Innovations in Asphaltic Pavement Edge Profiles to Improve Safety and Reduce Maintenance Costs

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ABSTRACT

That certain edge profiles are superior to others in terms of vehicle handling and stability has been demonstrated by vehicle testing since the early 1980s. The literature leading up to the assessment of degree of hazard of some edges and the characteristics of “safe” edges is presented. Here it is demonstrated by more recent testing and field trials an optimum edge profile can be easily produced during construction that is both safe for vehicle traversal and of improved characteristics relative to pavement maintenance.

INTRODUCTION

The possibility of a driver losing control after the vehicle goes off the paved surface onto a shoulder has caused highway engineers great concern. Why this occurs and under what conditions it can occur has been the subject of research efforts by Klein, Johnson and Szostak (1), Nordlin and Stoughton (2,3), and Zimmer and Ivey (4). These efforts have been summarized in a recent TRB State of the Art Report, AThe Influence of Roadway Surface Discontinuities on Safety@ (5). Recently Graham and Glennon have tried to use computer simulation to study the phenomenon of vehicle loss of control due to pavement edges (6). In all these efforts no one tested a broad group of naive drivers, a recognized shortcoming. To alleviate this problem the Transportation Research Board sponsored a study at the University of Michigan Transportation Research Institute and Texas Transportation Institute. Testing of a wide spectrum of drivers in highway environments that included edges of different sizes and shapes to better define driver performance was conducted (7).

Contrary to the main objective it was found not feasible to test drivers in a naive condition. Early efforts never resulted in a naive driver producing an Aedge scrubbing@ condition, the first part of the maneuver. The Ascrubbing@ condition was a necessary pre-condition to driver performance because it was viewed as the most critical situation, when there is an inappropriate action or inaction by a driver. The following scenario describes of the elements of an edge drop “scrubbing” condition.

1. A vehicle is under control in a traffic lane adjacent to a pavement edge where an unpaved shoulder is lower than the pavement (Figure 1).

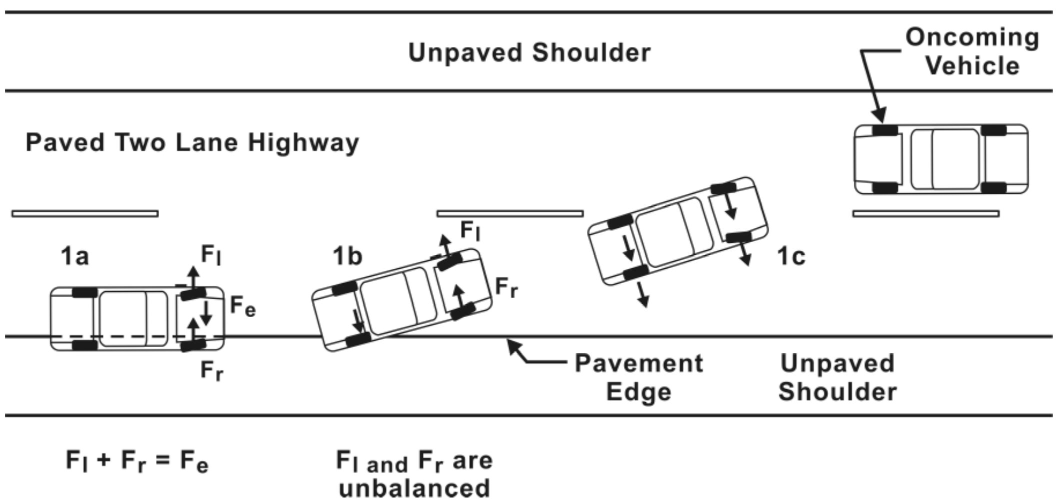


Figure 1. Loss of Control Phenomenon

2. Through inattention, distraction, or some other reason the vehicle is allowed to move into a position with the right wheels on the unpaved shoulder and just off the paved surface.

3. The driver then carefully tries to gently steer the vehicle to gradually bring the right wheels back up onto the paved surface without reducing the speed significantly.

