Single-Vehicle Run-Off-The-Road Incidents: Is The Highway The Cause?

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Each year, run-off-the-road (ROR) vehicle crashes cost our society an estimated $110 billion, killing approximately 16,000 people and injuring another 1,000,000.[1] This type of crash occurs when a vehicle leaves the traveled way, encroaches onto the shoulder and beyond, and either overturns or hits one or more natural or manmade fixed objects, such as drainage structures, guiderails, bridge abutments, utility poles or trees. The chances of severe injury or death increase greatly when a stray vehicle overturns or strikes a fixed object. The ROR incident is on the rise, making up 33% of total crashes in 1995 and 38% in 2000. 41% of crashes that involve fatalities occur on two-lane rural highways. ROR crashes are initiated when something goes wrong -it could be driver error, a mechanical failure, highway deficiency, or a combination of these factors. The intention of this article is to explore a forensic engineer's use of various tools to determine if the negative highway conditions were or were not a cause of a ROR incident.

ADDRESSING THE SINGLE-VEHICLE RUN-OFF-THE ROAD PROBLEM

The components of the ROR problem are the roadway itself, the vehicle and the driver. These components, considered together, are a system that must operate in harmony. Each component of the system has limitations and is subject to failure. For purposes of this paper, it is assumed that the vehicle is in good mechanical condition and safety has not been compromised.

The driver's ability to control the vehicle can be affected by the roadway conditions. ROR incidents often occur when the laws of physics overcome a driver's ability to control the vehicle. Other physical and mental limitations can affect the driver's performance, such as intoxication, inexperience or fatigue. For purposes of this paper, we will assume no such limitations exist.

According to the United States Department of Transportation, Federal Highway Administration statistics, 25% of all highway fatalities occur on horizontal curves.

Therefore, the main focus of this paper will consider a two-lane, level, rural highway with a tangent (straight) section approaching a horizontal circular curve in wet weather. An improper cross-slope combined with inadequate maintenance of the roadway is a recipe for disaster, especially in wet weather conditions and a relatively high traffic volume. Tangent sections of highways carry normal cross slope (slopes that fall in both directions from the centerline of two-lane roadways); curve sections are super-elevated. Provision must be made for a gradual transition from one to the other. One method is to maintain the centerline profile grade of each roadway while raising the outer edge and lowering the inner edge to produce the desired super-elevation (see Figure A - page 91). This involves first raising the outside edge of the pavement with relation to the centerline until the outer half of the cross section is flat (point B in Figure A); next the outer edge is raised further until the cross section is straight (point C in Figure A); then the entire cross section is rotated as a unit until full super-elevation is achieved (point E in Figure A).

There are three other methods of achieving super-elevation runoff (see Figure A). All four methods also facilitate transverse pavement surface drainage. However, if improperly designed, constructed, or maintained, hydroplaning or hydrostatic drag can occur in wet weather. For example, if sufficient distance (i.e., more than 328 feet) is not available to permit tangent run-out lengths to return to a normal crown section, there is a long length where the edges of pavement and centerline are at the same elevation and poor transverse drainage can be expected. The rate of cross slope on curves, as well as on tangent alignment, is an important roadway geometry safety element. Cross slope or crown on tangents or on long-radius curves is complicated by two contradictory controls. A reasonably steep cross slope is desirable to minimize water ponding on flat sections of uncurbed pavements that may occur as a result of pavement imperfections or unequal settlement. A steep cross slope is desirable on curbed pavements to confine the flow of water to a narrow width of pavement adjacent to the curb. On the other hand, pavements with steep cross slopes are objectionable in appearance and may be annoying and uncomfortable in operation.

Providing adequate drainage for a highway involves the fundamental physical characteristics of the roadway, including the cross slope of the roadway and shoulders.

When it rains, water should run across and off the pavement. Water should not accumulate on the roadway surface. Without a properly crowned and uniform roadway surface, water on the roadway does not run off but rather ponds or flows into the irregularities in the roadway surface. Irregularities include wheel ruts and depressions in the roadway surface, potholes and patches. When there is wheel rutting on a grade, water runs down the grade in the ruts. The resulting water accumulation can be much greater than the storm runoff itself.

