National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

DIGEST 71 - MAY 1975

Selection of Safe Roadside Cross Sections

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 20-7, Task 2, "The Relation of Side Slope Design to Highway Safety," by Graeme D. Weaver, Eugene L. Marquis, and Robert M. Olson, Texas Transportation Institute, Texas A & M University, College Station, Texas. The Project was proposed by the AASHTO Standing Committee on Engineering and Operations.

THE PROBLEM AND ITS SOLUTION

Wide, flat slopes adjacent to the traveled way are recognized universally to have an important protective influence in those occasional situations where vehicles leave the roadway. Because of economic necessity, something less than the ideal must often be provided. The study reported herein was undertaken to obtain urgently needed factual information that can be used in selecting slopes and slope and ditch combinations that provide a reasonable degree of safety to errant vehicles consistent with economic reality.

The Highway Vehicle Object Simulation Model (HVOSM) that was developed at Calspan Corporation and extended at Texas Transportation Institute was used to investigate vehicle behavior at three critical regions of the roadside: the hinge-point between shoulder and front slope; the front slope; and the toe-of-slope region, including four ditch configurations. Vehicle operating conditions included speeds from 40 to 80 mph, encroachment angles of 7, 15, and 25 degrees, with and without driver steering. Driver steering was used when simulating attempts on the front slope to return to the roadway. Terrain features included slopes from 3:1 to 10:1 with two coefficients of friction. Twenty-four full-scale vehicle tests were conducted to validate the model for roadside slope traversal.

Two criteria were used to evaluate roadside traversal: vehicle rollover and vehicle acceleration in the three principal axes. The resultant vehicle accelerations were evaluated using suggested tolerable acceleration levels similar to an ellipsoidal envelope of acceleration proposed elsewhere (Hyde, A.S., "Biodynamics and Crashworthiness of Vehicle Structures," Wyle Laboratories Research Staff Report WR 68-3, Volume III of IV, March 1968). Based on this principle, severity indices were proposed to evaluate the various roadside combinations. The severity index concept provides a means of comparing the relative severity of the effects of various roadside cross sections on the occupants of vehicles traversing them.

Based on the previous work, the following tolerable acceleration limits were established for the study:

Restraint	Maximum Acceleration (G's) Lateral	Longitudinal	Vertical
Unrestrained occupant	5	7	6
Lap-belt restraint	9	12	10
Lap-belt and shoulder restraint	15	20	17

The following mathematical procedure was used to evaluate the resultant effect:

$$SI = \sqrt{\left(\frac{G_{lon}}{G_{xl}}\right)^2 + \left(\frac{G_{lat}}{G_{yl}}\right)^2 + \left(\frac{G_{ver}}{G_{zl}}\right)^2}$$

in which:

- SI = Severity index;
- G_{lon} = Acceleration experienced in longitudinal axis, G's;
- G_{lat} = Acceleration experienced in lateral axis, G's;
- G_{ver} = Acceleration experienced in vertical axis, G's;
- G_{xl} = Tolerable acceleration in longitudinal (X-axis) direction, G's;
- G_{yl} = Tolerable acceleration in lateral (Y-axis) direction, G's; and
- G_{zl} = Tolerable acceleration in vertical (Z-axis) direction, G's.

This form follows the ellipsoidal theory of failure proposed by Hyde.

The normalizing values used in the severity index equation are based on the unrestrained occupant values. Therefore, the severity index equation becomes

$$SI = \sqrt{\left(\frac{G_{lon}}{7}\right)^2 + \left(\frac{G_{lat}}{5}\right)^2 + \left(\frac{G_{ver}}{6}\right)^2}$$

A severity index of 1.0 represents a resultant acceleration that may be tolerated safely by an unrestrained occupant. A severity index of 1.6 represents the upper limit of acceleration considered safe for seat-belt restraint. This severity index serves as an excellent analysis tool when evaluating various roadside combinations.

FINDINGS

The following findings that are pertinent to the design of roadside cross sections were drawn by the researchers:

Hinge-Point Region

1. The hinge-point created by the planar intersection of slopes 3:1 to 10:1 produced no critically adverse effects.

2. Although maximum vehicle roll angles were produced by crossing the hinge-point, no traversals approached vehicle rollover.

Front Slope Region

1. Return maneuvers can be attempted without vehicle rollover on smooth, firm embankments 3:1 or flatter at speeds to 80 mph and encroachment angles of 15 degrees.

2. To permit recovery, a coefficient of friction of at least 0.6 must be available and embankment surfaces must be relatively uniform.