4. The right front wheel encounters the pavement edge at an extremely flat angle and is prevented from moving back onto the pavement. The driver further increases the steer angle to make the vehicle regain the pavement. However, the vehicle continues to scrub the pavement edge and does not respond. At this time there is equilibrium between the cornering force to the left and the edge force acting to the right, as shown in Figure 1a.

5. The driver continues to increase the steer input until the critical steer angle is reached and the right front wheel finally mounts the paved surface. Suddenly, in less than one wheel revolution, the pavement edge force has disappeared and the cornering force of the right front wheel may have doubled because of increases in the available friction on the pavement and the increases in the right front wheel load caused by corning (see Figure 1b).

6. The vehicle yaws radically to the left, pivoting about the right rear tire, until that wheel can be dragged up onto the pavement surface. The excessive left turn and yaw continues, and it is too rapid in its development for the driver to prevent penetrating the oncoming traffic lane (Figure 1c).

7. A collision with oncoming vehicles or spin out and possible vehicle roll may then occur.

The best that could be achieved in the TRB study was to test a wide spectrum of untrained drivers who were coached into the scrubbing condition. Problems with documentation of edge drop heights prevented a direct comparison of this work with the earlier Zimmer and Ivey (4) testing. The obvious difference was that the performance variation of 146 untrained drivers was greater than the variation of the five drivers used in earlier testing.

The Zimmer and Ivey (4) report developed what was to remain the Astate of the art@ for pavement edge evaluation for the next 20 years. It is summarized by Figure 2. This figure was constructed using the following subjective rating system.

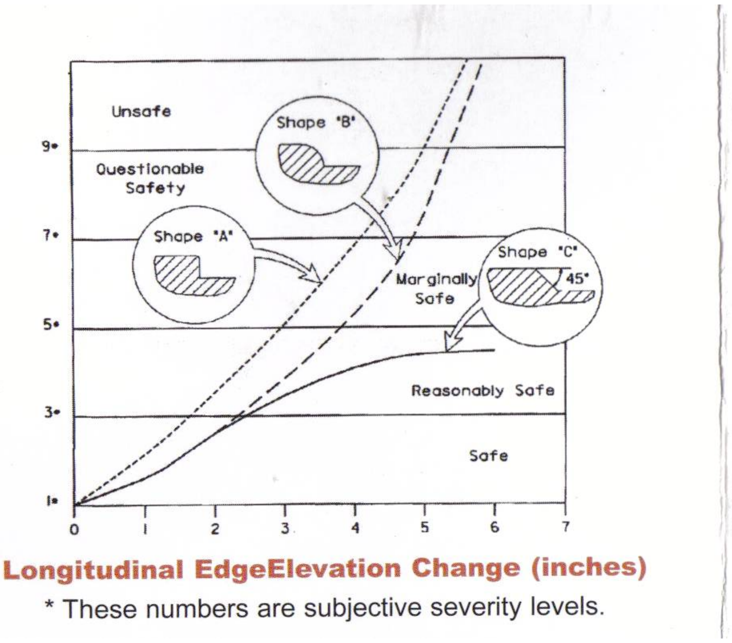


Figure 2. Relationship Between Edge Geometry and Safety for the Edge Scrubbing Condition

SUBJECTIVE RATING SYSTEM

The system was developed to allow the driver to express the severity of each test run immediately upon completion. This system consisted of a numerical ranking from one to ten. One (1) was no detectable effect and ten (10) was a complete loss of control. To assist the driver in assigning a number to their impression, an aid was prepared for their referral when deciding on an appropriate value. This aid is shown below.

