Figure 6. Photo. Pattern of depressions cut into pavement surface creates sound and vibration to alert drivers who are drifting out of the travel lane. ©Joel Carillet/iStock.

Case Study: Rumble Strips

The breakthrough innovation of rumble strips emerged from concerted experimentation on an existing idea—patterned pavement markings—in a controlled highway transportation setting. Rumble strips are patterned indentations in roadway pavements that alert drivers by generating sound and vibration when a vehicle's tires pass over them. Rumble strips provide a proven safety benefit at a relatively low cost. Continuous rumble strips are now widely placed along roadway shoulders to prevent run-off-road (ROR) accidents, along centerlines to reduce head-on collisions, and across roadways to alert drivers of upcoming hazards such as sharp turns, toll booths, or intersections. Various other names have been used to describe the concept of rumble strips: singing lanes, singing roads, sleeper lines, safety edge, and Sonic Nap Alert Pattern (SNAP). Several U.S. States experimented with rumble strips in the 1950s, with early implementations of rumble strips in travel lanes reported in California and New Jersey as early as 1953.[21] Shoulder rumble strips were first deployed in 1955 along stretches of the Garden State Parkway in New Jersey, but they were removed 10 years later because of a lack of consensus over their effectiveness and concerns about their cost.[22]

The widespread deployment of rumble strips—which occurred in the 1990s—depended on a new technology for milling the strips into the roadway, controlled investigation into their specific design configurations, and cost-benefit studies of their deployment. During the mid-1980s, researchers recognized three research gaps related to the cost-benefit of rumble strips. First, nearly all rumble strip studies focused on areas where the occurrence of ROR crashes was known or presumed to be high. As a result, rumble strips' effectiveness on "average" roads was not generally measured. Second, these studies introduced concerns over maintenance and cost: PennDOT found the strips a "debris catch-all," and California's interchange-loop rumble strip trial was discontinued because of expense.[21] None of the studies

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attempted to rigorously measure the cost-benefit of the treatments. Finally, while several rumble strip implementation sites experimented with a variety of surface treatments, no concentrated effort was made to differentiate among the effectiveness of varying treatment types.

The breakthrough of rumble strip technology into its current widespread adoption resulted from the next generation of carefully studied implementation efforts, led primarily by the Pennsylvania Turnpike Commission in the late 1980s. The Commission identified drift-off-road (DOR) accidents as an increasing problem and began in 1987 to experiment with rumble strips as a possible solution.[23] The Turnpike's snow-plowing requirements prevented the use of raised rumble strips tested in previous trials, so the Commission began investigating recessed patterns that could be rolled or raked into the pavement.

The Commission's tests of milling procedures proved successful and offered the additional benefit of increased in-car noise generation over rolled-in patterns. At about the same time, evaluations of the initial 18-month, 7-mi deployment of SNAP indicated a 70-percent decrease in DOR accidents and no complaints about debris or water retention.[23] As a result, the Commission initiated plans to deploy SNAP across the State's Turnpike system and carefully evaluated the results. SNAP's initial success reinforced the use of milling, and the Turnpike Commission accelerated installation, focusing specifically on milled-in strips that could be retrofitted to existing roads. As a result, 80 percent of the Turnpike had been retrofitted by the end of 1994.[23] This system-wide rollout also led to rapid cost reductions in early SNAP installations, coincident with new innovations in the milling procedure that allowed continuously moving milling machines to cut multiple SNAPs at a time. The cost of one SNAP unit fell from approximately $1 per foot of roadway in 1991 to $0.30 just 3 years later.[24]

The Commission also investigated the milling procedure for rumble strip installation and the effectiveness of various rumble strip geometries. The Commission's initial tests focused on continuous strips, as well as varying depth (between ¼ and ½ inch) and width (between 2 and 4 inches). Only the ½-inch-deep by 4-inch-length pattern generated measureable noise levels in truck cabs. In all tests, spacing between strips was set to 12 inches (center to center), and the width of the strips (perpendicular to vehicle travel) was 16 inches.[23] The Turnpike's adoption of the milling procedure in 1993–1994 meant that the strip width needed to be extended to 7 inches to allow the milling head to

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Modern, continuous shoulder rumble strips introduce a clear safety benefit for ROR crashes that far exceeds their cost of installation. Many studies of the effectiveness of shoulder rumble strips indicate that they can reduce overall crashes by 14 to 17 percent. Further, shoulder rumble strips have been documented to reduce ROR crashes by 7 to 41 percent. Centerline rumble strips may reduce head-on crashes by 21 to 68 percent.[25] Critically, rumble strips are crash prevention rather than crash mitigation devices: if rumble strips function correctly, an accident can be avoided altogether.

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reach a ½-inch-depth at the center of the strip.[24] The standardized placement of a rumble strip 4 inches from the roadway edge lines was also finalized in these tests.[23]

When the Commission presented its initial findings on rumble strip technology to the Transportation Research Board in 1994, it generated both interest and questions regarding statistical significance, traffic exposure, control segments, and "accident migration."[24] Researchers for a set of rigorous follow-up studies confirmed the positive impact of rumble strips, estimating a 65-percent reduction in DOR accidents attributable to the technology. Investigators of further research documented a 60-percent reduction in accidents on roadway segments with rumble strip installations.[24]

Other States quickly began to install and evaluate the technology. Researchers for a New York State Thruway study produced a cost-benefit estimate of $182 in benefits for every dollar spent on the technology. They also estimated a further decrease in rumble strip installation cost to below $0.20 per foot, which included milling, sweeping, and maintenance.[25] FHWA took note of these study findings and distributed them to all FHWA division offices, beginning a policy push for widespread adoption of rumble strip technology.

Rumble strips are now so widely recognized as a form of driver feedback that several vehicle manufacturers use similar "artificial" vibrational feedback in their lane-departure warning systems. However, some stakeholders have expressed concerns about the impact of rumble strips on cyclists, including both bicycle and motorcycle riders. Though most highways prohibit the use of bicycles, New York State DOT conducted tests to ascertain that the preferred rumble strip design did not present a danger to cyclists.[25]