3. Almost no returns can be executed when the coefficient of friction is as low as 0.2 (a more probable coefficient than 0.6).

4. Vehicle rollover can be expected for return maneuvers attempted above 60 mph if the embankment is soft or rutted.

Toe-of-Slope Region

1. The severity of traversal of ditches less than about 8 ft wide is essentially the same for comparable slope combinations regardless of ditch shape.

2. The trapezoidal ditch configuration represents the most desirable cross section from a safety standpoint, particularly for ditches wider than 8 ft.

3. Front slopes steeper than 4:1 are not desirable because their use severely limits the choice of backslopes producing a safe ditch configuration.

4. Slopes 3:1 or steeper should be used only where site conditions do not permit the use of flatter slopes.

APPLICATION OF FINDINGS

If constraints other than safety dictate that the necessary recovery distance cannot be provided, it is logical to assume that guardrail or some other redirection barrier will be used. Its placement becomes critical with respect to the hinge-point. Figure 1 shows two lateral distances that must be considered. The distance, D_1 (shaded), outlines the area in which the vehicle could pass over a 27-in. -high barrier due to hinge-point ramping effects. This variable distance is dependent on encroachment conditions and hinge-point geometry. D_2 represents the maximum offset achieved during the return maneuver. Table 1 summarizes the distance for each case studied. It should be noted that in several high-speed/high-angle encroachments the vehicle traveled beyond the toe-of-slope in negotiating the return path.

Desirably, slope combinations would be selected such that unrestrained occupants could be expected to sustain no injury and the vehicle would not incur major damage during traversal. However, site conditions such as restricted right-of-way or other factors beyond the designer's control may dictate the use of slope combinations steeper than desirable. Therefore, Figures 2, 3, and 4 provide a basis for evaluating ditches formed by slope combinations for various degrees of expected severity. These curves provides the design engineer an objective basis to select traversable slope combinations and ditch shape under 60 mph/25-degree encroachment conditions such as might be encountered on high-speed facilities. The design curves are applicable for ditch location up to 60ft from the edge of the roadway.

The 1.0 severity index curves are based on no-occupant-restraint conditions; the 1.6 severity index curves are applicable for seat-belt restraint.

The charts were developed on the basis of an assumed relationship for the effect of vehicle resultant g-forces on seat-belt-restrained and unrestrained vehicle occupants. The findings will be enhanced by a validated relationship; the information should be updated when such a relationship becomes available.