<u>SEVERITY CODE</u>:

1. Undetectable	6. Extra Effort
2. Very Mild	7. Tire Slip (Slight lateral skidding)
3. Mild	8. Cross C. L. & Returned
4. Definite Jerk	9. Crossed C. L., No Return
5. Effort Required	10. Loss of Control (Spin Out)

The "severity code" was given the following definitions based on what amounted to a simple Delphi approach involving drivers, research engineers and the electronic data evaluations. They are:

- Safe: No matter how impaired the driver or defective the vehicle, the pavement edge will have nothing to do with a loss of control. This includes the influence of alcohol or other drugs and any other infirmity or lack of physical capability. (Includes subjective severity rating values 1 through 3.)
- Reasonably safe: A prudent driver of a reasonably maintained vehicle would experience no significant problem in traversing the pavement edge. (Includes severity values 3 through 5.)
- Marginally safe: A high percentage of drivers could traverse the pavement edge without significant difficulty. A small group of drivers may experience some difficulty in performing the scrubbing maneuver and remaining within the adjacent traffic lane. (Includes severity values 5 through 7.)
- Questionable safety: A high percentage of drivers would experience significant difficulty in performing the scrubbing maneuver and remaining in the adjacent traffic lane. Full loss of control could occur under some circumstances. (Includes severity rating values 7 through 9.)
- Unsafe: Almost all drivers would experience great difficulty in returning from a pavement edge scrubbing condition. Loss of control would be likely. (Includes subjective severity values 9 and 10.)

Even though this system is subjective and prone to variability from driver to driver, it proved a good indicator when confined to any one driver=s reactions to the entire matrix of tests. This rating value was later used as the dependent variable when sorting by computer on various combinations of conditions.

Examples of edges that can produce tire scrubbing and the potential for loss of control are shown by Figures 3 and 4.

The evaluation criteria given by Figure 2 was endorsed by Humphreys and Parham in their 1994 study for AAA Foundation for Traffic Safety (8). They recommended the construction of a Type C (45^{O}) edge on all new asphaltic concrete construction. A type C 45^{O} edge had been shown by Ivey and Sicking (9) to lower the Aeffective@ edge height of a 4-inch edge to one inch (see Figure 5).