The United States Department of Transportation's (USDOT) 1983 Functional Requirements of Highway Safety Features states:

> Drainage of water from the surface is affected by the cross slope and "smoothness" of the surface. Quality of Safe Operations is affected by the friction between the tires and the surface.
>
> Surface drainage is essential to avoid hydroplaning. When there is a film of water on the surface, a tire will ride up on the water; thus steering control is lost because the tire/pavement friction is lost. Drainage of rainwater from the pavement surface to the roadside is influenced by three primary factors:
>
> (1) the cross-slope of the pavement;
>
> (2) the roughness of the pavement surface; and,
>
> (3) wheel ruts, depressions, potholes, etc., that trap water or slow its sideways movement

The Pennsylvania Department of Transportation, in their 1996 Maintenance Manual, state:

> Drainage is one of the most essential elements to be considered in the maintenance of a highway system. A surface drainage system is provided to permit water to flow from the roadway surface as rapidly as possible, and away from the highway.

The New York State Department of Motor Vehicles has long recognized the significance of alerting drivers to dangers of water on the roadway surface. Their Driver's Manual states:

> When it starts to rain, dust and oil form a slick, greasy film on the road. Wet leaves can also be slippery and hazardous. So be aware roads may be very slippery, even in a light rain. Increase your following distance. Be careful on curves, turns and expressway ramps.
>
> In heavy rain, your tires may actually begin to ride on the water, rather than the pavement. This "hydroplaning" results in a loss of traction and control. It usually occurs at higher speeds, drive slower in heavy rain. If you feel your vehicle losing traction, slow down even more. Good tires with deep tread help prevent hydroplaning.

Seasonal and weather factors have strong influences on skidding behavior. Rain is a major factor. Skidding occurs more on wet pavements than dry pavements because water impairs the contact between tire and pavement. To establish this contact, the tire must wipe the water away. A layer of water from rainfall that is not completely wiped away may result in extremely low coefficients of friction, particularly at high speeds; this is known as hydroplaning.

Tire hydroplaning under wet roadway conditions is always a possibility. In fact, under certain conditions, wet roadways can be as slippery as icy roadways. Many studies and reports verify these facts.

A water skier illustrates the hydroplaning concept. As the skier's speed is increased, the skier slowly rises to the surface and eventually hydroplanes on the water's surface. When the water skier slows or stops, he sinks into the water. So it is with vehicle tires; when stopped, the tires rest on the roadway surface. As the vehicle's speed increases, a film of water begins to develop between the tires and the road surface. Eventually, the tires will ride entirely on the film of water and the tires will hydroplane. When this occurs, the driver will have a difficult, if not impossible, time controlling the vehicle.

Several years ago, the National Aeronautics and Space Administration and the Department of Commerce, Bureau of Public Roads, did extensive testing on the effects of wet roadway surfaces and tire hydroplaning. The results were dramatic. The tests indicate that roadway texture, depth of water, tire pressure, condition of the tires, and dust, dirt and/or oil on the surface are the main factors that contribute to the severity of the hydroplaning tendency.

By placing a high-speed camera in a pit covered with glass on a roadway, the test shows a partial loss of traction at 25 mph in a ½ inch depth of water. The test further indicates that at 50 mph in ½ inch of standing water, the tire does not make any contact with the glass at all. The tire is actually riding on a film of water. Under these circumstances, the tires act like the skis of the water skier described earlier.

Another factor that occurs under wet roadway conditions is "hydrodynamic drag." Hydrodynamic drag is the force felt by a tire as it moves through water; it is similar to a friction force that retards the vehicle. Every driver has felt his vehicle "tug" to the left or right when the vehicle passed through a puddle of water on the roadway. A safety problem arises when the force is applied to the wheels unequally. An unequal force can be destabilizing, especially when coupled with hydroplaning.

Hydrodynamic drag, in combination with loss of traction, can influence vehicle movement. For a vehicle with one front wheel on pavement with only a thin film of water and the other front wheel on pavement with standing water, a steering torque would be required to counterbalance the torque produced by the hydrodynamic drag. This steering torque would require a steering wheel correction of approximately 40 degrees. Then, if such a correction was made, and full pavement contact was suddenly regained, it could cause movement toward the opposing traffic lane and subsequently, a possible ROR incident, before appropriate steering correction could be accomplished. In the case where both front wheels are fully hydroplaning, but there is a variation in water depth laterally, the unequal drag forces could cause yaw instability with little or no corrective steering capability available. There is little doubt that the drag forces generated by positive water depths could pose a ROR hazard to drivers.

