traversal and consequently contribute most significantly to the resultant g-forces. Lateral and longitudinal g's, although not exactly negligible, play only a minor role. Therefore, criteria based on literature concerning vertical g-forces were selected. Human tolerance levels of acceleration were selected for three types of occupant restraint:

<u>Restraint</u>	<u>Tolerance Level (g)</u>
None	0 to 6
Seat belt	6 to 10
Seat belt and shoulder harness	10 to 17

#### DISCUSSION OF PRELIMINARY FINDINGS

From the HVOSM results, it was apparent that the 3:1 side slopes produced severe vertical g-forces regardless of ditch shape or back-slope steepness. It was, therefore, recommended that 3:1 side slopes be used only when flatter slopes are not feasible. When the front slope was flattened to 4:1, vertical g-forces in most cases were reduced from severe levels to the tolerable level for seat belt restraint or less. On the other hand, flattening the front slope from 4:1 to 6:1 did not produce such a significant reduction in vertical g's.

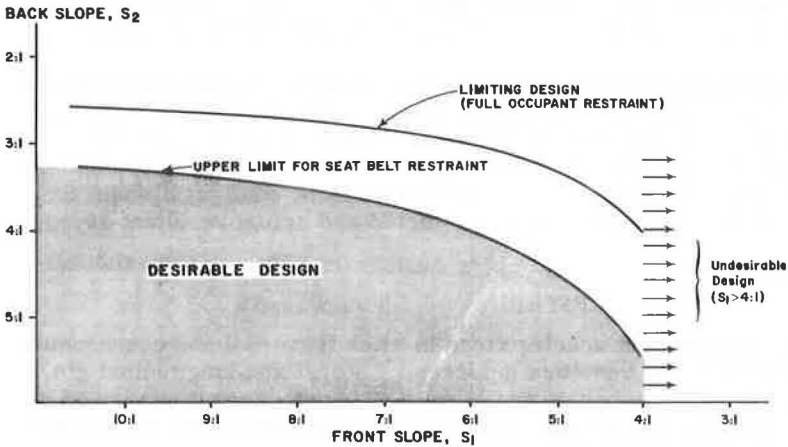
In general these results were borne out during full-scale testing. The 16 tests on the 4:1 and 5:1 back slopes with a front slope of approximately 7:1 revealed that these combinations could be safely negotiated at speeds up to 60 mph with no rollover hazard and with only moderate discomfort if the driver was adequately restrained. The 3:1 back slope (7:1 front slope) appeared quite formidable. The test vehicle was remote-controlled rather than driven; thus, the effect on an occupant can only be estimated. However, based on vehicle damage sustained during these tests and the peak g's measured, slopes of this steepness are not considered desirable design.

Vehicle dynamic response is influenced appreciably by the speed and angle at which the vehicle enters the ditch region. The test driver experienced considerable difficulty in achieving the 25-deg exit angle at speeds of 50 and 60 mph due to rear wheel drift, yet he had a 42-ft wide pavement in which to negotiate the turn. A 25-deg encroachment angle at these speeds can be executed by a professional driver under certain conditions but probably is too severe for design purposes.

The resultant g-forces were only slightly higher for the V-ditch than for the corresponding round ditch in every test but were appreciably higher than they were for the trapezoidal ditches investigated. Therefore, to design for the most critical situation, we developed recommended slope combinations based on the more severe V-ditch configuration. These tentative design curves are shown in Figure 1. Although the curves are applicable for V-ditches, design of a small-radius round ditch using these curves would not be appreciably conservative because very little difference in vehicle response was found between the V-ditch and the small-radius round ditch.

The two curves represent the upper bounds of safe combinations of slopes for two types of occupant restraint, seat belt restraint for desirable and full restraint (seat belt and shoulder harness) for the limiting curve. The curves can be entered with a

Figure 1. Tentative design recommendations for V-ditches.



known front slope (axis  $S_1$ ) to select a safe back slope (axis  $S_2$ ) or vice versa. For example, given a 6:1 front slope, the upper limit for limiting design would be a 3:1 back slope and more desirably would be a 4:1 back slope. Of course, a 5:1 back slope would be even more desirable inasmuch as this combination falls well within the desirable range.

#### CONTINUING RESEARCH

As mentioned previously, there are three areas of concern in the roadside slope design process. The work to date has provided needed information regarding the toe-of-slope region, at least with respect to V- and small-radius round ditches. Currently, design curves are being developed for the other ditch configurations investigated in the computer study. Also, a comprehensive study is being made of the effect of the hinge point and the side-slope region on vehicle rollover and driver recovery maneuvers. The final product of the individual phases will include objective design criteria with which the designer may evaluate alternatives and thus achieve optimum safety in his design for the total roadside slope region.

#### ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway Officials in cooperation with the Federal Highway Administration and was conducted under the National Cooperative Highway Research Program. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, nor does this paper constitute a standard, specification, or regulation.

#### REFERENCES

1. Weaver, G. D. The Relation of Side Slope Design to Highway Safety. Texas Transportation Institute, Res. Rept. 626-2, May 1970.
2. Weaver, G. D., Marquis, E. L., and Luedecke, A. R., Jr. The Relation of Side Slope Design to Highway Safety. Texas Transportation Institute, Res. Rept. 626A-1, March 1972.