Figure 3. Shape A Edge, 3 ¾ " height

Figure 4. shape B Edge, 2 3/4 " height

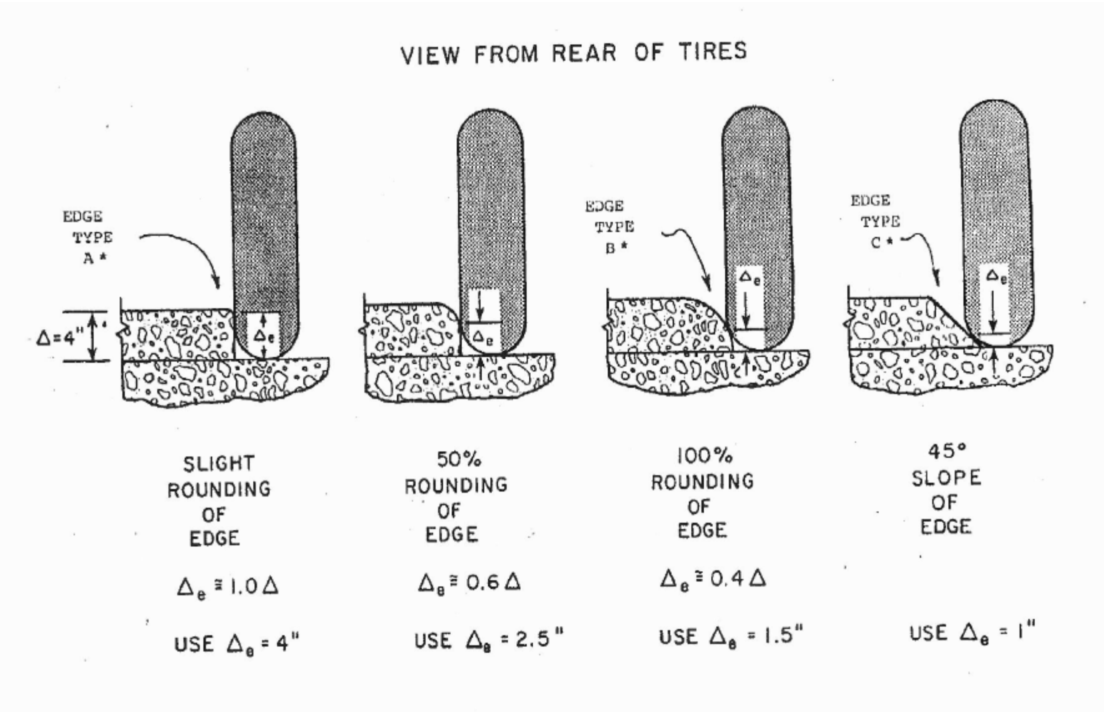


Figure 5. Effective Edge Heights for Different Edge Shapes

Based on this series of publications , the Federal Highway Administration began a campaign with the states to produce the Asafety edge@ on new ACP construction (see Figure 6). Field trials were in progress in Georgia and New York that demonstrated the feasibility of producing the "safety edge." It was found, however, that it was easier to produce a 30^{O} edge that had a predictably lower effective height (i.e. less influence on a vehicle tire) than the 45^{O} edge (see Figures 7 and 8). After conferring with the authors, FHWA decided to recommend a 30^{O} edge. Figure 8 shows that crossing the 30^{O} edge is roughly 60% of the "severity" of crossing a 45^{O} edge of equal height.

While this chart from the latest FHWA brochure endorsing "The Safety Edge" is reasonably accurate for speeds up to 55 mph, it must be considered somewhat liberal in its estimate of the influence of a Shape A edge at 70 mph. When this chart was developed initially in 1983 (excepting the curve on "Optimum Edge Designs"), the speed limit in the U.S. was 55 mph due to the oil embargo. Such is no longer the case.

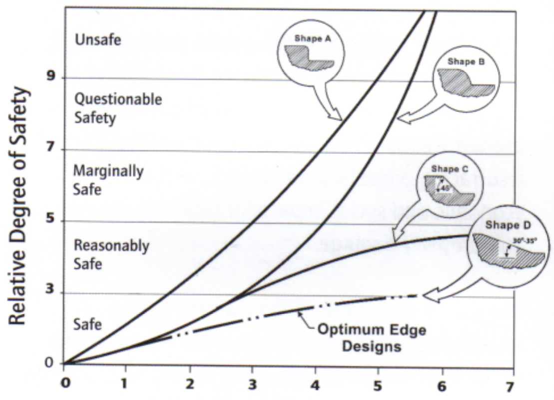
In response to the 70 mph speed limits now common, Zimmer conducted tests at 70+ mph on Type A (90^{O}) edges for the Texas DOT in 1995. The results of these tests are given by Figure 9.

Placement of the Shape A, 70 mph curve is shown on Figure 10 along with an estimated position of the Olson data. Figure 10 graphically summarizes the latest information on the relative degree of safety of different edge shapes and heights, and compares it to the work referenced in the 1983 TRB State of the Art Report (5). Informal testing on Shape C (45^{O}) and one of the optimum edge design (30^{O}) does not indicate a need for changing the position of these curves in response to the higher 70 mph speed.

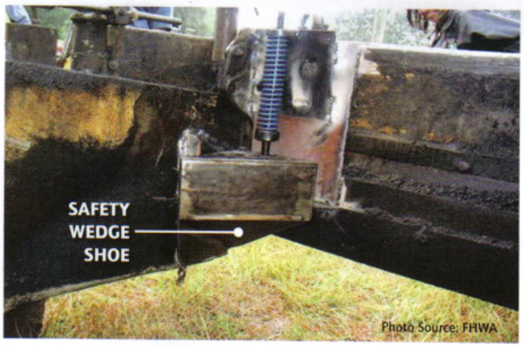
Perhaps of most importance is the influence of the Shape D, "Optimum Edge Designs" which shows edge heights up to 5 inches remain in the "Safe" zone.

Relative Safety of Various Edge Elevations and Shapes

The chart below shows how various edge shapes relate to safety at speeds of up to 70 mph.



Graphic Source: Zimmer and Ivey, Texas Transportation Institute



The Safety Wedge Shoe is a special edging device that asphalt paving contractors can install on new or existing resurfacing equipment to shape the Safety Edge.

Contact the FHWA for More Information about the Safety Edge and other Roadway Departure Crash Countermeasures

For more information about Roadway Departure issues and effective countermeasures to prevent Roadway Departure crashes, go to the FHWA Office of Safety's Web site at **http://safety.fhwa.dot.gov/** and click on "Road Departure." FHWA contacts for technical assistance with the Safety Edge are listed below.