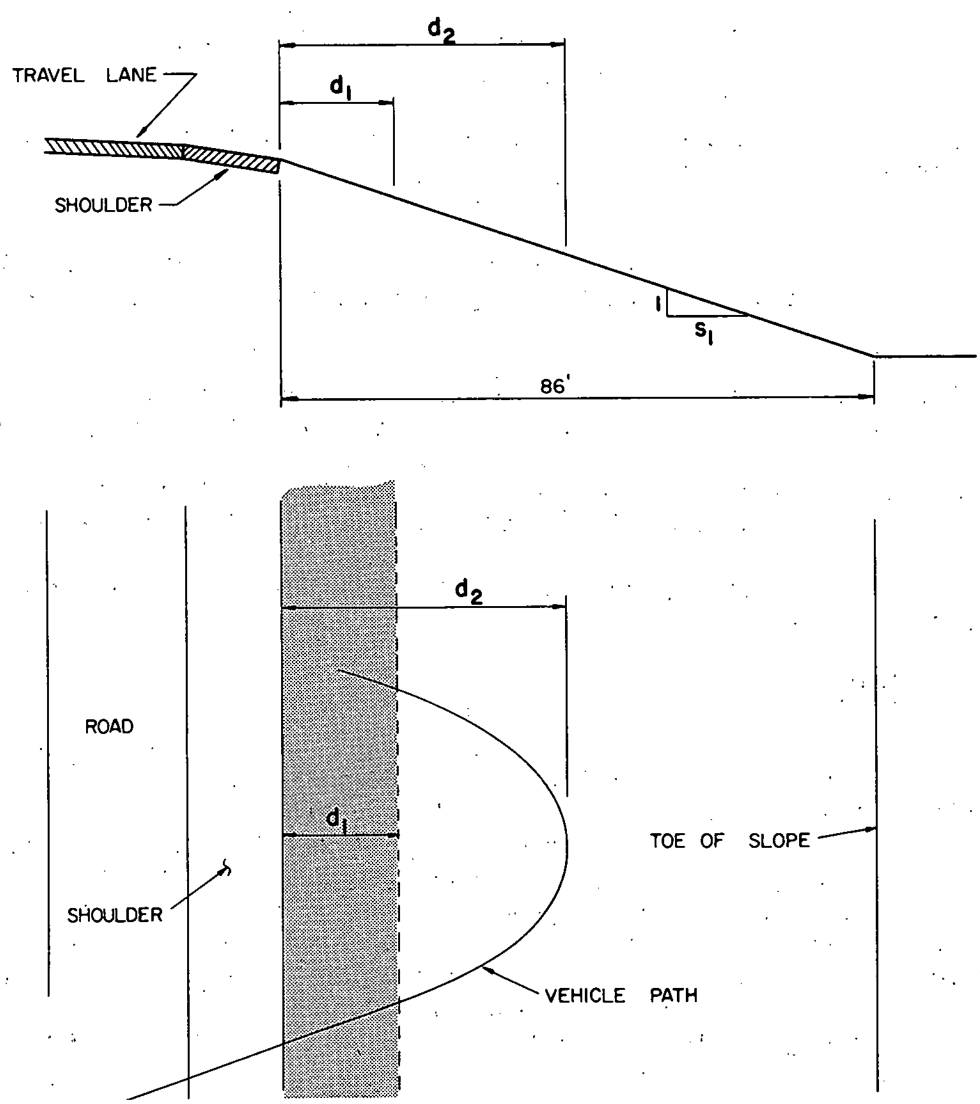

Figure 1. Vehicle path on embankment for return maneuver.

TABLE 1

SUMMARY OF CRITICAL LATERAL DISTANCE
TO ACCOMMODATE RETURN MANEUVER

Initial Speed (mph)	Encroachment Angle (deg)	Encroachment Slope	d_1 (ft)	d_2 (ft)
80	7	3:1	11	60
		4:1	2	54
		5:1	1	51
		6:1	0	48
		10:1	0	44
	15	3:1	13	138*
		4:1	8	125*
		5:1	6	118*
		6:1	3	113*
		10:1	1	103*
60	7	3:1	1	40
		4:1	1	36
		5:1	0	35
		6:1	0	34
		10:1	0	33
	15	3:1	8	111*
		4:1	6	90*
		5:1	2	84*
		6:1	1	81
		10:1	0	73
40	7	3:1	0	25
		4:1	0	25
		5:1	0	25
		6:1	0	25
		10:1	0	25
	15	3:1	0	61
		4:1	0	56
		5:1	0	53
		6:1	0	51
		10:1	0	48

*Vehicle travels beyond toe of slope (see Figure 1)