Therefore, the most significant concern from a wet weather incident is the loss of the intended surface water drainage paths and the resultant reduction of friction between the tire and the road. The daily use of a roadway causes wheel ruts to form in the traveled lane. These wheel ruts develop into depressed channels that redirect the surface runoff, even in a light rain. When those channels get deep enough, they can create hydroplaning/hydrodynamic drag from what was an otherwise minor rainfall event. Repair of these wheel rut depressions requires resurfacing or replacement of the pavement.

SUMMARY AND CONCLUSIONS

Irregular cross slopes and rutted wheel paths, especially at the beginning and end of horizontal curves, cause water to collect and flow in the wheel paths, creating the conditions for hydroplaning and hydrodynamic drag.

Proper design, construction and vigilant maintenance of the cross slopes, and super-elevation of the high speed roadways of today, will go a long way to guard against the unintentional results of excessive water on the pavement surface.

It is the engineer's responsibility to provide reasonable levels of safety within existing economic, physical, and behavioral constraints. Design, construction and maintenance issues, if overlooked or not continually monitored, can and do often result in being the cause of serious injury producing or even fatal ROR incidents.

ENDNOTES

[1] U.S. Department of Transportation, Federal Highway Administration, Safer Roadsides, Harry W. Taylor and Leonard Meczkowski, 2003.

REFERENCES

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3. U.S. Department of Transportation, Federal Highway Administration, Lane Departure Strategic Action Plan, March 2005.

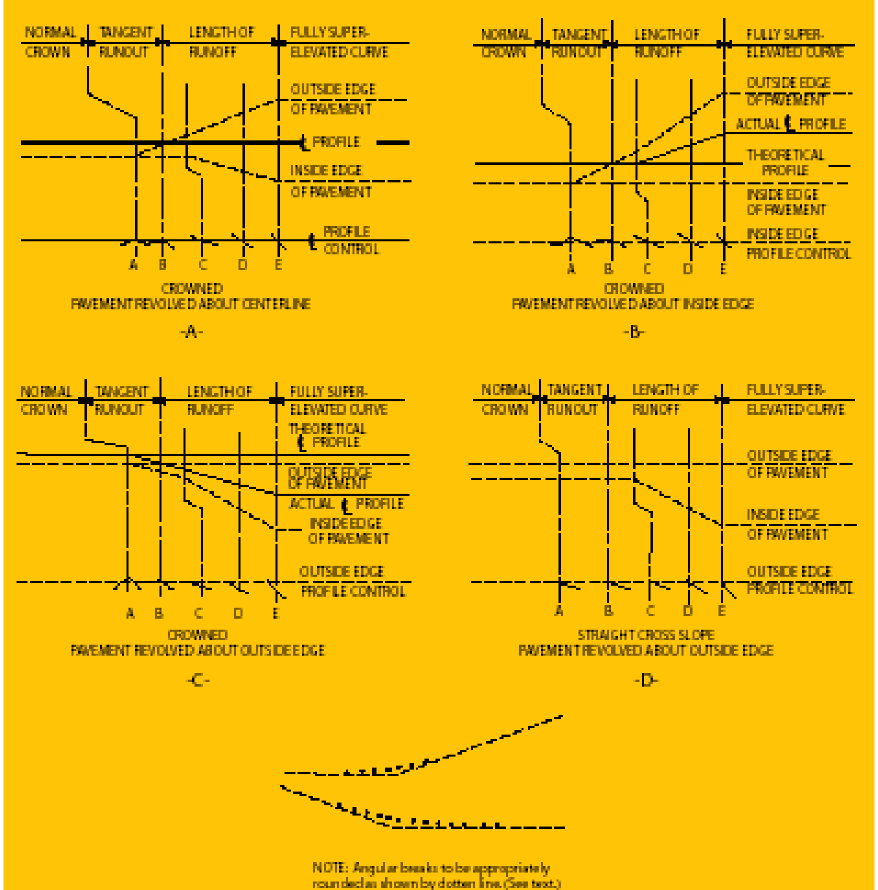
4. U.S. Department of Transportation, Federal Highway Administration, Safer Roadsides by Harry W. Taylor and Leonard Meczkowski, 2003.

5. U.S. Department of Transportation, Federal Highway Administration, Functional Requirements of Highway Safety Features, 1983.

6. American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets, 1990.

7. Journal of the National Academy of Forensic Engineers, Forensic Engineering Aspects of Hydroplaning Issues in Roadway Accidents, Ronald J. Hensen, Ph.D., P.E., 2005.

Figure A: Diagrammatic profiles showing methods of attaining superelevation for a curve to the right.



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