CONTACTS

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Figure 6. FHWA Recommendations

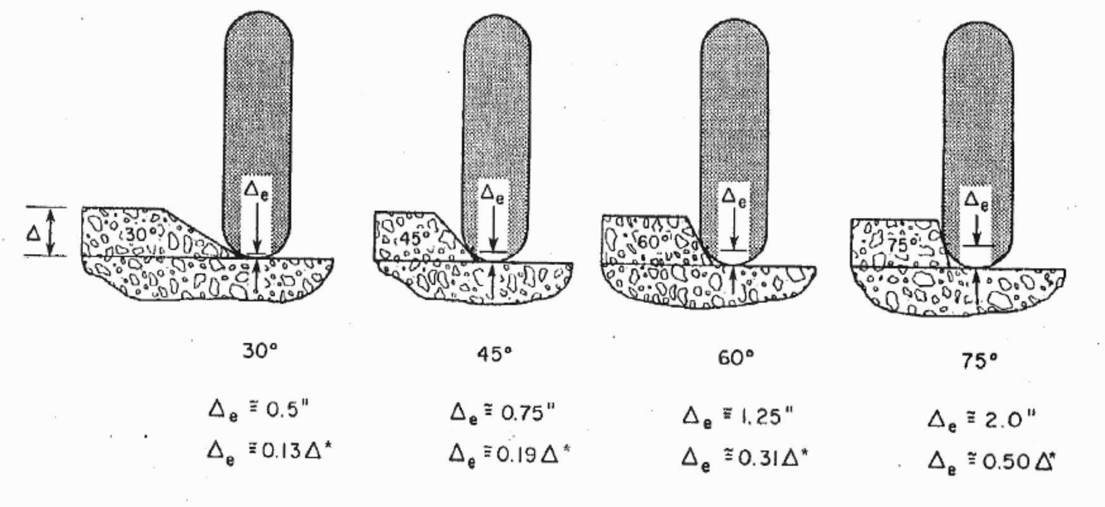

Figure 7. Influence of Edge Slope on Effective Edge Heights