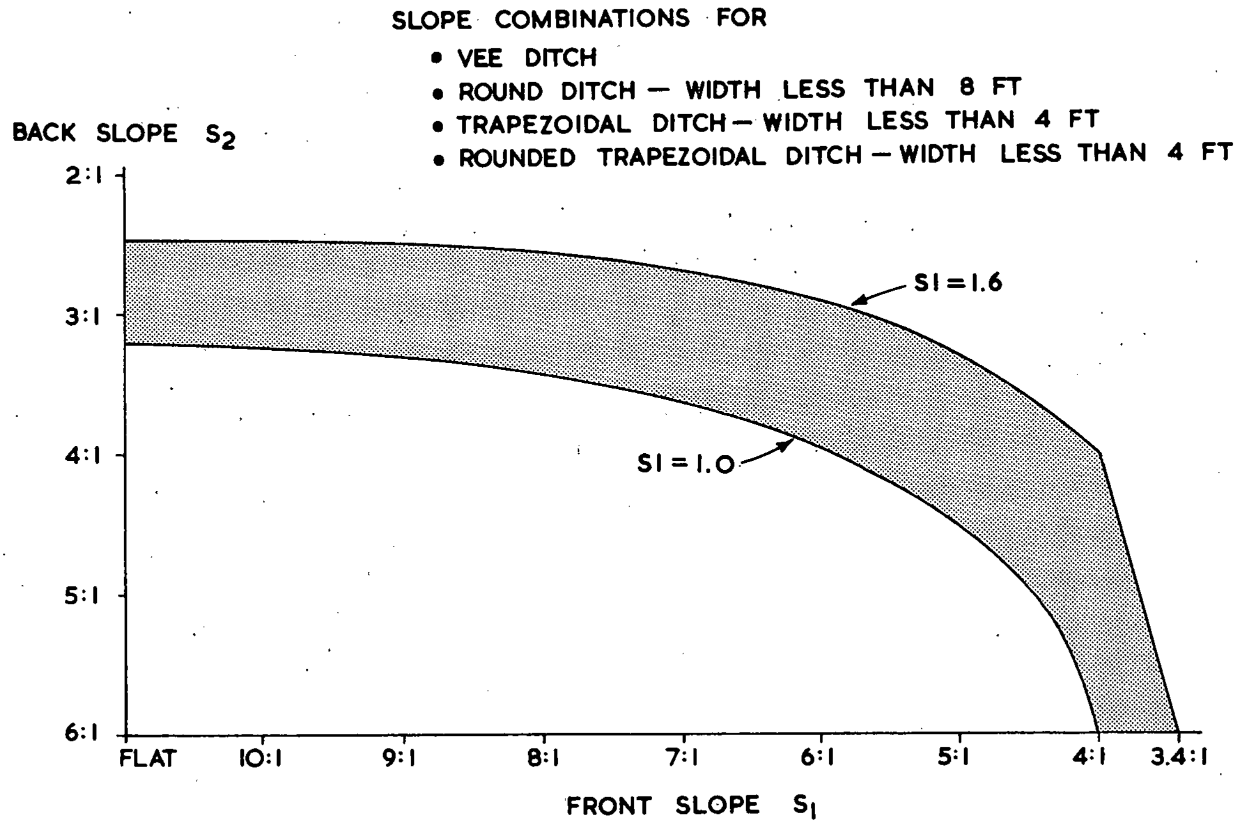

Figure 2. Ditch evaluation curves for roadside slope combinations (Curve A).