*For Δ = 4 inches

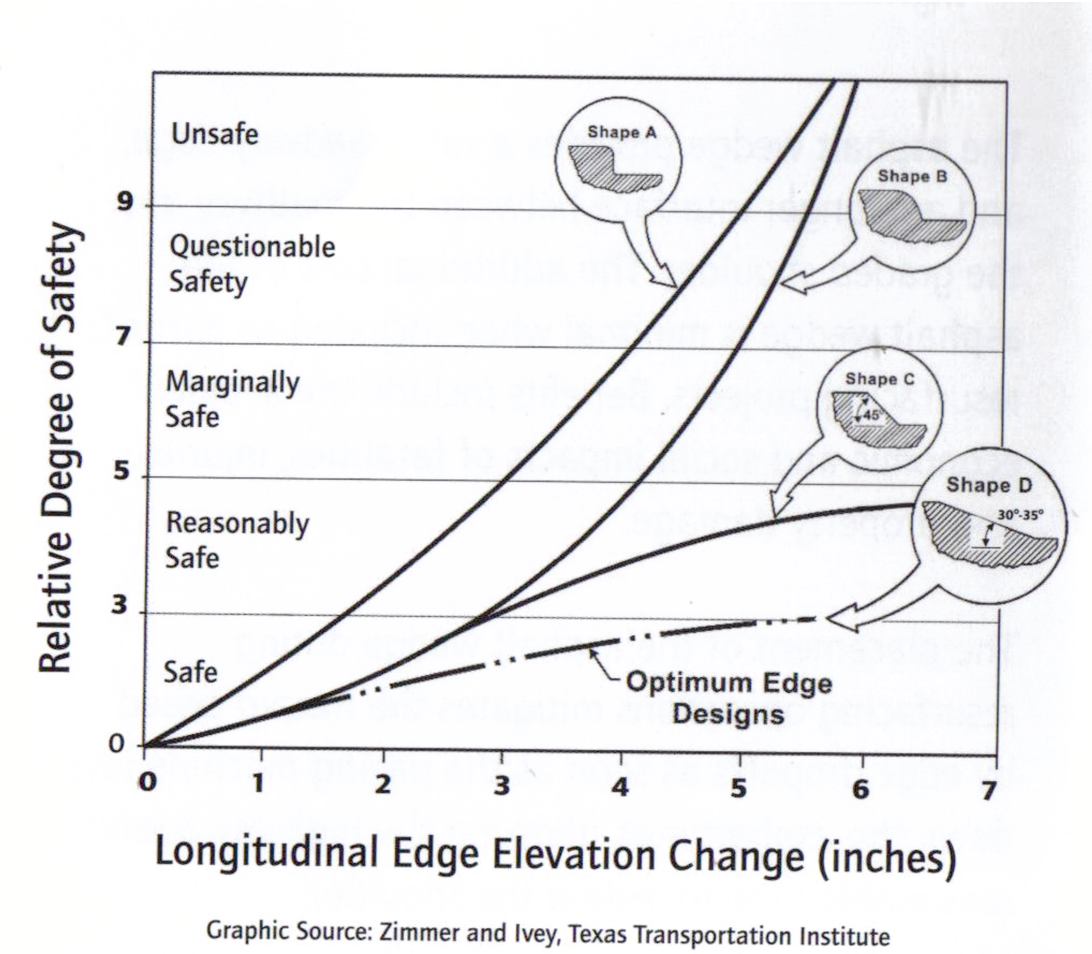

Figure 8. Comparison with Shape D, one of the more optimum edge designs.

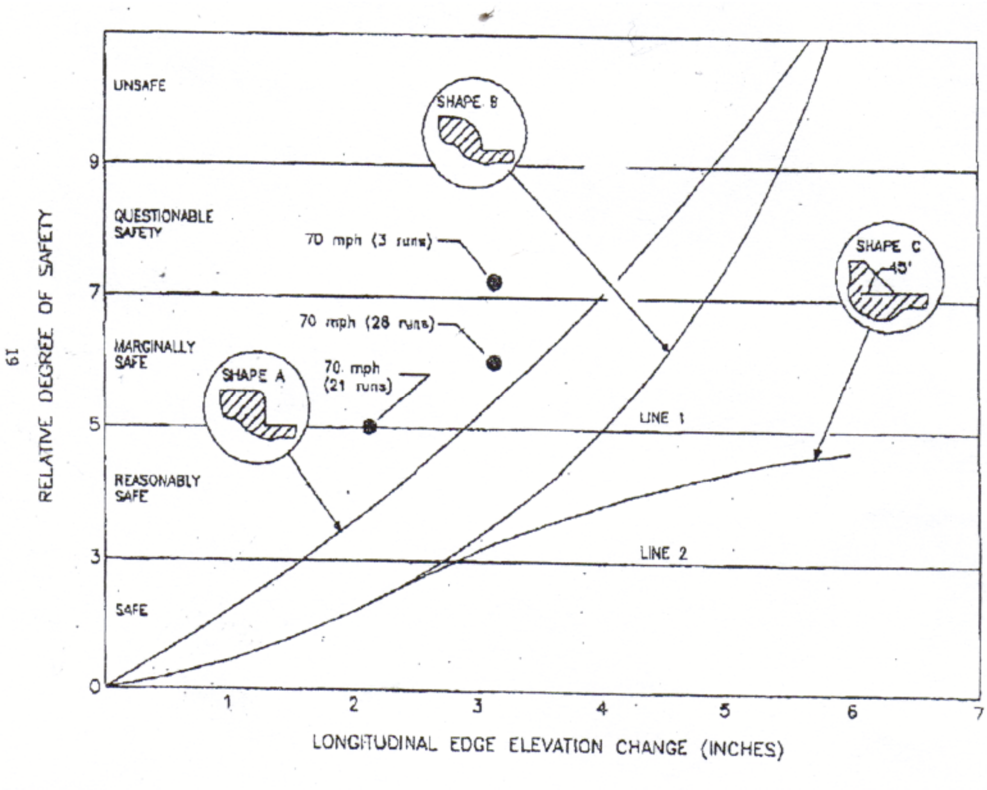

Figure 9. Comparison with 70 mph.

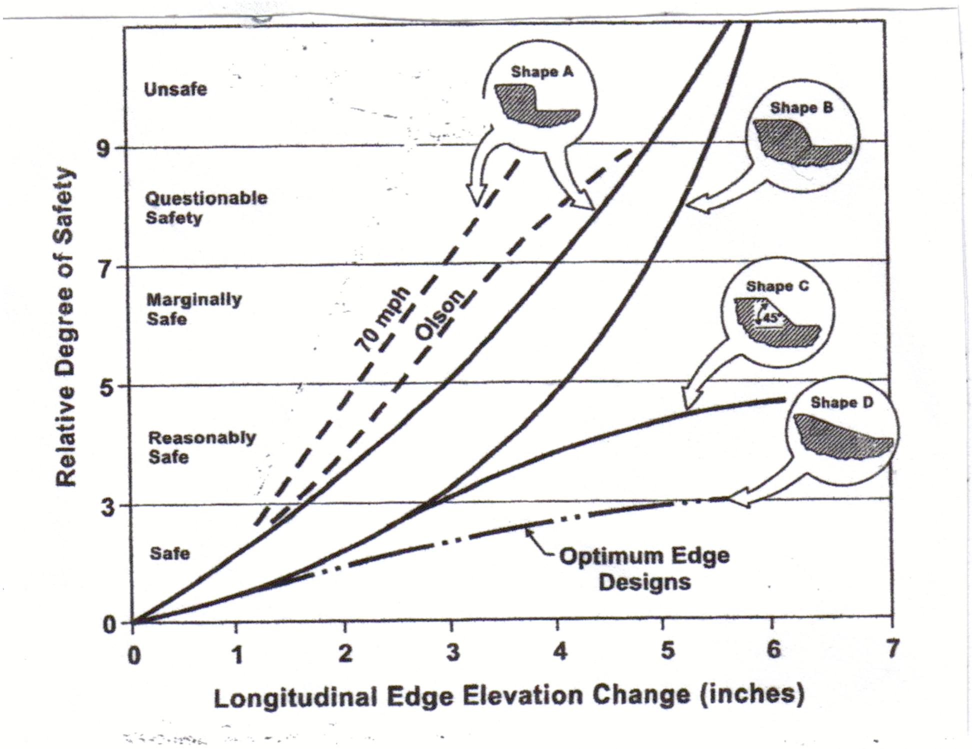

Figure 10. New Information Compared to 1983 (5).

CONCLUSION

The combination of previous findings and the modifications suggested by subsequent work on a larger group of drivers, the influence of higher speeds and of the optimum edge designs can be summarized by Figure 10. The "Relative Degree of Safety," in terms of the subjective severity levels defined previously, is plotted against the "Longitudinal Edge Elevation Change." Six curves are plotted, one for each pavement edge profile shape plus two revised placements of the Shape A curve. These were the curves suggested by the Olson (7) and Zimmer results. Shape A is the sharp edge common to Portland Cement Concrete pavements. Shape B is the rounded edge common to asphaltic concrete pavements. Shape C is the 45 degree edge shown in Figure 11. This figure graphically illustrates the importance of constructing "Optimum Edge Designs," Shape D (see Figure 12).

These designs (Shape D) keep edge heights up to 5 inches in the "safe" zone as shown by Figure 10.

SAFE - No matter how impaired the driver or defective the vehicle, the pavement edge will have nothing to do with a loss of control. (This includes the influence of alcohol and/or other drugs and any other infirmity or lack of physical capability.) (Includes the subjective severity levels 1 through 3.)

This is the optimum goal for construction and maintenance. One that is clearly reachable on new construction and one that may be gradually accomplished throughout the highway system.

Figure 11. Shape C Edge, 3 1/2" height

Figure 12. Shape D Edge, 2 1/8" height

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