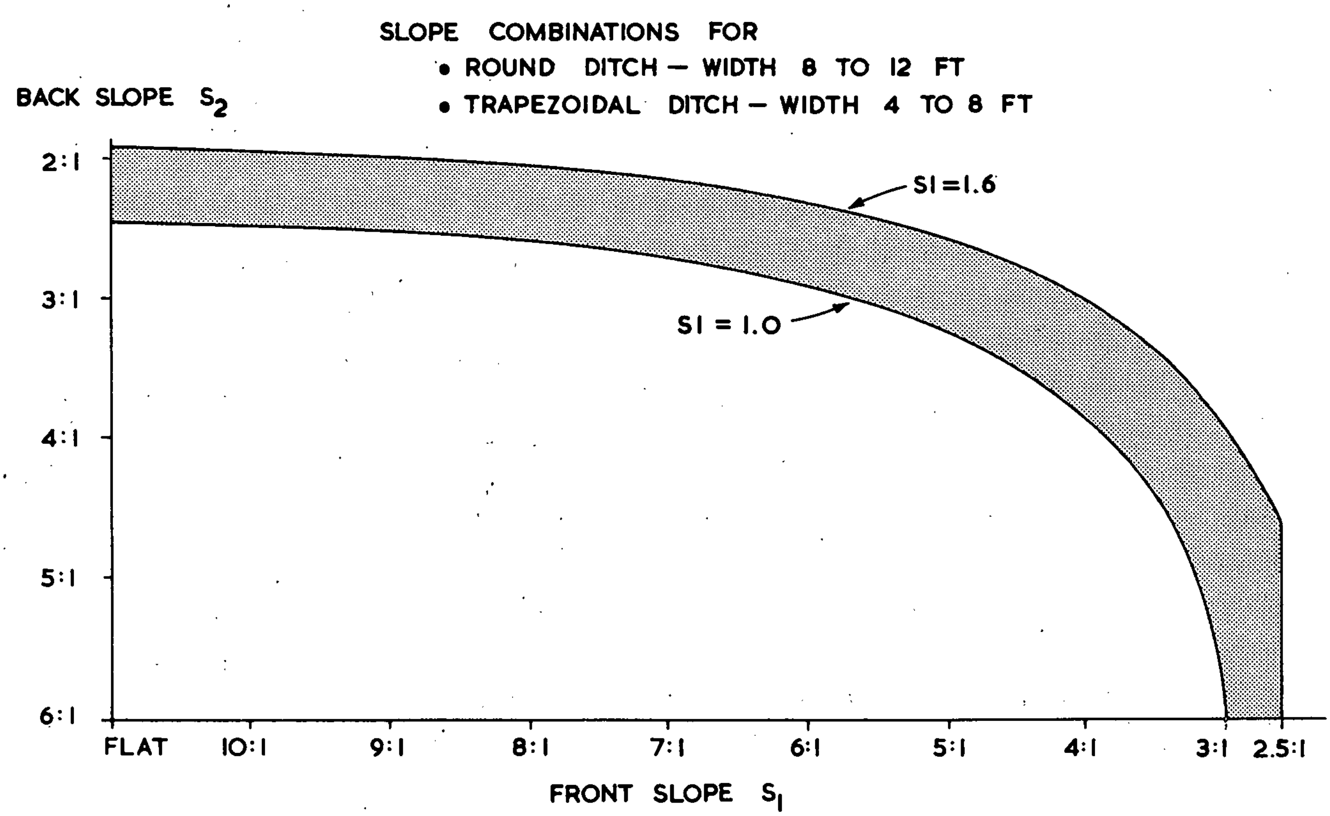

Figure 3. Ditch evaluation curves for roadside slope combinations (Curve B).

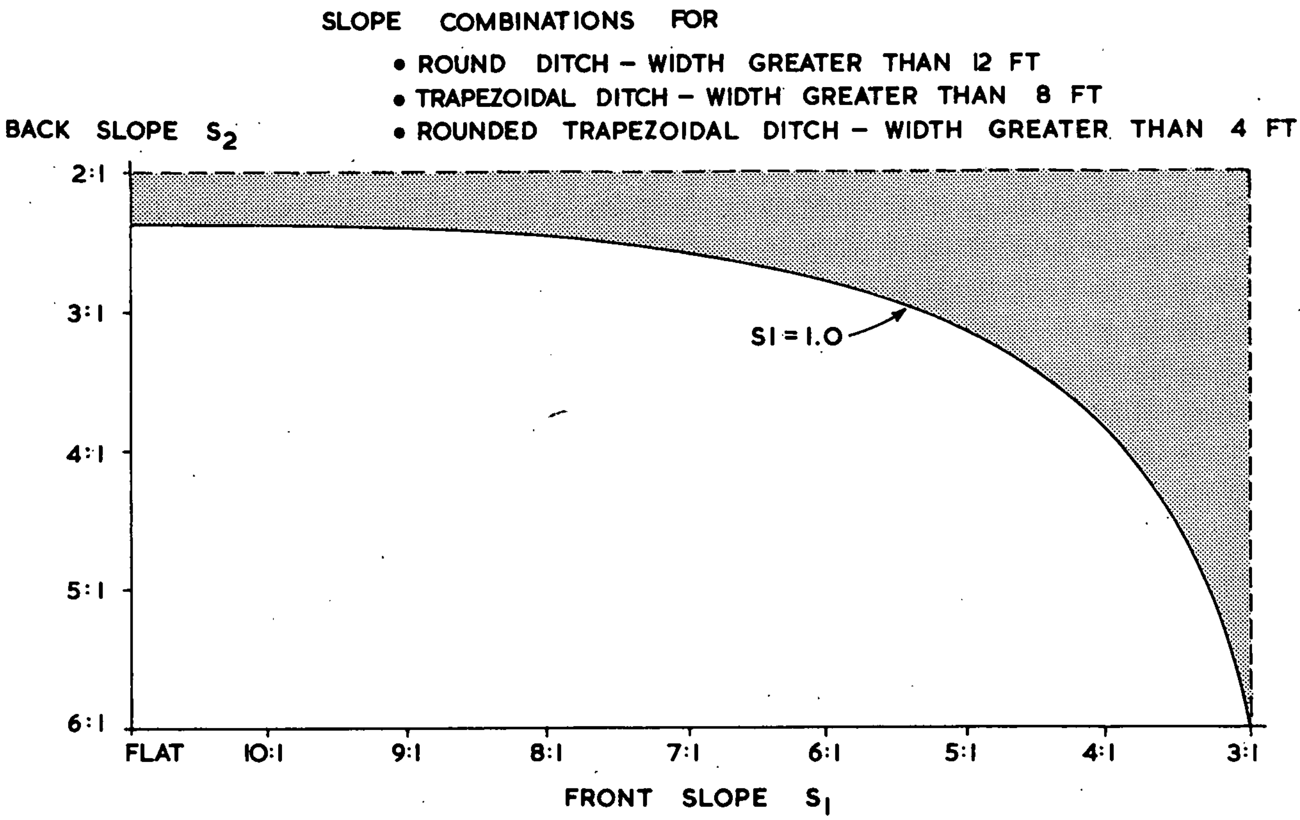

Figure 4. Ditch evaluation curves for roadside slope combinations (Curve C).

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